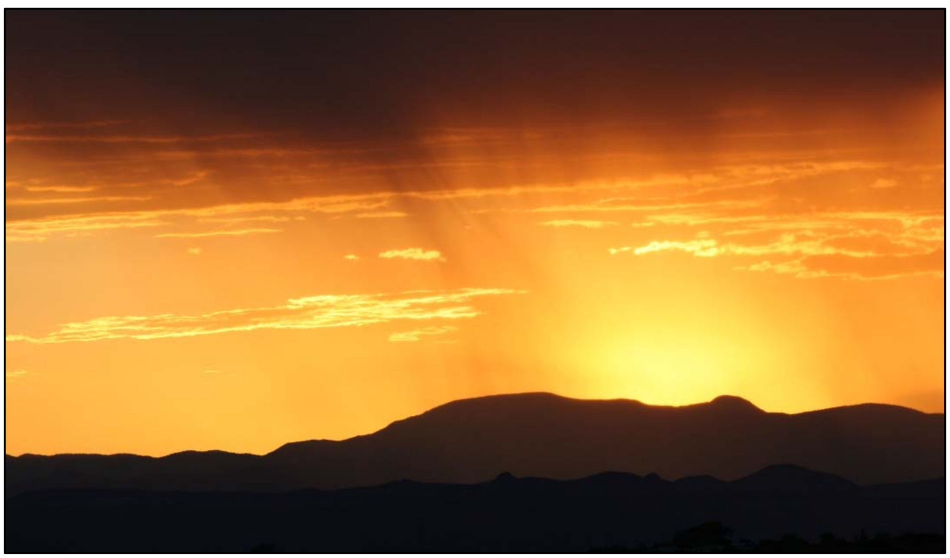
July 11, 2012

Preliminary Assessment Report: Climate Change and the Santa Fe Watershed

Bureau of Reclamation WaterSMART Program Initiative



Prepared for:

Bureau of Reclamation **City of Santa Fe** ***Santa Fe County***

Prepared by:

Amy C. Lewis, Hydrology and Water Planning

And

Karen MacClune *and Kari Tyler*
Institute for Social and Environmental Transition

In cooperation with
Claudia Borchert[1], Dagmar Llewellyn[2], Karen Torres[3],

[1] City of Santa Fe, [2] Bureau of Reclamation, [3]Santa Fe County

Acknowledgments

The authors would like to thank the reviewers of the document who, in part, provided information on existing actions in the Santa Fe Watershed: Jan-Willem Jansen of Ecotone, and Craig O'Hare and Duncan Sill of Santa Fe County, Brian Drypolcher and Katherine Mortimer with the City of Santa Fe and Jonne Hower, Amanda Erath and Dave Truman, with the Bureau of Reclamation. We would also like to thank the City of Santa Fe for providing the venue for the workshop and for the 120 members of the community that participated and offered their insights on the vulnerabilities of their systems.

Table of Contents

Appendices

Appendix A. Workshop agenda
Appendix B. Workshop participants
Appendix C. Summary of climate science presentations
Appendix D. Proposed actions

List of Figures

Executive Summary

Under a Bureau of Reclamation (Reclamation) WaterSMART Program Initiative, the City and County of Santa Fe have collaborated with Reclamation to conduct a preliminary assessment of system vulnerabilities to climate change in the Santa Fe Watershed and consider alternatives for creating a more resilient watershed. To understand the systems that are relevant in the Santa Fe watershed, members of the community were invited to learn about the impacts from climate change that are predicted for the area and to provide their insight into how the predicted changes may affect the systems that they are most concerned with. This report captures the expertise of the authors and presenters, as well as the information gathered at a one-day workshop held in Santa Fe on March 6, 2012 with 120 participants.

Predicted impacts for the watershed include:

- Reduced stream flow due to greater evapotranspiration and thus less runoff;
- Diminished snowpack, and earlier spring melt of existing snowpack;
- Earlier peak snowmelt runoff and lower peak flows;
- Drier mid- to late-summers;
- More severe and more frequent droughts; and
- More intense precipitation events that increase peak storm flows, with an accompanying potential for more sediment transport and erosion and further degradation of the Santa Fe River.

Participants worked in small groups to describe physical, biological and socio-economic systems within the Santa Fe Watershed, particular vulnerabilities of those systems, and solutions for creating more resilient systems, and ultimately, a more resilient watershed. The systems range from forest ecosystems to farms to transportation and energy systems. The vulnerabilities are numerous, including the increased risk of catastrophic fire, flooding, and erosion.

Fortunately, the Santa Fe Watershed has benefited from numerous projects that will enhance the system resilience under climate change. These projects, such as forest thinning, riparian restoration, and storm water management, could be mapped in order to highlight and prioritize the areas needing additional restoration or treatment.

1 Purpose

The purpose of this report is to preliminarily assess the vulnerabilities of systems in the Santa Fe watershed to climate change based on input obtained during a March 6, 2012 workshop and from research conducted by the authors. This Preliminary Assessment Report identifies "qualitative climate-change impacts on water supply sources, ecosystems, quality of life, agriculture and local food production, landscapes, land use and water demand" as directed by a Memorandum of Agreement between the partners (Reclamation et al., 2011). It is part of a larger Basin Study under Reclamation's WaterSMART Program, and as such evaluates the extent to which changes in the water supply will impact fish and wildlife habitat, listed endangered species, water quality, and flow- and water-dependent ecological resiliency, in partial fulfillment of the requirements in Element 2 of Reclamation's Basin Study Framework.

> ***"Deep, crushing cycles of drought are part of the natural history of the Southwest and, for all practical purposes, they always have been. Building resilience against drought into the region's water systems and cultural practices would be a wise course, irrespective of the cause or timing of the next emergency. Perhaps the dangers now arising from anthropogenic climate change will goad us into doing the things we should have been doing all along… to strive for resilience,--the capacity of an ecosystem to experience disturbance without losing its essential character and becoming something else."***
>
> ***Bill deBuys, 2011***

1.1 Introduction

Climate change may alter many aspects of life in the Santa Fe basin, including the availability of water to the city and county, as well as the health of forests and other ecosystems. To prepare for these changes, the City of Santa Fe, Santa Fe County and the Bureau Reclamation are partnering on a Basin Study through the US Department of Interior Bureau of Reclamation Water SMART Initiative Basin Studies Program (Reclamation, 2011). Through the Santa Fe Basin Study, of which this report is one component, the partners seek to:

1. assess the projected impacts of climate change on the Santa Fe watershed and on the City and County's water supplies;
2. quantify the potential impact of climate change on the potentially available water supply from each of the three sub-basins that supply surface water to the City and the County (the Santa Fe River Basin, the Upper Rio Grande, and several tributaries to the San Juan); and

3. assess the vulnerability and possible shortcomings of the current long-range water supply strategies; and
4. evaluate new mitigation and adaption strategies and integrate them into the region's water supply plan as necessary.

The results of this study will be presented to the Public Utilities Commission in the hope that the information gathered can inform efforts to create a more resilient community. The initial part of this study calls for public input and the preparation of a preliminary assessment report of qualitative climate change impacts on water supply sources, ecosystems, quality of life, agriculture and local food production, landscapes and land use, and water demand.

> ***"It stands to reason that a grassland with a diversity of grasses--some that flourish with fourteen inches of rain, some that prosper with just eight--will fare better through fluctuating conditions than will a monoculture of a single species."***
>
> ***Bill deBuys, 2011***

To seek stakeholder input, the project partners sponsored an interactive workshop, held on March 6, 2012 in Santa Fe, in which federal, state, local, private, and non-profit groups and individuals were invited to contribute to and gather information for this preliminary assessment report. Workshop goals were to identify vulnerabilities in human and non-human systems and to assess how climate change may affect these systems. . The focus of the workshop was primarily on system resilience and adaptation, versus mitigation measures. The Santa Fe River watershed was specified as the system boundary, which allows for a more holistic approach to the analysis of system impacts and the development of potential solutions. The use of a systems approach to the analysis of vulnerabilities and adaptations allowed consideration of impacts and solutions in smaller units and scales; although it was recognized that interconnections and overlap between systems may not be completely captured. Climate-change experts provided the foundation for the workshop by giving a summary of climate-change projections for the Santa Fe Watershed, the southwestern forest response to drought and the historical and sociology impacts of climate change.

Breakout groups provided input on a range of climate-change impacts of various physical, biological and socio-economic systems within the Santa Fe Watershed. Groups were asked to identify how climate change may threaten a system of concern, begin prioritizing how those risks should be responded to, and brainstorm initial adaptation actions that can be taken at the city and county-level to build resilience to those systems in the face of those impacts.

This report also summarizes the many present and past activities in the watershed that are already building resilience in our watershed. It is our hope that this report will also serve as an educational tool for decision makers and the public of the ways that a community might prepare for climate change.

1.2 Background

The Santa Fe River originates near Lake Peak at an elevation of 12,408 ft. in the Sangre de Cristo Mountains and flows to the west through the City of Santa Fe and down to the Rio Grande at 5,220 ft. elevation (Figure 1). The Santa Fe Watershed is approximately 256 square miles and includes many ephemeral channels such as the tributaries of Arroyo Hondo, Arroyo de los Chamisos and Arroyo Mascaras.

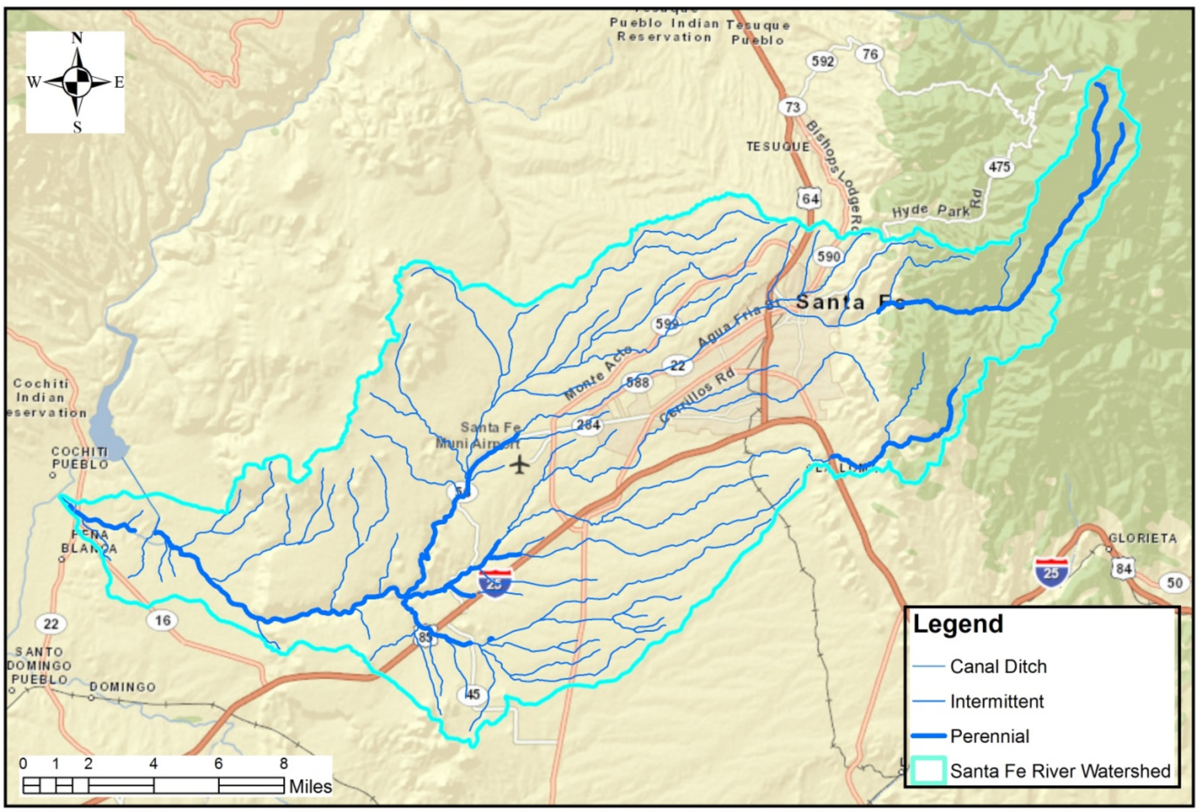


Figure 1. Aerial view of the Santa Fe Watershed.

1.3 Relationship to Other Planning Efforts

This assessment is intended to complement numerous other planning efforts in the Santa Fe community that seek to enhance sustainability or resilience. In the city and county of Santa Fe, such efforts include the City's Sustainable Santa Fe Commission and the County's Sustainable Growth Management Plan.

The City adopted a Sustainable Santa Fe Plan (SSFC, 2008) in 2008, which is associated with the U.S. Mayors Conference on Climate Change, and identifies ways that community could prepare for the effects of global warming. While the focus of the Sustainable Santa Fe Plan is on community and municipal actions to reduce carbon emissions (mitigation), the Plan has an insightful list of potential adaptation actions, including local food production. The Annual report of 2010 Activities highlights progress in establishing more local food production, in part through new community gardens, and increased education and outreach.

The Santa Fe County Sustainable Growth Management Plan (SFCO, 2010) was developed to provide direction for future growth and sustainable development through the adoption of goals and policies. One of the key issues identified is the environmental impacts and resource scarcity that is likely to result from shifting climate patterns. With limited acreage (about 15,000 acres) of irrigated land within Santa Fe County, several strategies were developed to enhance food security, protection of water resources and greenhouse gas management were adopted to improve the potential for local and economic sustainability. Efforts and other incentives that promote efficient water uses and farming techniques and protection of indigenous food sources which are resilient to drought are key strategies adopted by Santa Fe County.

Santa Fe County established the Office of Renewable Energy and Energy Efficiency in the spring of 2011 (http://www.santafecountynm.gov/public_works/energy). Through investment in renewable energy and energy efficiency education and technical assistance, Santa Fe County proposes to reduce energy use and greenhouse gas emissions. Additionally, an energy-efficient green building code will promote energy efficiency, water conservation and renewable energy improvements to existing and proposed developments.

Definitions

Systems – include both infrastructure (e.g. food supply, water supply, transportation, energy, shelter, communication, health, education, finance) and ecosystems (e.g. agricultural land, parks, wetlands, rivers, range land, forests) that provide services or functions for humanity.

Vulnerability – the underlying fragility or weakness in a system that leaves it open to harm or damage; for example, a drinking water system serviced only by surface water supplied from one small river is highly vulnerable to drought.

Resilience – the capacity of a system to absorb disturbances, and still have the same basic structure and ways of functioning OR to elegantly anticipate and move to a new a way of functioning. A resilient system is flexible and modular (e.g. a forest can be made more resilient through thinning and/or prescribed burns which reduce the stressors that could cause it to fail during a wildfire). In people, resilience is the ability to cope with stress and adversity.

Adaptation – taking action to minimize the impact of, take advantage of, or cope with changes that are occurring or are expected to occur.

Mitigation - an act that lessens the intensity or force of something unpleasant; the act of making a condition or consequence less severe. In relation to climate change, mitigation usually refers to actions to decrease greenhouse gas emissions.

2 Climate Change: What the Science Says

Human activities are increasing concentrations of greenhouse gasses such as carbon dioxide and methane in the atmosphere, and these gases are trapping increasing heat near the Earth's surface. In response, global average air temperatures near the Earth's surface are rising, oceans are warming and expanding, land-based ice is melting, sea ice is thinning and permafrost is melting, precipitation patterns are shifting, and plants and animals are growing, migrating, and responding in different ways, places and times. The evidence for climate change that is being documented in the world around us is concordant with the climate science and physics captured in global modeling; there is no longer any doubt that our climate is changing. A detailed description of the climate science is provided in Appendix C.

There is no longer any doubt that our climate is changing.

The releases of greenhouse gasses that have occurred to date commit us to a certain degree of climate change, regardless of future emissions.

The greenhouses gasses that have been released to date commit us to a certain degree of climate change, regardless of future emissions; and, currently, global emissions are accelerating rather than decreasing, and therefore we are committing ourselves to increasing warming. This means that, in addition to working to limit future emissions and associated warming, we will need to adapt to existing and at least near-future climate changes.

The goal of the Preliminary Assessment Workshop was to introduce climate change and its potential impacts in the Santa Fe Basin to a broad group of local stakeholders, and to solicit from those stakeholders their primary areas of concern and their initial thoughts about how to take action. This section discusses the impacts climate change is likely to have on the Santa Fe Basin.

2.1 Climate Change Projections for Santa Fe Basin

Climate change is already occurring in the Santa Fe Basin, as evidenced by measured temperature increases. Average temperatures in the watershed have risen about 2 ^{o}F since 1900. Continuing CO_2 emissions around the world will trap additional heat near the Earth's surface, so that temperatures will continue to rise for the foreseeable future, in the Santa Fe watershed and elsewhere. Global climate models (called General Circulation Models, or GCMs) project that air temperatures in the Santa Fe Basin could increase an additional 5.5 to 6.5 °F by 2100 (Figure 2).

Increasing temperatures impact the circulation of moisture in the atmosphere, which it turn impacts precipitation patterns. Though models suggest that the amount of precipitation that falls in the Santa Fe watershed may remain relatively unchanged, when and how it falls is likely to shift. The combination of increasing temperatures and changes in precipitation patterns will significantly impact Santa Fe and surrounding communities, lands and ecosystems.

There are three primary elements of climate change that will have direct impacts on, and associated implications for, water resources in the Santa Fe Basin: 1) rising temperatures, 2) changes in precipitation patterns, and 3) increases in climate variability.

These changes are not going to be smooth, steady changes over time. Instead, climate change is expected to increase the variability of our already extremely variable climate. Currently, record wet spells can be followed by record droughts; record hot-summers followed by record winter cold-spells. Climate change is likely to bring even more variability, with even higher high temperatures and with more variability within and between seasons and from year to year. Spring and fall weather may become even more mercurial, with implications for plant survival and growth. Individual precipitation events may become more intense, while dry periods become longer and hotter. These impacts will exacerbate the already formidable water-management challenges in the Santa Fe basin, and may also create new water challenges.

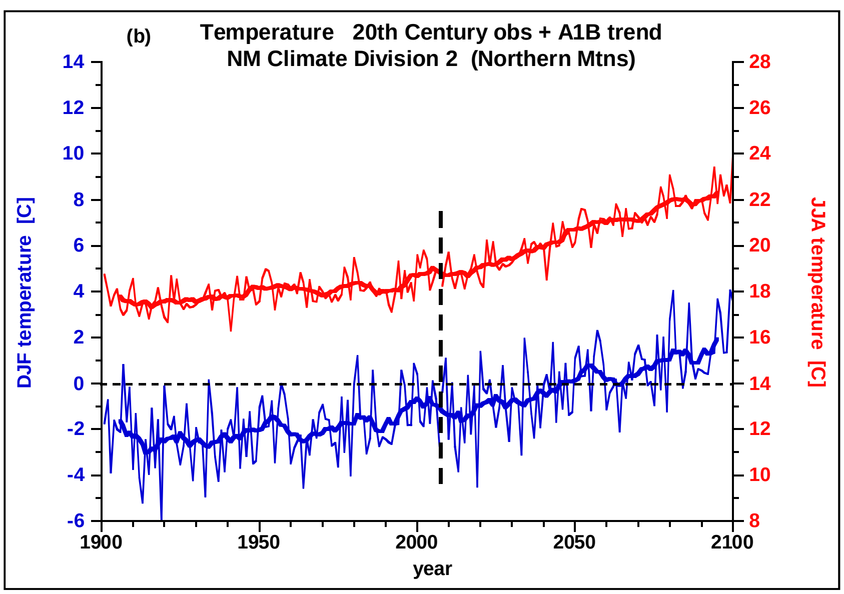


Figure 2. Temperature for winter and summer seasons, 1900 to 2100.

2.2 Climate Change Impacts to Santa Fe Basin Hydrology

Projected changes in temperature and precipitation will have implications for summer aridity, for winter precipitation (increasingly falling as rain rather than snow), and for spring snowmelt runoff timing and volume (Figure 3).

All systems that depend on water are vulnerability to water availability, changes in the timing of water availability, sensitivity to high or highly variable

Global climate models project a transition to a much more arid climate in the Southwest by the mid-21st Century, primarily due to increasing rates of evaporation and increasing water use by plants, which will result from the projected higher temperatures. Evaporation and plant water use are directly related to surface temperature; warmer air holds more moisture. If precipitation remains relatively constant and evaporation and plant water use increase, then surface runoff and groundwater recharge will decrease. Irrigation water demand and riparian water consumption will increase, and non-irrigated vegetation will likely become water stressed.

Higher temperatures will also impact winter snowpack depth and spring snowmelt timing and volume. Climate models project decreases in snowpack throughout the western mountains because, as temperatures increase, more winter precipitation is expected to fall as rain rather than snow. By mid-century, the Southern Rocky Mountains are projected to experience a 20 to 70% reduction in snowpack.

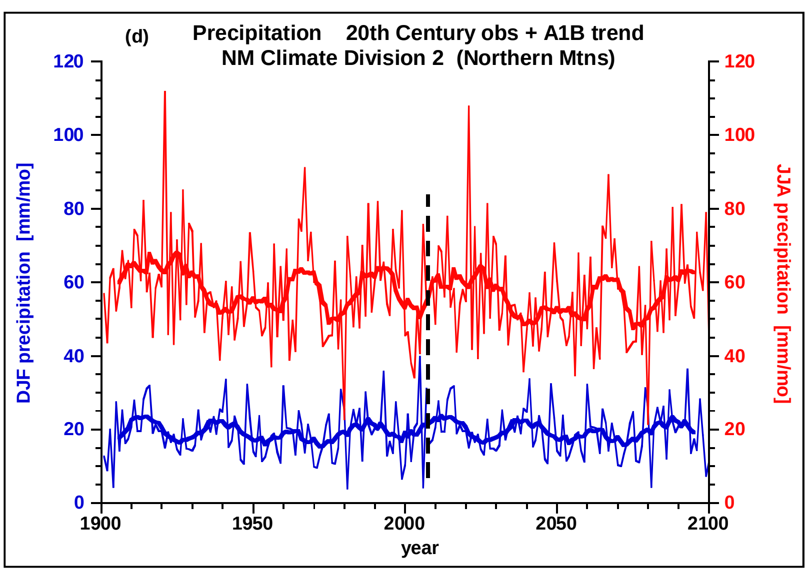


Figure 3. Annual precipitation for winter and summer seasons, 1900-2100.

What snow does fall will melt earlier, due to higher spring temperatures, rain falling on snow, or intense spring windstorms blowing dust onto the snow, making it absorb more sunlight and melt faster. By 2050, spring runoff could be 15 to 35 days earlier than it was under pre-development conditions. This much-earlier peak runoff date, driven by warmer temperatures, may also have lower peak flows, due to less snow. This earlier runoff may fill McClure and Nichols reservoirs over a relatively brief period and then overflow the reservoirs and continue downstream. Therefore, even if the total runoff were comparable to average historic supply, much of this water may become unavailable, and therefore may cause the Santa Fe water supply to be short more often.

Snowpack currently feeds a late-spring flood pulse on the upper Rio Grande and its tributaries. In their 2008 paper, Hurd and Coonrod found that in the warmer climate projected for New Mexico; there would be an earlier and smaller snow-fed flood pulse, and a reduced total stream-flow volume, especially in the late spring to early summer. Their projected reductions in flow for the Middle Rio Grande are (Hurd and Coonrod, 2008):

- 2030: 4 - 14% reduction
- 2080: 8 - 29% reduction

Santa Fe River stream-flow projections are similar to those for the Middle Rio Grande. Cox et al., in their 2011 modeling analysis, project an annual decrease in stream flow above McClure Reservoir of 11-18% by 2060 compared to the historic record from 1950 to 1999. These temperature and precipitation projections, and their associated impacts to snowpack, snowmelt, stream flow, evaporation and plant water use, have significant implications for virtually all water-related systems in New Mexico. Reservoir storage and river operations will be impacted by changes in volume and timing; these in turn will impact water availability for urban, agricultural and ecosystem use. Changes in precipitation intensity and snowpack may further impact groundwater recharge. As a result, all systems that depend on water will need to be evaluated for their vulnerability to reduced water availability and changes in the timing of water availability, and for their sensitivity to high or highly variable temperatures, aridity, and drought.

"Potential Effects of Climate Change on New Mexico", Technical State Agency Working Group, State of NM, 2005

The projections of future New Mexico climate presented below rely heavily on the evaluation of climatologists with expertise in southwestern climate (Gutzler 2005, Overpeck 2005). These projections are for the late 21st century and are based on the assumption that global anthropogenic emissions of greenhouse gases continue to increase in a "business as usual" fashion, with no measures undertaken to reduce emissions globally:

Temperature

- Average New Mexico air temperature substantially warmer
- Greater warming of winter temperatures, nighttime minimum temperatures, and higher-elevation temperatures
- More episodes of extreme heat
- Fewer episodes of extreme cold
- Longer annual frost-free periods

Precipitation

- A higher proportion of winter precipitation falling as rain; earlier snowmelt where snow still accumulates
- More extreme events (torrential rain, severe droughts)
- Potential exacerbation of historical patterns of wet and dry cycles, including likely recurrence of multiyear drought (like the 1950s)

2.3 Case Study: Southwestern US Forest

> ***"By 2050, average summer temperatures may equal those of the worst drought years that the Southwestern U.S. has experienced in the past 1,000 years."***
>
> **Dr. Park Williams**

A particularly arresting example of the potential for cascading impacts of climate change is the predicted effect of increasing temperatures on Southwestern forests. Dr. Park Williams, who spoke at the workshop, has been studying how forest fires correlate with rates of water use by plants, winter snowpack, drought indices, and pine beetle outbreaks. He has found that all of these factors are strongly correlated; dry winters coupled with dry, hot summer conditions stress the trees, making them more susceptible to pine beetles and more prone to forest fires.

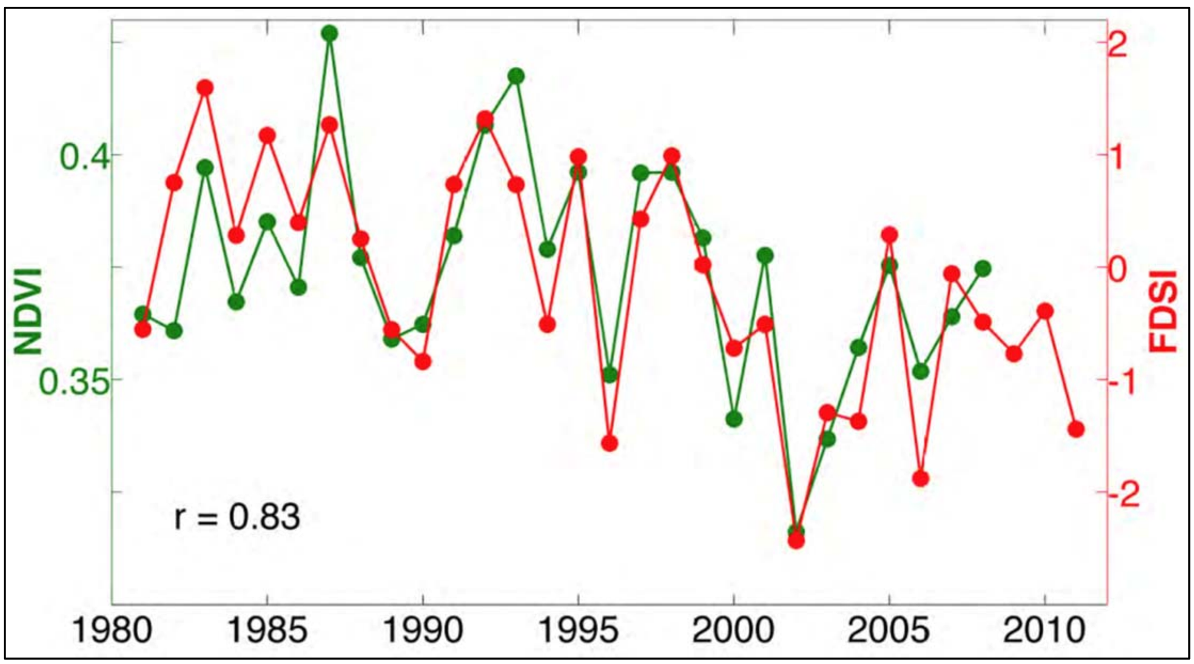


Figure 4. Correlation between summer vegetation greenness index (NDVI) and the Forest Drought-Stress Index (FDSI) (Williams, 2012).

Dr. Williams used this information, combined with historical data from tree rings, to develop a "forest drought stress index" (Figure 4). Low index values indicates conditions prime for forest fires. The index was particularly low in northern New Mexico in 2002, 2006, and 2011, all years with particularly high fire damage in this region. New Mexico experienced the worst fire season on record in 2011, when the Los Conchas fire burned 150,000 acres in the Jemez Mountains. The Pacheco fire burned about 10,000 acres in June 2011 and came within two miles of the Santa Fe Watershed.

If climate models are correct, by the 2050s average drought stress will equal that of the worst drought years that the Southwestern U.S. has experienced in the past 1000 years.

Drought-induced forest fires are normal in New Mexico. For example, tree-ring data suggest that regionally extensive droughts in the late 1200s and late 1500s caused increased forest fires throughout the Southwestern U.S., also periods for which Dr. Williams' calculated the forest drought severity index to be low. However, climate projections suggest index values will become more negative in the future. By about 2050, Dr. Williams predicts that forest drought stress index values for even the wettest, coolest years will equal or exceed the values experienced during the 1200 and 1500 "mega-droughts", the 1950s drought, and the recent 2002, 2006 and 2011 summers. By 2050, average conditions will equal that of the worst drought years that the Southwestern U.S. has experienced in the past 1000 years (Figure 5).

In the near future, forest fires are likely to become more frequent, and possibly larger (depending on how we manage our forests). These forest fires in turn affect the stability of the landscape. The more intense rainstorms that are expected are likely to increase erosion, and cause the accumulation of ash and sediment in our rivers. As we saw in 2011 with the severe erosion following the Los Conchas fire, these changes can prevent the use of surface water for drinking by communities such as Santa Fe for many months.

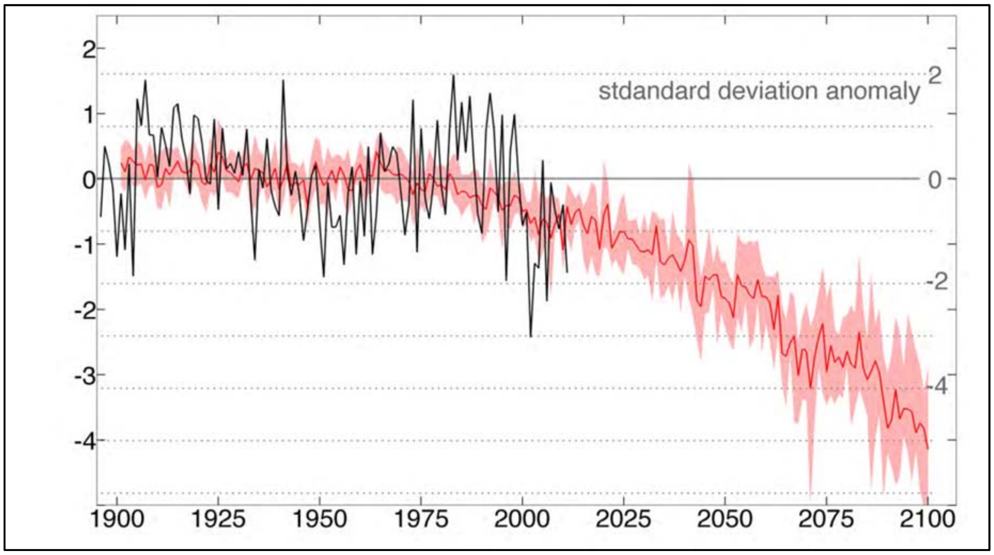


Figure 5. Projected and historic FDSI derived from measured data (black).

Within a few decades, maintaining ecosystems as forests, rather than allowing conversion to scrublands or grasslands, may only be possible in wetter or otherwise milder climatic niches. Other areas will convert to non-forest vegetation types.

2.4 So What Next?

The projected impacts of climate change include:

- Lower stream flows due to both less runoff and greater water use by plants;
- Diminished snowpack, and earlier snowmelt of existing snowpack;
- Drier spring seasons, with earlier peak runoff and lower peak flows;
- Drier mid- to late-summers;
- More severe droughts;
- More intense precipitation events, with an accompanying potential for more sediment transport and erosion and for declining aquifer recharge; and
- Loss of ponderosa and mixed-conifer forest ecosystems.

All of these impacts are primarily temperature driven, and are expected to occur even if there are no significant changes in annual precipitation. These impacts are virtually certain; however, because climate modeling provides us with **projections**, not **predictions,** we are not able to specifically predict the impacts or their timing.

Global circulation models are mathematical representations of our best understanding of the critical processes that drive our climate. The models are run for a series of greenhouse-gas emissions scenarios that we think are plausible potential futures. The result is a range of model outputs that we hope capture the conditions we are likely to experience in the future. However, since the future greenhouse-gas emissions will be determined by human and societal behavior, we cannot say with certainty where, within that range we will fall. Nor can we say whether we have captured the full range of possible futures.

So, we are left with irresolvable uncertainty. And, because much of this uncertainty is dependent on which future pathway humanity chooses, we will be unable to fully resolve it. However, the level of uncertainty around climate is no greater than uncertainty around population projections, economic forecasts, and technological changes, and yet we regularly conduct planning dependent on those variables. We have enough information about future climate to begin planning for and addressing it.

Bill deBuys describes the temptation to sink into despair when faced with the reality of climate change in the Southwest. In deBuys' book *A Great Aridness* (deBuys, 2011) he describes the work of numerous researchers and their study of the impacts of climate change that are already being felt in the Southwest. He says that we may already be in a mega drought, and can only know after several decades have passed, and:

"In a way, our decisions for the future should be the same, no matter whether we are a few years inside a mega drought or lucky enough to have decades of relative abundance ahead of us. Deep, crushing cycles of drought are part of the natural history of the Southwest and, for all practical purposes, they always have been. Building resilience against drought into the region's water systems and cultural practices would be a wise course, irrespective of the cause or timing of the next emergency. Perhaps the dangers now arising from anthropogenic climate change will goad us into doing the things we should have been doing all along… to strive for resilience,--the capacity of an ecosystem to experience disturbance without losing its essential character and becoming something else. It stands to reason that a grassland with a diversity of grasses--some that flourish with fourteen inches of rain, some that prosper with just eight--will fare better through fluctuating conditions than will a monoculture of a single species."

"There is only the age-old duty to extend kindness to other beings, to work together and with discipline on common challenges, and to learn to live in the marvelous aridlands without further spoiling them."

3 Public Participation

The daylong workshop generated an inspiring amount of interest and engagement from a broad cross-section of community members. Within 24 hours of the workshop announcement, registration was half-full, and it was full, with a waiting list, a week before the event. Event attendance was capped at 120 participants, to ensure that all attendees could be engaged in and actively contribute to small-group breakout discussions and large-group conversations. Participants were from a wide range of backgrounds, with 40 percent from state, tribal, federal and local governments, 26 percent from non-profit organizations, and the remainder private citizens or environmental consultants. The participant list is included as Appendix B.

3.1 Engagement & Small-Group Discussion

The community in Santa Fe has thought extensively about both water and climate change. Most attendees came to the workshop with at least some background knowledge about climate change, potential climate change impacts, and possible responses. They also came with prior knowledge and concerns about water, water demands, and potential solutions for current water issues. Workshop organizers capitalized on this expertise and experience, setting an ambitious agenda for the day.

The workshop asked a lot of participants: to learn new technical information; to work in small groups along with people they did not know; to break water basin management down into components that were unfamiliar; and then, to collaborate to identify and prioritize possible solutions. Attendees' ongoing engagement throughout the day indicated commitment, interest and concern about the issues of water management and climate change.

The day began with a series of presentations about climate change, ranging from the big-picture projections of impacts to Santa Fe, to a fairly technical picture of how climate change could impact local forest ecosystems that illustrated how climate science is conducted, to a broad overview of the social ramifications and ways that we, as individuals, might choose to engage with what is perhaps humanity's greatest challenge.

Following the early-morning plenary presentations, participants chose themed breakout groups in which to participate. There were two sessions of small group conversation: in the first, participants chose between breakout groups themed around water or ecology; in the second, participants chose between land use; quality of life and agriculture; and food security. Themes were intentionally broad to allow participants to explore the issues they found most relevant. Within the breakout groups, participants were further divided into tables of about 10. Table groups were asked to work together to identify key systems of interest, current vulnerabilities of those systems, how vulnerabilities would be intensified or change in response to climate change, and key thresholds at which, under the strain of climate change, those systems would be stressed to a point of lasting damage. Because attendees came from diverse professional and personal backgrounds, they came with a variety of interests, agendas and expectations of the event. The small-group conversation offered an opportunity for participants to speak to what their own interests were, and to listen to the particular interests that others brought to the table. Through the opportunities in small-group conversation, participants quickly identified that there were many, and diverse, competing interests and agendas for water management. The comprehensive experience of the small groups exposed the challenges inherent in reducing complex systems to their component parts.

The breakout groups demonstrated an impressive capacity to engage in high-level mapping of water management as a complex, adaptive system. Conversations in break-out groups repeatedly highlighted that important systems are interrelated and that a reductionist approach, identifying singular points of action without taking into account holistic interactions, would be doomed to fail. The groups expressed an expectation that resilient water management be holistic, and indicated the capacity of the community to collaborate and learn.

Two themes came clearly through the reflection on systems: that comprehensive, holistic approaches to watershed management are essential; and that social, cultural and political change is critical to achieving the physical system changes that are needed. Workshop participants were clearly comfortable with the idea that change will need to be facilitated at individual, group, and community scales and encompass both behavioral changes and learning. Participants were enthusiastic and supportive of suggested solutions that hinged on innovative learning, the growth of Santa Fe as a community, and a change in the community's relationship to water.

3.2 Generation and Prioritization of Solutions

Following two rounds of themed breakout sessions, the workshop closed with a plenary session in which participants were asked to discuss solutions and identify priority actions. Attendees enthusiastically offered a wide and creative range of approaches to diverse problems associated with water management. The more readily actionable solutions are presented and discussed in Section 5; the full list of proposed activities is included as Appendix D.

During this brainstorming and prioritization of solutions, it became clear that there is a lot of work already underway at different levels in the community around climate change, sustainability, resilience and water. Much could be accomplished through collaboration and communication between these efforts, and any that grow out of the workshop, to develop and share emerging solutions. Chapter 5 describes potential solutions that were suggested in the workshop, along with efforts that are already underway.

Overall, the workshop demonstrated that there is great energy and potential for sustainable change in the Santa Fe community. A common interest was expressed in working toward a future that reflects that sustainability, along with an understanding that getting there will require collaboration, education, and ongoing engagement.

3.3 Workshop Follow-up

Responses from one-on-one conversations during the workshop, from workshop evaluation forms, and from emailed feedback from participants paints a picture of a community with core capacities for managing change and a willingness to engage the challenges of the future. Throughout the workshop, participants willingly learned from each other. Many participants offered feedback that they had a better understanding of the complexity involved in engaging different perspectives and managing competing agendas than they did at the beginning of the day. From the presentations in the morning, participants shared that they enhanced their understanding of the urgency, and imminent reality of the drastic changes in the environment that are likely to result from changing climate. Though the day was challenging, by the end of the day people also expressed the strength of their convictions and commitment to continue to work towards greater resilience for the watershed, and shared the sense that everyone was in it together. Participants wanted to learn what others were doing, what projects are underway or planned for implementation, and what opportunities for engagement and learning are being generated.

4 Systems and their Vulnerabilities

The Santa Fe Watershed consists of multiple small, basin-scale systems embedded within a larger, regional system. In the workshop, we asked participants to share and explore systems of interest and/or concern to them. This section summarizes and expands on the systems explored at the workshop.

Systems Include:

Infrastructure: food supply, water supply, transportation, energy, shelter, communication, health, education, finance

Ecosystems: agricultural land, parks, wetlands, rivers, range land, forests.

While this discussion segregates the various physical, biological and socio-economic systems within the Santa Fe Watershed these systems are interconnected and are part of a complex whole. This disaggregation allows for examination of the aspects of climate change that will prove challenging or threatening to each system. This, in turn, allows for better anticipation of the timing and nature of the impacts that will need to be addressed. Re-aggregation then allows us to combine activities that can benefit multiple systems simultaneously, reducing the vulnerability of one system by reducing the vulnerabilities of associated systems.

Vulnerability – the underlying fragility or weakness in a system that leaves it open to harm or damage

Vulnerability to climate change is defined by the IPCC as "the degree to which geophysical, biological and socio-economic systems are susceptible to and unable to cope with, adverse impacts of climate change" (Pg. 783 of IPCC, chapter 19, Schneider et al., 2007). The purpose of defining the vulnerabilities is to assess how to make each system less vulnerable and thus, more resilient.

The following discussion of systems, though extensive, is not comprehensive.

4.1 Water Supply Systems

Water supply systems include surface and groundwater sources and the human demand for water. There are also water supply implications for ecosystems; these are discussed in section 4.2.

4.1.1 Surface Water

The Santa Fe River, which supplies surface water for Santa Fe and Santa Fe Basin acequias, is vulnerable to several aspects of climate change. First, the availability of water could be greatly compromised if the forest in the upper watershed experienced a high-intensity fire; as explained by Park Williams at the workshop, the risk of catastrophic fire increases with the projected drier climate. As observed in other parts of the Rocky Mountains and Jemez Mountains, a severe thunderstorm following a catastrophic fire could result in debris flows; sediment accumulation in the municipal reservoirs, and flooding of the downstream valley (e.g. downtown Santa Fe). Sediment and ash in the runoff could compromise the operation of the water treatment plant.

Second, increasing temperatures will decrease the amount of available water because of increasing evaporation and increasing water use by plants, which will result in decreasing runoff and decreasing groundwater recharge. Cox et al. (2011) estimates that the average yield of the Santa Fe River into McClure reservoir will decrease by 11 to 18 percent by 2060 below the historic average from 1950-1999.

Third, also as a result of increasing temperatures, an increasing percentage of winter precipitation is projected to fall as rain, rather than snow, reducing snowpack water volume. Remaining snowpack is projected to melt earlier, potentially impairing Santa Fe's capacity to store the runoff for use at a later time, if inflow comes off too fast and exceeds the capacity of the reservoirs. Santa Fe's water rights are greater than the storage capacity of the reservoirs and the ability to divert the city's water right is dependent on both stored water and inflowing water. If more of the annual runoff occurs over a shorter time period (i.e. a few weeks) the reservoirs could fill and spill. This could be followed by very little inflow to the reservoirs from the Santa Fe River the remainder of the year.

Like the Santa Fe River, the Rio Grande and Reclamation’s San Juan-Chama Project water systems are vulnerable to fire, reduced flow, reduced snowpack, and earlier snow melt. They are susceptible to water-quality degradation from intense thunderstorms that carry nutrients, sediments, pathogens and toxins into the Rio Grande from Los Alamos National Laboratories and other communities upstream. Increased temperatures will affect the self-purification capacity of these rivers by reducing the amount of oxygen that can be dissolved and used for biodegradation, also impacting aquatic life. Increased precipitation event intensity can trigger flash flood events and escalate erosion.

All of the city and county's surface water sources, including the Santa Fe River, the Rio Grande and Reclamation's San Juan-Cham project, are subject to interstate compacts. In particular, Santa Fe’s right to store water is limited when New Mexico is under Article VII restrictions under the Rio Grande Compact, which occurs when supplies for Reclamation’s

Rio Grande Project (the irrigation project downstream of Elephant Butte Reservoir) falls below specified thresholds. Under the Compact terms, the City can divert water at a rate equal to the inflow to McClure Reservoir until reservoir storage reaches the pre-compact rights of 1,061 ac-ft. Subsequent stream flow must either be diverted by the City of Santa Fe, by-passed or "purchased" by exchange. Climate Change projections suggest that Article VII of the Compact will be in effect much more frequently under future, drier conditions. Theoretically, Santa Fe County's rights to native water of the Rio Grande could be curtailed to support deliveries under the Rio Grande Compact, although this has not yet happened. San Juan Chama waters supply can be curtailed if the supply is insufficient, or if the supply is constrained under the Colorado River Compact.

4.1.2 Groundwater Supply

The vulnerability of groundwater supply is less well understood than surface water vulnerabilities because the mechanisms and timing of recharge are more difficult to quantify. Climate change projections suggest future precipitation may be delivered in fewer, more intense events giving the above-ground flow less time to infiltrate into the aquifer. Groundwater recharge generated from snowmelt will also likely be reduced as a result of a smaller snowpack area and shorter melt season. Both factors would contribute to a lowering of the water table and a reduction of water storage in the aquifers in the Santa Fe watershed.

4.1.3 Water Use

Water use for all human sectors is expected to increase with higher temperatures – from a greater need for irrigation (unless different crop types and irrigation techniques are implemented) to greater demand for domestic and commercial, urban and rural uses. Outdoor watering and use of swamp coolers will likely increase with higher temperatures. Cooling demands for power plants, industry, and businesses will increase. Parks and green spaces within the city will require more water, unless vegetation types are transitioned or replaced. Even artificial turf, which has been installed for over a decade in many city parks and schools, may require water to reduce the heat of the surface.

4.2 Ecosystems

Climate change will pose increased or new stresses for virtually all Santa Fe Basin ecosystems (Figure 6). The Santa Fe Watershed ecosystems and habitat are controlled most significantly by elevation and water availability. From the alpine conditions above tree line at 12,400 ft. elevation to the wetlands where the Santa Fe River discharges to the Rio Grande (5200 ft.) all systems are predicted to be subjected to the predicted climate changes. Further detail is provided in the following subsections on possible impacts on specific ecosystems, including forest habitat, grassland habitat, riparian habitat, aquatic habitat, and wildlife habitat. The Nature Conservancy (Robles and Enquist, 2011) rated the Middle Rio Grande Watershed, which includes the Santa Fe Watershed, as "most vulnerable" based on the predicted temperature increase and the number of species of concern.

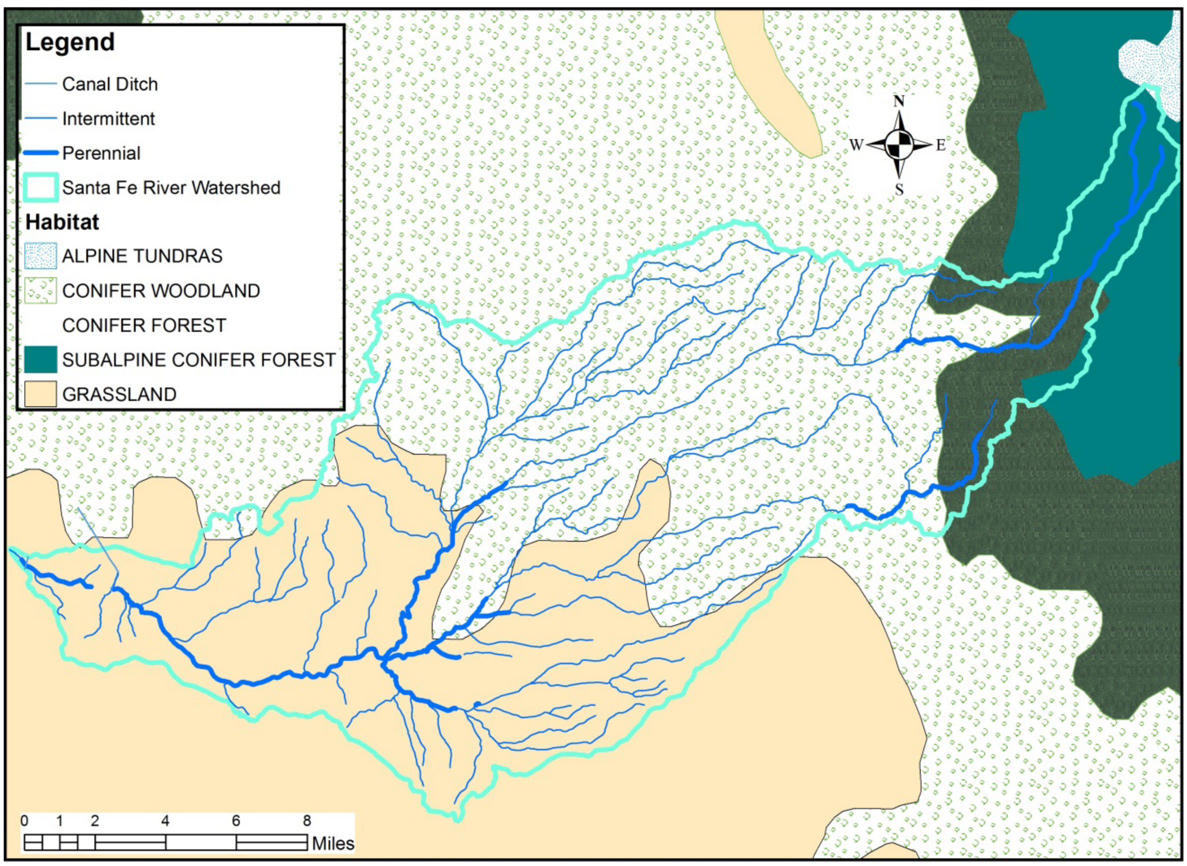


Figure 6. Habitats in the Santa Fe Watershed (TNC, 2012)

4.2.1 Forest Habitat

The Santa Fe watershed forests at the higher elevations are composed of Douglas fir and aspen, mixed-conifer zones, which progress to ponderosa pine and Gambles oak at about 10,000 feet, and then to piñon pine and juniper at the elevations below about 7,500 feet . Forest habitat is vulnerable to both decreases in cold-season precipitation and increases in warm-season vapor pressure deficit (Williams, 2012; see section 2.2.1). Stress from either of these factors leave forests increasingly susceptible to insects and forest fires. At the same time, increased minimum temperatures increase insect survivability and increased maximum temperatures increase fire risk. Even relatively healthy sections of forest may be impacted or lost to catastrophic fires started in other areas. Conifer woodlands are projected to decrease from a total area of 10 percent to 1 percent in the Middle Rio Grande Valley by 2030 (Click et al., 2011).

4.2.2 Grassland habitat

At elevations below about 6,500 feet, the non-developed land transitions from piñon-juniper savanna to native grasslands with nutrient-rich grasses of blue gramma and ring muhly. Increased temperatures will favor grassland habitat pests and invasive species, which have a high germination rate and start growing before native grasses. These non-native grasses will quickly out-compete native perennial vegetation, which will put native grasslands at higher risk. Decreases in soil moisture and increases in plant water use will stress grasses, leading to subsequent die-off and contributing to erosion. The resulting topsoil losses may lead to further grassland degradation, creating a negative feedback loop. Grassland degradation would result in a transition from native, nutrient-rich grasses to invasive species such as cheat grass and buffel grass, which lack the nutrients needed by native wildlife. Semi-desert grasslands are predicted to decline from 38 percent to 25 percent with a complete loss of plains grasslands by 2030 (Glick et al., 2011).

4.2.3 Riparian Habitat

Riparian habitats occur along streams and areas beyond the channel confines where flooding occurs, and includes perennial and ephemeral reaches. The riparian habitats thrive in the perennial reaches of the Santa Fe River above Nichols reservoir and below the wastewater treatment plant, and in Arroyo Hondo upstream of the intersection with I-25 (Figure 1). The riparian habitat is vital to many species, including beaver, migratory birds, the listed endangered species southwestern willow flycatcher, and the northern leopard frog, which is designated as a sensitive species under the Endangered Species Act. Riparian habitat along intermittent reaches of streams is vulnerable to vegetation loss from droughts and longer-term reduction in overall stream flow. Intense runoff events may rework the riparian channel, leading to down-cutting and incision and/or deposition of sediment. The riparian habitat around the springs at La Cienega could be impacted by a reduction in groundwater recharge, which, along with continued pumping of the aquifer, could reduce the flow into and the area of wetlands.

The riparian habitat along ephemeral reaches is vulnerable to climate change. Increased runoff volumes will have a scouring effect on ephemeral streams, leading to increased bank erosion and channel degradation. The increasing frequency and force of bank erosion and overbank flows will threaten adjacent property and infrastructure, undermining trails, wells, roads, bridges, fences, and buildings. Intermittent dry spells will lead to the die back of plants along ephemeral streams, causing soils on banks and terraces to be more susceptible to erosion. As a result, heavy flows will transport more sediment and deposit sediment in flat and wide channel section or upstream from bridges and other obstacles in the channels. Altered sedimentation patterns will most likely exacerbate bank erosion and undermining of structures adjacent to sediment plugs. There will be an increasing need to update FEMA maps that indicate flood prone areas and flood risks to structures, even for ephemeral streams.

4.2.4 Aquatic Habitat

The aquatic habitat in the Santa Fe watershed includes the cold-water fishery in the reach above Nichols reservoir, where Rio Grande cutthroat trout and rainbow trout enjoy a nearly pristine habitat. The 12.7-mile reach below the wastewater treatment plant is designated as a marginal cold-water fishery and warm-water fishery, which provides habitat for the Rio Grande sucker, a listed sensitive species (BLM, 2010). Aquatic habitat is highly sensitive to water supply and quality, but also to temperature. The thresholds for aquatic habitat are defined as “warm water fisheries” or “cold water fisheries” because of the species supported by these habitats. Water temperatures above 20 ^{o}C (68 ^{o}F) impair the quality of a cold-water fishery, making it unsuitable for many of the native trout; thus aquatic habitat will be directly impacted by increased temperatures.

4.2.5 Wildlife Habitat

Wildlife, such as bears, mountain lions, elk, deer, beaver, squirrels, rabbits, hares, foxes, bobcats, antelope and a wide variety of birds, are abundant in the Santa Fe watershed. Wildlife habitat, which includes the forest, riparian, and aquatic habitats, will become increasingly stressed as water and food supplies diminish. As temperatures rise, the number of hours in a day when a species may be active will likely be reduced, thereby reducing their ability to forage and hunt. If habitat area diminishes due to vegetation loss and ecosystem degradation as a result of warmer temperatures and human activities, migration pathways (i.e. the connections between habitats) become smaller, placing an additional burden on animals already stressed by development and highways. Piñon Jays nest mainly in stands of piñon-juniper and their population trend in the Santa Fe National Forest is downward due to the wide-scale loss of piñon associated with drought and Ips beetle infestation (BLM, 2010). Some animals, such as the Abert's squirrel in the upper Santa Fe Watershed, live in forests with ponderosa pine trees, which serve as their sole source of food; a drastic reduction of ponderosa forests would therefore have a big impact on the Abert's squirrel. Species reliant on non-forest ecosystems may prosper, however. For instance, reduced snow pack could allow elk to forage at elevations they were previously unable to reach, though because elk eat woody plants; their access to new areas could cut into nesting habitat for birds that rely on deciduous environments (Hagner, 2012).

An assessment of the Middle Rio Grande valley found that five out of nine of the amphibian species are vulnerable to climate change (Glick et al., 2011). They also identified the southwestern willow flycatcher, the western yellow-billed cuckoo and the common yellowthroat, birds that depend on riparian habitat, to be among the most vulnerable to climate change. Of the 36 mammals assessed, they found that five are the most vulnerable: New Mexico meadow jumping mouse, beaver, woodrat, hoary bat and black bear because of their reliance on riparian areas, dense vegetation or specific vegetation. The jackrabbit and desert shrew populations are expected to increase due to expansion of their habitats.

Clearly, there are opportunities for some wildlife species and drawbacks for others. Whether any particular species thrives or declines will depend on the specific habitat needs of the species and the impact of climate change on the habitat, food chain or ecosystem upon which the species depends.

4.3 Agriculture and Food Security

Agriculture in the Santa Fe watershed includes 720 acres (Longworth et al., 2008) most of which are in the La Cienega area, with a few small farms located throughout the urban area. The vast majority of food is imported rendering high food security vulnerability. There is a growing regional emphasis on shifting the community's dependence on the global food market to more local supplies. Impacts to local agriculture and food security are growing concerns as climate change is projected to reduce water supply and effect additional stresses (environmental and economic) to the crops and livestock.

4.3.1 Acequias and Farming

Acequias and farming in the Santa Fe watershed are vulnerable to many aspects of projected climate change. First, climate change is expected to increase water stress on crops. The projected earlier snowmelt may result in the majority of runoff occurring before peak growing season. Then, during the peak growing season, when less water is available, increased temperatures will increase crop water demand. Currently, most of the agriculture within the Santa Fe River Watershed is spring fed or supplied by treated City of Santa Fe effluent from the municipal wastewater plant. Agriculture that is currently spring fed may not be adequately supplied if groundwater recharge rates are reduced due to changes in precipitation and temperature. The four acequias in the urban area benefit from the storage capacity of the city’s two reservoirs.

Second, increased weather variability during the growing season will stress crops. Projected increased thunderstorm intensity, amplify the risk of higher winds, larger hail, and more flooding to crop production. The projected larger diurnal temperature fluctuations may make growing crops more difficult.

Third, the growing urban demand for water has already resulted in the transfer of water rights from agriculture to other uses in the Santa Fe watershed. The increased difficulty of crop viability described above will likely place additional pressure on farmers to sell their water rights. This transfer of additional water rights to urban or domestic use may threaten the long-term viability of small scale, acequia agriculture.

And fourth, genetically engineered crops, now prevalent in the basin, may be maladaptive. “Genetic engineering and biotechnology have developed strains of crops with improved yield and/or pest and weed resistance under current climatic conditions, but it is unclear whether they will prove as resilient as native seeds to climatic extremes the future may bring. Cross-pollination of the genetically engineered crops with native crops is threatening seed sovereignty for farmers in the region, who believe native seeds can tolerate drought much better (Ralph Vigil, personal communication at workshop). Additionally, pesticide-resistant "super bugs" and herbicide-resistant "super weeds", which have evolved in response to the genetically engineered crops, will place additional stress on the crops.

It is possible climate change will benefit some crops in the short term. Increased temperatures could improve growing conditions for crops at the cold-limit of their range, and increased CO2 could increase growth rates for some crop types. However, if "business as usual" climate change progresses beyond the next few decades, most studies suggest these short-term benefits will be overwhelmed by new or intensified existing stressors discussed above.

4.3.2 Ranching

In the Santa Fe watershed, ranching is primarily focused on the high desert plains of the Caja del Rio mesa and in the grasslands northwest of the City. Ranching will likely experience reduced grassland quality due to increased water use by the plants on which the livestock depends, and increased frequency and severity of drought. This will reduce the carrying capacity of the land. Longer, drier summers will also limit natural filling of stock ponds and speed stock-pond drying. More extreme winter and spring weather could increase calf mortality. Hotter, drier summers may increase cattle heat stress, which could increase mortality and/or reduce growth rates.

4.3.3 Food Security

Currently, and at first glance, Santa Fe's overall food supply is not particularly vulnerable to local climate change due to its very limited local production. Only a small percentage of the food consumed in Santa Fe is grown within a 200-mile radius. Without a detailed mapping of the origins of the majority of locally-consumed food, it is difficult to identify the food security risk climate change poses for the Santa Fe Basin. An increased commitment to local food production may increase the basin's overall water demand, thus shifting a benefit in the food system to vulnerability in the water supply system.

4.4 Land Use and Quality of Life

Human activities and enjoyment of living in the Santa Fe Watershed are at risk of impairment by climate change. Thoughtful decisions and actions will need to be taken to maintain and improve quality of life.

4.4.1 Recreation

Recreational activities dependent on the lands and waters in and around the Santa Fe watershed will be impacted by climate change. The ski season will be reduced, and eventually may be too short for ski resorts to be viable. Rafting on rivers near our basin will be impacted in part depending on how reservoir operation and storage are handled in the future; rafting during peak-flow season will shift earlier in the year, and potentially for shorter periods of time. Changes to water quality and water temperatures will impact aquatic species mortality and morbidity, potentially impacting recreational fishing opportunities. The hunting season will be impacted as species shift and are stressed by changes to forest ecosystems. Wildfires or the threat of fires may increasingly impact hiking trails and campgrounds.

However, the projected changes may have some recreational benefits. For example, warmer winter temperatures may increase winter visits to parks, improve winter camping conditions, and expand the opportunity for cool-season rafting.

4.4.2 Landscaping and Parks

Landscaping and parks will be vulnerable to increased temperatures and will require more water. Water shortages may result in limits to outdoor watering. With warming temperatures, the parks may be used for more days of the year. Perhaps Santa Fe is less vulnerable because of its leadership in low-water intensity parks and green spaces; this may prove to be a skill-set that can be exported to other communities both in- and out-of-state.

4.4.3 Air Quality

Air quality may be impaired by wildfire, drought, and higher winds associated with more intense storms, which accelerate the distribution of smoke, dust, pollen and other particulates. Heat also tends to intensify the impacts of urban air quality contamination (Patricia Romero-Lankao, NCAR). Reduced air quality may result in increased allergic and respiratory issues for local citizens.

4.4.4 Streetscapes and Urban Habitat

Streetscapes and urban habitat are vulnerable to the projected increase in storm intensity and higher temperatures. More intense storms may result in short-term urban flooding, with impacts to commons areas, homes, businesses and transportation routes. Higher temperatures, particularly summer heat waves and increases in nighttime high temperatures, may place increased stress on urban dwellers, particularly the elderly, infirm, and infants, and on urban vegetation. Increased temperatures will also place greater stress on streets and pavement, resulting in the buckling and cracking of concrete and/or blacktop surfaces during heat waves. Decreases in urban vegetation in response to potential water limitations may increase the city heat-island effect. The effect could be mitigated, to some degree, through the planting of shade trees. But if these are not low-water-use trees, this planting may increase overall water use.

4.5 Energy Systems

Santa Fe is powered primarily by electrical power and natural gas, and in rural parts of the County, propane and rural electric cooperatives. New Mexico Gas Company provides the natural gas. Electrical power is primarily supplied by the Public Service Company of NM (PNM), who generates and purchases power from a mix of sources (EPA, 2012)

- Coal-fired power plants - 38.6 percent;
- Natural gas powered plants – 35.7 percent,
- Nuclear power - 16.5 percent;
- Hydropower - 6.1 percent; and
- Renewables (solar and wind) - 3.1 percent.

4.5.1 Power Generation

With the exception of wind and solar power, the electrical power sources listed above requires some amount of water for their functioning, either for cooling or turbine driving. Water demands for thermal power plants (e.g. coal and natural gas-fired) increase with increasing air and water temperatures. Increases in ash or sediment in water supplies may also impact generation capacity and potentially lead to increasing energy costs.

Hydropower generation is particularly susceptible to climate impacts to water availability. In particular, the City's 93 kW turbine-generator unit powers the treated water distribution. Power generation will be reduced if less surface water is available. Local solar power production could be impacted by smoke and dust accumulation on panels during forest fires and drought. Solar power generation efficiency is reduced as temperature increases. Local power production and energy availability will also be impacted by climate events distant from New Mexico. For example, coastal storms coupled with sea level rise will increasingly disrupt offshore extraction and coastal refining of fuel, reducing power plant and automotive fuel availability and increasing prices.

4.5.2 Energy Consumption

Consumption of energy is affected by temperature changes. Across the U.S., projected temperature increases will increase warm-season cooling demand (from 8 to 35%) and decrease cool-season heating demand (5 to 35%) (U.S. Climate Change Science Program, 2008). In the Santa Fe Basin, where a majority of warm-season cooling is via evaporative coolers or non-existent, increased cooling demand will increase both household water and electricity consumption.

4.5.3 Power Transmission

Power transmission can be impacted by extreme low-temperature events, intense precipitation, and wildfires. In February 2011, very low temperatures (-20 ^{o}F) dramatically increased gas and electrical demand in New Mexico and Texas. Simultaneously, the increased electrical demand exceeded supply, triggering rolling brown-outs that shut down natural gas compressor stations, disrupting gas transmission (Aaboe, 2012). In summer 2011, a Lubbock, Texas gas well-field lost power for two weeks when a wildfire burned the power lines.

High temperatures can impact pipelines handling supercritical fluids, and electrical reliability can be affected by high soil temperatures and soil dryness (U.S. Climate Change Science Program, 2008). Infrastructure, particularly pipelines, can be impacted by intense precipitation events, cold-extremes causing unexpected freezing, and heat and drought extremes causing cracking and buckling of soil and pipes. While Santa Fe basin may not contain all of the impacted infrastructure, effects elsewhere will likely propagate into the power-supply grid within the region.

4.6 Transportation Systems

Climate change will impact ground and air transportation through increased temperatures, high winds, intense rains, smoke and dust, resulting from increased droughts, dust storms and wildfires. Bridges and culverts are generally designed for threshold flood events; flood events exceeding those design specifications will result in flooding and possible infrastructure damage. Similarly, thermal expansion of expansion joints in bridges, paved surfaces, runways and railroad and light rail rails may exceed design specifications with increased warming, causing buckling. Increasing dust storms during droughts and/or with high wind events, and smoke due to wildfires, may dramatically impair visibility. Fuel usage in cars is also increased, by 12% at highway speeds, with the use of air-conditioners.

Increasing temperatures also impact air transportation uniquely: warmer air is less dense, requiring longer runways, more speed, and more fuel to lift planes off the ground (TRB, 2008). For some airports, this could eventually require longer runways or limit the usage of larger planes to cooler seasons.

4.7 Economic Systems

Climate change will pose interesting new demands on existing economic systems. Whether these demands are vulnerabilities or opportunities will depend on how we respond to them, and will vary for different economic sectors. For example, sectors that will see new challenges include insurance and tourism. The insurance sector has been very proactive to date around the changing risk-frequencies of damaging events. This has led to increases in premiums as well as refusals to provide insurance in areas where risks are increasing, such as for homes in areas of increased wildfire risk or in floodplains. Such limitations to insurance coverage may become even more widespread in the future.

Tourism will be heavily influenced by global and national economics and by local recreational opportunities (see Section 4.4.1). Global and national economics, and consequently tourist travel and spending, will be impacted by politics as well as climate change, and are therefore even more uncertain that climate change alone. The tourism sector is probably best advised to broaden its client base, tourism activities, and seasons to build resilience.

More broadly, local businesses may see increasing energy and cooling costs, and may be impacted by flooding and air quality concerns. Local households will also see these impacts, as well as increased food costs as both global and national agriculture will be impacted by changing climate coupled with increasing global energy costs and growing global population. Local households and businesses could also be impacted if climate change and water scarcity leads to reduced property values due to reduction in quality of life, though increases in growth management to address limited water supply could just as likely boost property values.

4.8 Sociological (body politic/community)

Government, community, and cultural institutions may become stressed while facing the challenges posed by climate change. Some institutions will be able to evolve to deal with fluctuating climate conditions and societal expectations around climate; others will not.

Citizens expect their governments, whether local or national, to provide certain services, serve particular functions, create and modify laws, and enforce particular visions of “society”. Within much of the U.S., local governments are expected to maintain critical infrastructure like road networks or parks, and to provide the framework within which utilities or other companies can provide services. As described earlier, increased temperatures and greater precipitation variability will stress Santa Fe’s infrastructure. If the frequency of infrastructure disruption and destruction increases, the local government might find its ability to repair infrastructure in a timely manner greatly compromised.

Additionally, local governments are expected to make land use decisions and develop and enforce building codes. Santa Fe's local governments may need to grapple with balancing resource supply with increasing urban development. How the policy makers handle growth in the next 10-20 years will greatly influence how vulnerable the watershed might be to various aspects of climate change.

Governments are also in charge of managing and adjudicating property rights – in the Southwest, water is one of the most highly contested types of property. As climate variability and change alter the Santa Fe Basin hydrology, and economic preferences shift between agriculture, ranching, and urban demands, existing water rights systems may no longer be appropriate. Water rights and associated supporting legal structures will become more contentious in the future, challenging the ability of governments to adjudicate and balance demands.

Beyond water rights and land use/ infrastructure decisions, many local and state governments are also charged with emergency management and response during and after disasters. Wildfires, such as the 2011 Las Conchas fire, or extreme weather events can quickly overwhelm the capacity of local governments to respond and deal with the aftermath. National governments are increasingly being called upon to provide monetary, personnel, and equipment resources to local and state governments during and post-disaster. As discussed earlier, climate change is likely to increase both the frequency and intensity of certain types of hazards for New Mexico, particularly wildfires and drought.

Cultural and community institutions may also be impacted by the projected increases in temperature and precipitation variability. New Mexico and Santa Fe are home to varied communities with many rich cultural traditions, – from the traditional acequia-grounded agricultural communities, to the diverse Pueblos. The identities and cultural traditions of such communities have historically been linked to water, seasons, and associated cropping cycles. Reductions in water supply and changes in crop viability associated with climate change will alter cultural identities and community institutions throughout the Southwest, potentially leading to the collapse of small farming communities. Many communities' identities and traditions are evolving already due to changing economic and demographic conditions; climate change has the potential to exacerbate changes to such institutions.

5 Potential Solutions and Current Actions

Santa Fe Watershed stakeholders have been very active in efforts to create a more resilient community and watershed for many years. Under the historical climate, the watershed has periodically faced drought, water quality impairment, erosion and down-cutting of the river from urban development, and massive piñon pine die-offs (in 1950 and again in 2002), all of which are projected to increase in frequency and/or severity with climate change (Williams, et al., 2010). Likewise, the risk of wildfire has become very clear as residents of the Santa Fe Watershed have witnessed catastrophic fires to the west in 1996 (Dome Fire), 2000 (Cerro Grande Fire) and the Conchas Fire, which burned over 150,000 acres in 2011. Because of this history and experience of dealing with drought, pests and catastrophic forest fires, Santa Feans have been working to make the watershed more resilient.

In people, resilience also includes responsiveness, resourcefulness, and the capacity to learn.

Workshop participants eagerly shared their thoughts and ideas on actions that local governments and citizens could take to create a more resilient Santa Fe watershed. A long list of potential solutions to the projected of impacts of climate changes was identified from the workshop (Appendix D), as well as a long list of actions that is already well underway. We have sifted through those ideas to consolidate the suggestions and summarize what is being or has been done and what remains to be implemented. In this way we can provide clear guidance for the next steps for improving the resilience of the various systems.

We use “resilience” to mean the ability to absorb disturbances (including climate variability and extremes), to change or adjust, and then to re-organize and still have the same basic structure and ways of functioning OR to anticipate and elegantly move to a new way of functioning. Resilient systems are flexible, modular, and, if they fail, can fail safely. Thus, our goal is not simply to predict specific effects of climate change and address them one by one, but to strengthen the entire watershed, its component systems, and its inhabitants in ways that provide more flexibility in the face of an uncertain future. Further, we want to do this in ways that build on current efforts and concerns, so that the Santa Fe Basin continues to build more resilient systems in ways that respond to today’s climate, but that will also be resilient in the future.

The following proposed solutions are organized in the order of the systems discussed in Section 4, where appropriate. However, no solutions were proposed for the transportation or economic systems (perhaps because climate change is not predicted to have a significant impact on these sectors) and some of the proposed solutions either overlap with multiple systems (i.e. education) and we have presented those at the end of this section. We present the proposed solutions (represented with an arrow) followed with a summary of the current actions that are already underway (represented with an open bullet or discussion).

5.1 Water Supply Systems

Actions proposed for water supply systems were focused on water management strategies and demand reduction.

5.1.1 Water Management

Water management is a top priority for addressing the impacts of climate change. Here is what the workshop participants stressed:

- ➢ Negotiate agriculture-to-urban water transfers of limited term, to be implemented in times of drought or other emergency.
- ➢ Limit domestic well use and permits for residential and commercial groundwater pumping.
- ➢ Complete Santa Fe River Adjudication of water rights.
- ➢ Promote aquifer recharge/develop infrastructure and programs for aquifer storage and recovery: using excess surface water rights-or runoff that cannot be captured in the upstream reservoirs.
- ➢ Create task force to preserve/protect water freed up by conservation.

Conjunctive Use Plans in Place:

Conjunctive use strategies, which optimize the balance between groundwater and surface-water use, have been adopted by Santa Fe County and the City of Santa Fe. These strategies seek to maximize the use of renewable surface water when it is available, and save groundwater resources for use in times of drought. The Santa Fe County Conjunctive Management Plan for the Santa Fe Basin, adopted in 2009 (Ross, et al, 2009), created a policy with the benefits of 1) protecting local water resources, 2) enhancing the reliability of supply, 3) protects acequia water rights, 4) optimizes public asset through a multi-year rolling average for groundwater use, that reduce the number of local groundwater rights needed by the County, 5) reduced impact to other water rights holders by shifting the predominant source of supply from local groundwater to Rio Grande surface supplies, and 6) reducing depletions to springs and the Santa Fe River.

To address potential contamination from storm water entering the Rio Grande, an early warning system for contaminants has been coupled to an auto shutoff of Buckman Direct Diversion. The City and County have the Buckman wellfield as a backup supply to use when the surface water is not available due to drought or contamination.

Existing Limits on Individual wells:

The City of Santa Fe passed an ordinance to prohibit new domestic wells within 300 feet of an existing water line and the State of New Mexico regulations limit the installation of new domestic wells within 200 feet of an existing water system. Residents meeting these criteria are instead required to connect to the municipal supply.

Existing Drought Plans:

The City of Santa Fe currently has a comprehensive drought preparation and management approach, including:

- emergency water regulations (i.e., demand management),
- conjunctive use of surface and groundwater,
- long-term sustainability of the groundwater resources and
- a long-term water supply plan to meet future drought (City of Santa Fe, 2010).

Adjudication of Water Rights:

The Office of the State Engineer is responsible for adjudicating water rights in the State of New Mexico. The Santa Fe River adjudication (Anaya v. Public Service Company of New Mexico, Santa Fe County Cause No. 43, 347) was filed in 1971. The Office of the State Engineer intervened in 1975 and completed a Hydrographic Survey in 1978. Most of the subfiles recognizing individual rights have been completed, but the inter-se period, in which parties to the settlement can object, will not begin until the Office of the State Engineer has sufficient resources to commit to the adjudication (Singer, 2012).

Aquifer Storage and Recovery:

While no official aquifer storage and recovery projects have been implemented in the Santa Fe watershed, the City's in-stream flow program for the Santa Fe River will help to replenish the aquifer.

Use of Reclaimed Wastewater:

The City of Santa Fe has reused wastewater since 1940s, and today 28% of municipal wastewater is reclaimed and used for irrigation of parkland, playing fields, golf courses, as well as for dust control and wildlife/livestock watering. The City of Santa Fe is in the process of updating the 1998 Treated Effluent Management Plan with the Reclaimed wastewater use plan which explores the best approaches to maximizing the use of wastewater.

5.1.2 Demand Reduction

Water conservation is one way to reduce the stress on water resources and build resilience to predicted reductions in water supply. However, as Bill deBuys pointed out in his presentation at the workshop, if water saved from reductions in per capita water use is used to support housing development and local population growth, it can lead to demand hardening, in which a higher proportion of the water supply is used for essential uses, and there is less flexibility during drought. Water management plans (discussed under 5.10) can be used to establish policies that avoid demand hardening. Workshop participants stressed the need for public recognition that water is a scarce resource and that our community should continue to promote water conservation through:

- Tiered water rate structure - cheaper rates for those who use less.
- Incentives for addressing water leaks.
- Strengthen programs for water reclamation and reuse.
- Use municipal wastewater to augment water supply.

Santa Fe is a Leader in Water Conservation:

The City and County both have tiered municipal-water rate structures that promote water conservation. The City of Santa Fe adopted a water conservation ordinance in 1996 to reduce per capita demand through a tiered rate structure. Its water conservation programs include:

- a toilet retrofit program (see photo),
- rebate programs for water efficient appliances,
- a pre-rinse spray nozzle program for dishwashers,
- moisture sensors and evaporation controllers for landscape watering systems,
- a gray-water code that promotes use of some household wastewater for landscape watering, and
- Free water audits to check for leaks.

Through these programs, and a leak detection and repair program for the water distribution system, the City has reduced per-capita demand from 168 gallons per capita per day (gpcd) in 1995 to 104 gpcd in 2010 (www.santafenm.gov/index.aspx?NID=168).

Santa Fe County has a strong policy on water conservation which is implemented by ordinance to require water conservation measures for all new residential and commercial development within Santa Fe County. Additionally, property owners seeking to subdivide land or zoning changes are required to have water restrictive covenants limiting the amount of water a residence or development may use. Santa Fe County is exploring options for improving water conservation within existing small public water systems through a survey of these systems and their water use. This project is funded by the Bureau of Reclamation and includes multiple partners. The City of Santa Fe has adopted a water-harvesting element in its green building code. Santa Fe County has a code requiring rooftop harvesting for roof areas greater than 2,500 ft^2.

5.2 Ecosystems

Ecosystem strategies were primarily focused on forests and rangeland health and riparian restoration.

5.2.1 Forests and Rangeland Health

Foremost on the minds of workshop participants was the risk of catastrophic wildfire in the upper watershed and in the urban-forest interface. The Santa Fe River has provided the City of Santa Fe with a significant portion of its water supply, averaging about 40%. The source of this supply is the 17,000 acres of forest above Nichols and McClure reservoirs. The awareness of the risk of fire has developed over the past 15 years as Santa Fe residents have seen the great plumes of smoke from catastrophic fires in neighboring forests. The understanding of this risk was only heightened by Dr. Park Williams' presentation about the predicted decline of forests in the southwest (Appendix C). Here's what the participants recommended:

- Continue to treat the Santa Fe River upper watershed forests with prescribed fire, when conditions are favorable, to reduce the risk of catastrophic fires.
- Develop contingency plans and budgets for responding to large-scale fires in the Santa Fe watershed, with consideration for flood protection, recovery of water systems, and rehabilitation of reservoirs.
- Improve biodiversity in the watershed: convert the forests of the upper watershed from a near monoculture of ponderosa pine to a more diversion forest; promote a greater variety of ground cover throughout the basin; and protect grasslands.

Completed and Pending Forest Treatments:

In 2000, the City of Santa Fe and the USFS began thinning the Upper Santa Fe Watershed in the vicinity of the reservoirs. This work was initiated due to a growing recognition that the forest ecosystem was out of balance, with a high density of small diameter trees and a low density of desirable grasses, and thus vulnerable to a high severity fire. To date, 7,270 acres have been treated and an additional 2,900 acres are proposed for treatment to reduce the risk of a catastrophic wildfire. The treatments have increased the biodiversity and resilience of the forest to drought and fire.

The City of Santa Fe's Wildland Urban Interface (WUI) program provides information and assistance to homeowners about proper landscaping and methods to reduce the risk of fire in areas near the surrounding forests. The Santa Fe Fire Department has a full-time position dedicated to WUI issues. The City of Santa Fe's Fire department adopted the International Fire Code and the Wild Land Urban Interface Code that requires indoor sprinkler systems for homes built where access is limited and fire hydrants are not available.

New Mexico State Forestry, a division of the Energy Minerals and Natural Resources Department, joined with leadership from the City of Santa Fe and Santa Fe County as well as the State Cooperative Extension Service, to develop and implement a coordinated response to the bark beetle crisis and its impact on the community (www.emnrd.state.nm.us/fd/santafetrees/background.html).

The Santa Fe Piñon Initiative Steering Group has taken action to help educate the public about forest health and management of dead piñon trees. This group has produced a fact sheet for homeowners on how to reduce the risk of fire on their property (www.emnrd.state.nm.us/fd/santafetrees/pdf/firefacts.pdf.)

Forest Fire Emergency Response Plan:

The US Forest Service has a BAER (Burned Area Emergency Response) team in place to quickly evaluate the severity of a fire and propose treatments. The City is fortunate to have two reservoirs to help protect the city from flood and debris flows that often follow a catastrophic fire, but the storage capacity may not be sufficient to retain debris and sediment from a high-severity fire.

Initiatives to Improve Biodiversity of Rangelands:

The following Initiatives are underway to Improve Biodiversity of Rangelands:

- Santa Fe Conservation Trust works with landowners to retire development rights and keep land in its natural state.
- The Caja del Rio project was funded in 1999 through the New Mexico Environment Department's "319 Program" (a program to address non-point source pollution under Section 319 of the Clean Water Act) to restore grasslands, manage livestock, build water tanks, improve fences, and manage the watershed through controlled burns.

5.2.2 Riparian Restoration

The Santa Fe Watershed Association was established in 1997 and the Santa Fe River Commission was established in 1984 and reformed in 2007 as a standing committee of the City (resolution 2007-14). Due largely to the actions of these groups, the Santa Fe River has received a great deal of care over the past 15 years, from the headwaters in the Sangre de Cristo Mountains down to the Rio Grande. Some of these efforts are described here. The following are additional recommendations made at the workshop:

- Continue efforts to restore riparian areas; consider the impacts of restoration on the rest of the watershed (for example, on availability of water downstream, flood risk, and risk of debris plugging infrastructure)
- Employ best management practices to manage runoff, especially runoff from dirt roads, prevent erosion and gullying, and reduce runoff turbidity.
- Modify/design bridges and culverts to handle higher intensity runoff events, consider installing bottomless culverts.

Water for Ephemeral Reaches of the Santa Fe River:

The City of Santa Fe recently dedicated up to 1000 acre-feet per year from its Santa Fe River water supply to support in-stream flows in the urban reach of the Santa Fe River. The water will be released from Nichols Reservoir in pulses. One of the stated goals of the pulses is to "irrigate the trees and other vegetation along the river corridor to support the typical spring time activities within tree/plant (and faunal) annual life cycles as plants are beginning to draw water, beginning to produce buds and leaves" (Administrative Procedures for Santa Fe River Target Flows).

Riparian Restoration:

Many projects (Figure 7) have been funded through the NMED 319 Program (a program to address non-point source pollution under Section 319 of the Clean Water Act), which have included riparian restoration and other projects, all of which have help improve the resilience of the watershed.

The Canyon Preservation Trust, Randal Davey Audubon Center and US Fish & Wildlife Service have partnered with private landowners to address the riparian health between the old Two-mile dam site and the Acequia Madre head gate. The project, which began in 1996, involved mapping and restoring degraded areas (Grant, 2002).

The Santa Fe Watershed Association obtained a grant from NMED's Surface-Water Quality Bureau (SWQB) River Ecosystem Restoration Initiative (RERI) for Habitat Restoration along the Upper Santa Fe River. The project involved re-routing the river to its natural channel in the reach below Nichols Dam. Native vegetation was planted along the reach, and a river drop/fish ladder structure was constructed at Stone Dam. A second grant was provided by NMED SWQB RERI to construct erosion control structures; remove exotic species, thin vegetation to reduce fire hazard and plant native species at Aztec Springs and the Santa Fe River below Nichols Dam.

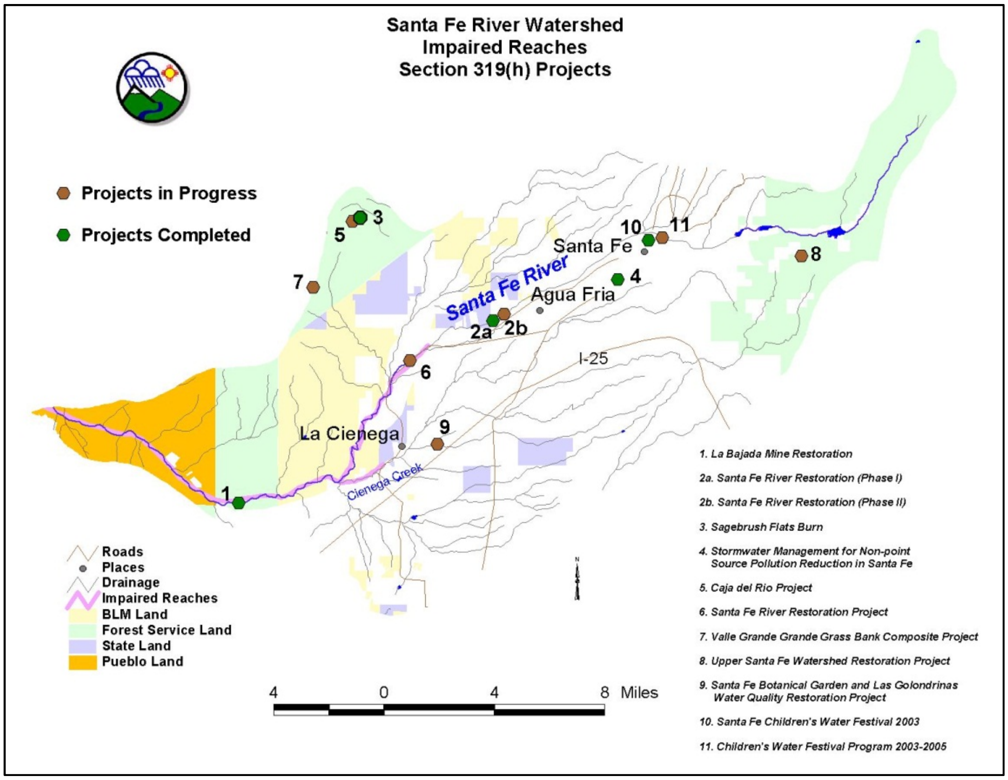


Figure 7. Santa Fe River Watershed Impaired Reaches Section 319(h) Projects (Franklin, 2012).

The Santa Fe River Corridor Master Plan was adopted in 1995, and included channel stabilization and trail system development between Patrick Smith Park and Frenchy's Park. The City of Santa Fe obtained a NMED SWQB RERI grant in 2009 for restoring riparian vegetative cover, improving infiltration and sinuosity, and stabilizing the channel and banks of the Santa Fe River along the 3.1 mile reach from Camino Alire to Frenchy's Park (Drypolcher, 2012). The grant also includes the re-design of the San Jose Road storm drain and planting of the area with native vegetation to stabilize river channel, improve hydrologic function, and provide wildlife habitat.

The City of Santa Fe and the Santa Fe Watershed Association are completing an assessment of the status of ephemeral stream (arroyos) in Santa Fe with a view to the needs for future repair, management, and stewardship. The City has developed a priority list for arroyo repair and maintenance, which was part of the adopted 2011 Bond Issue for public works projects.

The City of Santa Fe Public Works Department has undertaken a number of projects to keep traffic out of the river and prevent erosion and further down-cutting of the channel. These actions include:

- Construction in 2009 of a bridge at Siler Road that will keep traffic out of the river channel.
- Closure to traffic in 2009 of the crossing at Camino de Carlos Rael.

Santa Fe County Public Works built an improved crossing at San Ysidro in 2003 that protects the river from erosion and further down cutting. The County also installed a bank stabilization structure at Lopez Lane Bridge.

The State Land Office conducted river restoration on a reach 1 mile upstream of the State Road 599 crossing on State lands. This project was funded by NMED 319 Project funds.

The restoration of La Bajada Uranium Mine by the US Forest Service and Bureau of Land Management between La Cienega and the Village of La Bajada has also helped to restore the riparian habitat.

Water Quality Improvements on the Santa Fe River:

The Santa Fe River water quality downstream of the wastewater treatment plant has improved significantly over the past decade due to concentrated efforts of WildEarth Guardians, the City of Santa Fe, Santa Fe County, the Santa Fe Botanical Gardens, private landowners, the Santa Fe Soil and Water Conservation District and the Surface Water Quality Bureau of the New Mexico Environment Department (Guevara, 2011). The 12.7 mile-long reach was not meeting standards for pH, sediment and dissolved oxygen. Stock ponds have been built on the Caja del Rio to remove cattle from the stream, levees have been removed to enhance floodplain connection, wetlands have been constructed and cottonwoods have been planted. Water quality has improved and the stream is now meeting the water quality standards.

While the water quality has improved, the projects described above are not without controversy. This reach of the river is an artificial wetland created by the discharge of wastewater effluent. Some do not consider this reach to be “restored”, but instead to be an artificially created habitat that does not reflect historic conditions.

Comprehensive Wetland Restoration and Protection has been undertaken in Arroyo Hondo, Santa Fe County, with funding from the U.S. Environmental Protection Agency through the New Mexico Environment Department – Surface Water Quality Bureau, Wetlands Program.

The grant provided funding to prepare a wetlands action plan and improve the wetlands in Arroyo Hondo downstream of I-25 near an old dam site. In 2012, this same program funded a project that will produce a Wetlands Action Plan for the Santa Fe County area, a geo-hydrological analysis of surface and ground water flows into the wetlands in La Cienega, a technical field guide on wetland management, a series of pilot wetland restoration projects in the Cañada de los Alamos, Arroyo Hondo reservoir, San Marcos Arroyo, and Escalante Arroyo (Cerrillos Hills), and wetland planning and policy recommendations for local government agencies and landowners.

5.3 Agriculture and Food Security

To address additional stresses on the agricultural sector and food security from reduced water supply, earlier runoff, increased pests and more severe storms events participants at the workshop recommended the following:

- Incorporate urban agriculture in planning; encourage small farms in the city and county and food-scapes in commons areas to respond to the significant interest in increasing locally sourced food (less than 100 miles) that does not require shipping and supports local ecosystems and community members.
- Encourage cultivation of climate-appropriate crops by developing guarantees for seed sovereignty through buffer zones for genetically engineered crops.
- Improve irrigation infrastructure efficiency where such actions would not impair ecosystems and senior water rights.

Abundant Interest in Locally Sourced Food:

- The Farm to Table is a non-profit organization dedicated to promoting locally based agriculture through education, community outreach and networking (www.farmtotablenm.org). Farm to Table enhances marketing opportunities for farmers; encourages family farming, farmers' markets and the preservation of agricultural traditions; influences public policy; and, furthers understanding of the links between farming, food, health and local economies.

- Earth Care launched a Youth Food Cadre Program with nonprofit, school, and government partners leveraging federal funds to create AmeriCorps positions for young adults working to develop school and community gardens that provide food and health education, and support local producers and food organizations
- The Southwest Grass-fed Livestock Alliance SWGLA is an alliance of producers, consumers, land managers, conservationists, and researchers that seek to improve human, ecological and animal health, and strengthen local agricultural communities by educating producers, and the public about grass fed livestock products.
- Two new community gardens were opened in City Parks (SSFP Update, 2011).
- Farmers markets are held 7 days a week- Rail yard and Santa Fe Place in Santa Fe, El Dorado, La Cienega, and at the Flea Market.
- Further support the growing school garden program in Santa Fe and the integration of locally grown and school-grown food in school lunch programs. Schools with gardens include: SF High, Eldorado Community School, Monte del Sol Charter School, Acequia Madre Elementary, Salazar Elementary, Amy Biehl Community School, and others.

Current Actions to Protect Seed Sovereignty:

The New Mexico Food & Seed Sovereignty Alliance, with core members from the Traditional Native American Farmers' Association (TNAFA) and the New Mexico Acequia Association (NMAA) have a joint mission to "continue, revive, and protect our native seeds, crops, heritage fruits, animals, wild plants, traditions, and knowledge of our indigenous, land- and acequia- based communities in New Mexico for the purpose of maintaining and continuing our culture and resisting the global, industrialized food system that can corrupt our health, freedom, and culture through inappropriate food production and genetic engineering"(NMAA, 2012). The Alliance was successful in passing Senate Joint Memorial 38 and House Memorial 84 in the 2007 State of New Mexico Legislature, a Memorial that recognizes the importance of indigenous agricultural and native seeds to the food security of New Mexico as well as farmers' rights to keep their seeds free from GE contamination.

Santa Fe County Resolution No 2006-150 was adopted to commit the County to work towards the cultivation and preservation of "Chimayo Chile".

Efforts to Improve Irrigation Efficiency:

Santa Fe County, with funding from the Bureau of Reclamation, is currently assessing agricultural lands in the region to assess irrigation efficiency and whether an increase in efficiency would be beneficial to the system overall. Decreases in the consumptive use of irrigation or evaporation losses from the field that do not also result in negative impacts on crop yields can stretch the available surface-water supply so that it is available for more uses. However, decreases in water delivery that simply decrease the losses to the groundwater system can decrease the availability of water to wells or drains, which other users might rely on, and can negatively impact riparian habitat.

Because the agricultural sector has already been subjected to the stress of economic hardship and the expansion of urban areas, local have implemented measures to preserve agricultural lands and the food security that they can provide to the community. In 2006, Santa Fe County passed Resolution No 2006-184, which committed the County to protection of agricultural lands in production and the attendant water rights. In 2010, Santa Fe County passed Resolution No 2010-23, which committed the County to encourage and assist landowners who choose to voluntarily protect the open space character of their agricultural land in perpetuity. This resolution recognizes the benefits of conservation easements, the state income tax credits and the federal income tax deductions for those landowners that voluntarily decide to protect and support these agricultural lands.

Various land trust organizations, such as Santa Fe Conservation Trust, New Mexico Land Conservancy, Trust for Public Land, and The Nature Conservancy are active in Santa Fe to offer advice and broker conservation easements for the preservation of agricultural land.

Additionally, Santa Fe County's Open Lands, Trails, and Parks program has a mandate to protect and when desirable, purchase agricultural lands of conservation value for the community and has done so in the past, and may do so again if/when funds are made available.

The State of New Mexico has existing policies that support the protection of agricultural land, including:

- The New Mexico Land Use Easement Act (NMSA §§ 47-12-1 through 47-12-6), which aids landowners who wishes to donate a land use easement that specifies agricultural use in perpetuity.
- The New Mexico Property Tax Code (NMSA § 7-36-20 and 3.6.5.27) provides for tax relief for agricultural properties.
- The US government has policies that support the protection of agricultural land including:
  - The Federal Farm and Ranchland Protection Program which provides matching funds to help purchase development rights to keep productive farm and ranchland in agriculture.
  - The Federal Farmland Protection Policy Act which commits the federal government to the goal of conserving farmland in carrying out its public works and other development projects.
  - The Federal Internal Revenue Code that provides significant tax breaks for preservation of farmland.

5.4 Land Use and Quality of Life/Parks and Urban Landscaping

Parks and residential landscaping provide opportunities to address multiple climate change vulnerabilities on a small, but significant scale. Workshop participants stressed:

- Mulch, soil preservation, and other permaculture actions, such as landscape contouring to enhance storm water capture, slow down runoff, improve moisture retention, improve soils, and reduce water demand.
- Improve urban forests: Plant and maintain healthy trees within city limits to "cool" cities.
- Incorporate edible vegetation or "food scapes" in public landscaping.
- Provide tax incentives for green properties (infrastructure that is cooler, captures runoff, increases infiltration, is energy efficient, incorporates passive or active renewable energy, etc.).

- Require pervious pavement.
- Provide green-waste bins to residents and city/county composting.
- Allow limited, appropriate development in hazard-prone areas, such as the urban-forest interface, in balance with economic diversity and the availability of water supply

Small-scale storm water management activities:

Numerous projects have been funded through the New Mexico Environment Department's (NMED's) "319 Program" (a program to address non-point source pollution under Section 319 of the Clean Water Act) to reduce impacts from storm water runoff. These include:

- Contour swales, gabion check dams, splash pads, and tree and shrub planting at EJ Martinez Elementary School.
- Contour swales at numerous private residences.
- Contour swales and check dams at Alta Vista and 2nd street by Santa Fe Southern Railway.
- Contour swales, gabion check dams and splash pads at Calle Lorca Park.
- Erosion control structures and storm water filter structures in Arroyo de los Chamisos between Camino Carlos Rey and Avenida de las Campanas (with additional funding from the Santa Fe Community Foundation and the City of Santa Fe and in-kind support from local businesses).(picture from the Santa Fe New Mexican, May 18, 2010).
- Restoration of the Arroyo de los Piños at Museum Hill, which involved installing permeable pavement to reduce urban runoff and increase groundwater recharge, and channel restoration work in the headwaters of the Arroyo de los Piños at Museum Hill (with additional funding from Santa Fe Botanical Garden).
- Erosion control structures in Arroyo Saiz (Grant, 2002) by private land owners
- A gabion check dam, splash pad and French drains at the Llano St Pool/La Farge Library.
- Large scale, well-designed rock cascade structures at stormwater outflows in Arroyo Mascaras along north Paseo de Peralto, and into SF River along Santa Fe River Street.

The City of Santa Fe, Santa Fe County and the Cerro Gordo Ditch Association have adopted storm water ordinances. The City of Santa Fe’s Storm Water Management ordinance works with the EPA regulations to reduce pollutants from storm water by requiring best management practices (BMPs) at construction sites. The City also provides guidance for landscape design and methods to harvest runoff and reduce erosion through swales and check dams. Specific storm water related projects funded by the city include:

- El Parque del Rio (2012): a project that will capture stormwater along the Santa Fe River from St. Francis to Palace Avenue and redirects it to river corridor vegetation. Prior to this project, storm water bypassed the vegetation through traditional drop inlets, which over time lowered the water table and increased the channelization of the river. The El Parque del Rio project is utilizing Oxbow swales to allow water to infiltrate and in large rain events exit and continue to another swale or traditional storm water outlet. The project also utilizes the existing stone curbing near Old Santa Fe Trail to intentionally allow "leaking" under the sidewalk and hydrate the cottonwood canopy downtown.
- Various stormwater infiltration garden, rock run-downs, and spill pads along the Arroyo de los Chamisos between Santa Fe High School and Richards Avenue (by Earth Works Institute 2007-2011)
- Stormwater management in the Arroyo de los Pinos for the establishment of the Santa Fe Botanical Garden (funded by City of Santa Fe, managed by SF Botanical Garden; implemented by Earth Works Institute 2006-2010)
- Restructuring of existing storm-water drain exits to increase infiltration capacity on river benches, and
- Replacing asphalt parking areas near the river with permeable pavestones.

Improve Urban Forests

The Santa Fe Residential Green Building Code encourages planting of trees that are native or appropriate for local growing conditions and for species and locations that will, when the trees are mature, provide summer shading of streets, parking areas, and buildings to moderate temperatures.

Santa Fe Botanical Garden (www.santafebotanicalgarden.org) manages the Leonora Curtin Wetland Preserve and the Ortiz Mountains Educational Preserve and will soon begin construction of Santa Fe Botanical Garden at Museum Hill, which will join the two preserves as a lovely and serene space to experience nature. Santa Fe Botanical Garden celebrates, cultivates and conserves the rich botanical heritage and biodiversity of our region, and provides education and community service.

5.5 Energy Systems/Production and Consumption

While this report does not address ways to reduce CO_2 emissions, reducing energy production and use helps make our community more resilient. Workshop participants had many of the same recommendations for energy as they did for food security, basically to create more energy locally and reduce the expenses and vulnerabilities in transportation. Specific recommendations included:

- Decentralize energy infrastructure and produce more renewable energy locally.
- Introduce greater incentives for energy efficiency and renewable energy conversion (including incentives for such actions as improving insulation and installing solar panels and keeping them clean).
- Require more energy efficient buildings with passive cooling features.
- Municipalize city energy system.
- Install solar panels over parking lots to reflect heat and generate energy.

Current Local Production of Renewable Energy:

Santa Fe City and County have both invested in renewable energy infrastructure for the community. Renewable energy projects in the Santa Fe watershed include:

- The City of Santa Fe has a small hydropower plant (93 kW turbine-generator) powered by gravity-fed pressure in treated water pipes.
- The City of Santa Fe has a 1 Megawatt solar facility at the wastewater treatment plant
- The City and County have a1 Megawatt solar facility at Buckman Direct Diversion (BDD), and are planning another 1 Mw solar facility along the BDD raw water pipeline

Current Incentives for Local Energy Production

Residents currently receive incentives for installing solar photovoltaic and solar thermal systems. PNM has a Solar Energy Customer Program that allows customers to receive payment for renewable energy credit. Under this program, PNM pays the customer for the energy produced by their system, regardless of whether the customer consumed all of the energy produced. The costs of the systems receive a Federal income tax credit of 30% and a state tax credit of 10%.

Existing Building Codes for Energy Efficiency

The City of Santa Fe adopted a residential green building code on March 11, 2009 (Ord. 2009-09) with revisions dated January 11, 2012. (http://www.santafenm.gov/DocumentView.aspx?DID=9873). The green building code requires that all new homes meet stringent standards specified in the Home Energy Rating System (HERS) according to the size of the home. The City's energy efficiency standard for new construction is one of the most aggressive in the country. Santa Fe County is also in the process of adopting a green building code.

5.6 Sociological Systems/Public Engagement & Policy Change

Workshop participants were very passionate about the need for our community to be ready to respond to the cumulative impacts of climate change on the various systems. Suggestions included:

- Increase incentives for actions that address climate change.
- Highlight models of successful projects happening now.
- Foster inclusive discussions incorporating all components of community (including discussion of uncomfortable topics such as population growth and appropriate development).
- Enhance regional governance – connect government agencies across watershed.
- Build capacities of local governments for handling weather-related hazards.

What's Happening Now?

The Sustainable Santa Fe Commission is dedicated to creating a strong, resilient Santa Fe for current and future generations (http://sustainablesantafenm.ning.com). The Sustainable Santa Fe Commission is comprised of citizen volunteers with expertise in a variety of areas that advise the City Council on issues of sustainability

5.7 Monitoring

Monitoring of vulnerable systems to collect appropriate data is critical to furthering our understanding and their response to changes. In order to develop the appropriate adaptive management, monitoring should be established to evaluate the effectiveness of management activities. It is important to examine existing historic data to assess how local species and systems have already responded to climate change.

- Develop a monitoring plan that defines the appropriate location, timing, parameters, equipment and responsible party
- Monitoring equipment should be established before impacts occur

Current and future monitoring

Stream flow monitoring in the Santa Fe River began in 1913 with a USGS stream gage in the upper watershed. In 1998, the City of Santa Fe established more monitoring on the Santa Fe River (Lewis and Borchert, 2009). A series of monitor wells were historically monitored by the USGS and that monitoring is currently being conducted by contractors to the Office of the State Engineer. Monitoring of water quality is performed routinely by the New Mexico Environment Department Drinking Water Bureau on public water systems.

A monitoring plan was developed as part of the EIS for the forest treatments in the Santa Fe Watershed (USDA, 2001). This plan involved monitoring the impact of forest treatments on bird population, tracking the actual changes in vegetation density (overstory, ground cover and litter cover) and impacts to turbidity during the treatments. The Interstate Stream Commission is monitoring the impact of forest treatments on the water budgets in a paired basin study in the Santa Fe Watershed.

Santa Fe County has received grant funding to install surface and groundwater monitoring equipment in the La Cienega and La Cienguilla areas of the lower watershed. The goal is to monitor changes in spring and stream discharge along with groundwater levels to create a baseline of current hydrological conditions.

5.8 Education

Education can be used to increase awareness of the sensitivity of various systems to climate change and to provide information on actions individuals can take to improve the resilience of systems. Workshop participants suggested:

- City/county classes and public school curricula and demonstration on growing food, composting, conservation, xeric gardening, and rainwater harvesting.
- Tours of the water (Buckman Direct Diversion) and waste-water treatment plants, to educate residents and school children on the need for water conservation and the life cycle of municipal water.
- A Central clearinghouse for the community of water conservation information.

Educational Opportunities Abound:

Numerous non-profit organizations in the Santa Fe area have dedicated many volunteer hours educating the public and involving school children. The principal non-profit organization addressing climate change in the Santa Fe watershed is the Sustainable Santa Fe Commission, which is devoted to educating Santa Fe on and ways to reduce the community's carbon footprint and improve the resilience of our ecosystems (www.santafenm.gov/index.aspx?NID=685). Other organizations devoted to implementation of many of the educational outreach efforts include the Forest Guardians, the Santa Fe Conservation Trust, the Santa Fe Watershed Association, the Randall Davey Audubon Center and the NM Chapter of the Audubon Society, The Nature Conservancy, Quivera Coalition, and until recently, Earth Works Institute.

The City of Santa Fe works with the Santa Fe Watershed Association on an extensive education and outreach effort to provide education on forest and riparian ecology, water issues and ecosystems services. This outreach effort has included the development of an educational video, public hikes in the watershed, and environmental monitoring programs with middle and high school students. The city and the Santa Fe Watershed Association are also collaborating on the Climate Masters' program, a 10-week training program on climate mitigation and adaptation (www.santafewatersehd.org). The Santa Fe Watershed Association and Southwest Urban Hydrology collaborate to provide educational events in the community. For example, in May 2012, these organizations sponsored: 1) *Urban Watershed and Green Infrastructure*, a presentation on the impacts of a growing urban landscape on watershed functions, and 2) *Bio-retention Basin Workshop*, a hands-on workshop to implement bio-retention basins. . Both events provided instruction on the benefits of Green Infrastructure as a means to prevent local flooding, storm water pollution, urban heat-island effects, and habitat loss in urban watersheds.

The City of Santa Fe's Water Conservation Division of the Water Utility has a xeric demonstration garden, and several programs for education. These education programs include the Children's Poster Contest, Water Fiesta, and the River Xchange program (coordinated with Santa Fe County), in which 5th graders explore key water resource concepts through a year-long curriculum which includes focused field trips and hands-on activities . The City of Santa Fe, in 2002, also developed a handbook: "Storm Water as a Resource, how to Harvest and protect a dryland treasure in 2002.

The New Mexico Environment Department (NMED) developed a handbook for restoring riparian areas called "Healthy Streamside Wetlands, A guide to good stewardship for southwestern bosque and riparian wetlands" (www.nmenv.state.nm.us/swqb/Wetlands/HSW/index.html).

The Quivera Coalition has an annual workshop and numerous publications to educate ranchers and the public about rangeland management (www.quiviracoalition.org). The Quivera Coalition's publications include: *Let the Water Do the Work: Induced Meandering, an Evolving Method for Restoring Incised Channels* (Zeedyk and Clothier, 2012).

5.9 Visionary

Santa Fe residents understand the power of visual and artistic expression of ideas to create change. Here are a few visionary ideas suggested by the workshop participants:

- Appoint an Artist in Residence dedicated to the Santa Fe River to create images that foster respect for the resource
- Create sacred space around water, including a physical reminder, such as a table or alter, at meetings to remind people that water sustains life for all and should not be considered a commodity

One example of a visionary action:

Mayor David Coss named 2012 "Love Your River Year" and environmental artists Bobbe Besold and Dominique Mazeaud along with Santa Fe poet laureate Valerie Martinez have initiated a project called "River Runs through Us". The project engages the community to walk the 46-mile length of the river, and along the way to plant native species, listen to music and poetry and other activities to celebrate the river. The four-day journey in May 2012, was an exploration of the Santa Fe Watershed and is designed to create art, promote awareness, engage community, and illuminate our relationship with river systems, earth and water (http://riversrunthroughus.net).

5.10 Implementation

Initial steps that could enhance the effective implementation of the recommendations presented in this report include:

- More regional governance
- More communication and collaboration across government levels, beginning with the city and county
- Long-term ,rather than short-term, thinking
- Planning, including
  - Tools to optimize decision-making (which will be needed because climate change will leave us with less room for error)
  - Prioritization of actions

    - Integrated implementation of plans
- A diversity of decision-makers, coupled with deep community engagement

6 Next Steps

This preliminary assessment captures many of the vulnerabilities that the Santa Fe watershed may face under projected climate changes, as well as potential adaptation strategies to address these vulnerabilities and create a more resilient watershed. It also describes numerous projects that are ongoing in the watershed to enhance sustainability and resilience. Under the second phase of the Santa Fe Basin Study, the partners will quantify the potential impact of climate change on the available water supply from the watersheds that provide water to the City and County (the Santa Fe River Basin, the Upper Rio Grande and several tributaries in the San Juan), assess the vulnerability and possible shortcomings of the existing water plans, and develop strategies to address the concerns.

Below are additional strategies that local, regional or state governmental organizations and concerned citizens may consider as next steps to begin to adapt to the impacts that climate change will have in our region.

- Develop a GIS-based watershed-wide map for tracking of existing action in all sectors or systems. The map may be helpful in identifying the areas where further action is a priority.
- Develop and/or coordinate community-based, watershed-wide, technical advisory committees that focus on specific sectors or systems. These committees may develop more detailed visions, strategies and recommendations, implement activities, and/or track progress. To increase communication and coordination, we recommend that these advisory committees work closely within existing 'umbrella' organizations like the Sustainable Santa Fe Commission, and other existing planning and emergency groups.
- Increase communication and coordination among existing efforts to enhance effectiveness.
- Monitor key climate-change impacted parameters (temperature, precipitation, temperature extremes, and storm events) so that the picture of impacts and emerging trends can be identified.
- Implement the water-related recommendations from Phase 2 of the Santa Fe Basin Study.

- Enhance interagency and intergovernmental communication, planning and emergency preparedness coordination.
- Develop comprehensive public education program to teach the community, agency staff, and elected officials about the potential impacts of climate change and provide opportunity for collaborative citizen engagement.
- Seek funding opportunities to implement recommendations made in this report.

7 References

Aaboe, Eric, 2012. Personal communication with Amy Lewis regarding the natural gas shortage in February of 2011.

Borchert, Claudia, 2011. Santa Fe Basin Study proposal submitted to the Bureau of Reclamation available at:www.santafenm.gov/DocumentView.aspx?DID=9690.

BLM, 2010. Santa Fe River Canyon Riparian Forest Restoration Project. Proposed Action, Alternatives, and Preliminary Effects Analysis. DOI-BLM-NM-F020-2010-0007-EA

Chapman, David S. and Michael G. Davis, 2010. Climate Change: Past, Present, and Future. *Eos*, Vol. 91, No. 37, 14 September 2010, pp. 325-332.

City of Santa Fe, 2010. City of Santa Fe Water Conservation and Drought Management Plan, Sangre de Cristo Water Division. Nov 2010. http://www.santafenm.gov/DocumentView.aspx?DID=9834

City of Santa Fe Sustainable Santa Fe Commission, 2008. Sustainable Santa Fe Plan, Building a More Sustainable Future by Looking to the Past. Adopted Oct 29, 2008. Available at http://sustainablesantafenm.ning.com/

City of Santa Fe Sustainable Santa Fe Commission, 2011. Sustainable Santa Fe Annual Report of 2010 Activities.

City of Santa Fe Fire Department, Undated. Ready, Set, Go, Your Personal Wildfire Action Plan. (http://nm-santafe.civicplus.com/index.aspx?NID=359)

Cox, T. J., E. Lopez Calva, A.P. Navato, 2011. Quantifying Climate Change in Water Supply Planning for a Snowpack-Driven Watershed, AWRA 2011 SPRING SPECIALTY CONFERENCE Baltimore, MD.

deBuys, William. A great Aridness, Climate Change and the Future of the American Southwest. Oxford University Press 2011.

EPA, 2012. Website accessed on May 14, 2012: http://www.epa.gov/cleanenergy/energy-and-you/how-clean.html

Franklin, Abe. 2012. Email communication to Amy Lewis with map of NMED 319 projects. April 2, 2012.

Glick, P., B.A. Stein, and N.A. Edleson, editors. 2011 Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington, D.C.

Grant, Paige, 2002. Santa Fe River Watershed Restoration Action Strategy. Prepared pursuant to the Clean Water Action Plan and Unified Assessment of New Mexico Watersheds. Santa Fe Watershed Association.

Guevara, Daniel, 2011. Section 319 Nonpoint Source Program Success Story: Restoration Efforts Revive Riparian Vegetation and Improve Water Quality. EPA 841-F-11-001DD. July 2011.

Gutzler, David S. and Tessia O. Robbins, 2010. Climate variability and projected change in the western United States: regional downscaling and drought statistics. Climate Dynamics, 34:10.1007/s00382-010-0838-7.

Hagner, Charles J, 2012. Climate change alters birds' migration habits, nesting areas *in* Bird Watching. April 2012

Hurd, B.H. and J. Coonrod. 2008. Climate Change and Its Implications for New Mexico's Water Resources and Economic Opportunities, New Mexico State University, Agricultural Experiment Station, Technical Report 45, Las Cruces, NM. 28 p.

Lewis, Amy C. and Claudia Borchert. 2009. Santa Fe River Studies: Stream Flow. One of a series of reports produced by the City of Santa Fe. August 2009.

Longworth, J.W., J.M. Valdez, M.L. Magnuson, E. Sims Albury, and J. Keller. 2008. *New Mexico water use by categories, 2005*. Technical Report 52, New Mexico Office of the State Engineer. June 2008.Resolution 2011-17 LRWSP and Climate Change.

NAST, 2000. Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change. National Assessment Synthesis Team, US Global Change Research Program. http://www.gcrio.org/NationalAssessment.

NMAA. 2012. New Mexico Acequia Association website. http://www.lasacequias.org/food-and-agriculture/seed-alliance/ accessed on May 27, 2012.

Reclamation, City of Santa Fe and Santa Fe County, 2011. Memorandum of Agreement#11-1167 between City of Santa Fe, Santa Fe County, and Bureau of Reclamation available at www.santafenm.gov/DocumentView.aspx?DID=9691

Resolution 2006-54 – US Mayors Conference Agreement on Climate Change

Robles, Marcos and Carolyn Enquist, 2011. Managing Changing Landscapes in the Southwestern United States. The Nature Conservancy, Tucson, AZ.

Ross, Stephen C. Esq., Sayre, Doug, Torres, Karen M., 2009, *Santa Fe County Conjunctive*

Management Plan for the Santa Fe Basin. Adopted by the Santa Fe Board of County Commissioners January 13th 2009. (http://www.co.santa-fe.nm.us/userfiles/SFC_final_CMP.pdf

Santa Fe County, 2010. Santa Fe County Sustainable Management Plan. (http://www.santafecounty.org/growth_management/sgmp).

Schneider, S.H., S. Semenov, A. Patwardhan, I. Burton, C.H.D. Magadza, M. Oppenheimer, A.B. Pittock, A. Rahman, J.B. Smith, A. Suarez and F. Yamin, 2007. Assessing key vulnerabilities and the risk from climate change. Climate Change 2007: Impact, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, U.K. 779-810.

Seager, Richard, M.F. Ting, I.M. Held, Y. Kushnir, J. Lu, G. Vecchi, H.-P. Huang, N. Harnik, A. Leetmaa, N.-C. Lau, C. Li, J. Velez, and N. Naik, 2007. Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America. *Science*, Vol. 316. No. 5828, pp. 1181 - 1184 DOI: 10.1126/science.1139601.

Shaffer, Mark, Roger Griffis, and Gerry Barnhart, 2012. National Fish, Wildlife and Plants Climate Adaptation Strategy Public Review Draft. January 2012. (www.wildlifeadaptationstrategy.gov)

Singer, Arian. 2012. Personal Communication with Amy Lewis and Arian Singer of the OSE. May 23, 2012.

Stewart, Iris T., Daniel R. Cayan and Michael D. Dettinger, 2004. Changes in Snowmelt Runoff Timing in Western North America Under a 'Business as Usual' Climate Change Scenario, Climatic Change 62: 217–232.

Sun, Ying, Susan Solomon, Aiguo Dai and Robert W. Portmann, 2007. How Often Will It Rain? Journal of Climate, Vol. 20, pp. 4801-4818.

TNC, 2012. The Nature Conservancy Southwest Climate Initiative GIS Coverage: TNCAZ_SW_Biotic_Communities_GIS\sw_biotic_communities.shp

TRB, 2008. Potential Impacts of Climate Change on U.S. Transportation. Committee on Climate Change and the U.S. Transportation, Transportation Research Board Division on Earth and Life Studies, National Research Council of the National Academies. Transportation Research Board Special Report 290.

U.S. Climate Change Science Program, 2008. Effects of Climate Change on Energy Production and Use in the United States. Synthesis and Assessment Product 4.5.

February 2008. (http://www.climatescience.gov/Library/sap/sap4-5/final-report/sap4-5-final-all.pdf)

U.S.D.A., 2001. Santa Fe Municipal Watershed Project Draft Environmental Impact Statement. Santa Fe National Forest. March 2001.

Williams, A. Park, C. D. Allen, C. Millar, T. Swetnam, J. Michaelsen, C. J. Still, and S. W. Leavitt, 2010. Forest responses to increasing aridity and warmth in southwestern North America. Proceedings of the National Academy of Sciences, USA 107(50): 21289-21294.

Zeedyk, Bill and Van Clothier. 2012. Let the Water Do the Work: Induced Meandering, an Evolving Method for Restoring Incised Channels. Prepared for the Quivera Coalition. February 2012.

Appendix A. Workshop agenda

Santa Fe Watershed Climate Change Workshop

Santa Fe Community Convention Center, March 6, 2012

Agenda		
Time	Activity	Location
8:00-8:30	Sign-in	Sweeny F
8:30-8:45	Introduction **Councilor Bushee/Claudia Borchert City of Santa Fe** **Dagmar Llewellyn, Bureau of Reclamation** **Commissioner Vigil/Karen Torres Santa Fe County**	Sweeny F
8:45-10:30	Setting the Stage **David Gutzler**, UNM climate change expert – *Summary of climate change projections for the Santa Fe Watershed and the Southwest* **Park Williams**, Los Alamos National Lab ecologist – *Southwestern forest response to drought* **Bill deBuys**, author and conservationist – *Historical/sociology impacts of climate change*	Sweeny F
10:30-10:45	**Break**	Sweeny F
10:45 – 11:30	What can we do with this information? Karen MacClune, Institute for Social and Environmental Transition	Sweeny F
11:30-12:30	Parallel Breakout Session 1	
	Water	Milagro
	Ecology	Peralta
12:30-1:15	**Working Lunch**	Sweeny F
1:15-1:45	Parallel Breakout Session 1 continued	Return to group
1:45-3:15	Parallel Breakout Session 2	
	Land Use/Quality of Life	Milagro
	Agriculture and Food Security	Peralta
3:15-3:30	**Break**	Sweeny F
3:30-5:00	Break out session results and Next Steps	Sweeny F

David Gutzler Ph.D., University of New Mexico: Dr. Gutzler's interests include interactions between the atmosphere and land surface processes, especially energy and moisture fluxes. He hopes to contribute to the interesting research being done putting surface systems together with atmospheric systems. Dr. Gutzler has taught: Meteorology (a non-mathematical intro to weather science); Climatology (an upper- division undergrad survey of climate processes); Global Climate Change (upper level science & policy mix), and Physical Climatology (grad-level climatology course).

William deBuys, Author and Conservationist: Mr. deBuys has authored seven books his most recent being *"A Great Aridness: Climate Change and the Future of the American West* "(released by Oxford University Press, Nov. 2011). He was a 2008-2009 Guggenheim Fellow. As a conservationist, he has helped protect more than 150,000 acres in New Mexico, Arizona, and North Carolina. From 2001 to 2005, he served as founding chairman of the Valles Caldera Trust, which administers the 89,000 acre Valles Caldera Preserve. He lives and writes on a small farm in northern New Mexico.

Park Williams, postdoctoral researcher at Los Alamos National Laboratory: Dr. Williams' research focuses on how global climate variability influences drought in places where water is a limiting resource for life such as forests in the Southwestern United States. Using tree-ring records, he has determined how Southwestern forests have responded to drought, wildfires and bark beetles for the past 1000 years and has forecast how Southwestern forests should respond to climate change in the next several decades. He received a Ph.D. from the University of California, Santa Barbara in the Geography Department in 2009.

Karen MacClune, **ISET** has been engaging for over 5 years with cities around how to utilize climate change information in city planning processes to build resilience to potential climate impacts. ISET has been supporting communities to understand potential, local climate hazards and how their nature might evolve under climate change, to develop vulnerability and risk assessments to explore the potential direct and indirect impacts of those climate hazards, and to develop resilience plans which identify and prioritize mitigation, adaptation, and resilience building activities to be taken within the context of daily policy and operating concerns. As part of this work, ISET has created and continues to refine a resilience building curriculum to systematically walk communities through the steps involved in developing resilience plans. Dr. MacClune also has a PhD in Geophysics from the University of Colorado and extensive experience with New Mexico water issues, having worked for SS Papadopulos & Associates, Inc. for 8 years, with particular focus on work for the Interstate Stream Commission on surface water, groundwater, and water operations issues.

Artwork: 1st through 6th grade students in Santa Fe

Since 2003, The City of Santa Fe Water Conservation Office has hosted an annual poster contest. All public, private and charter elementary schools in Santa Fe are invited to participate. Participants range from 1st grade to 6th grade. Over 350 classrooms were invited to design a poster with a water conservation message. A first, second, and third place winner will be selected from each grade, for a total of 18 winners.

The artwork represented here is a sample of the posters both winning and non-winning that were received in 2011 and 2010. The posters represent children's interpretation of the future of water.

Appendix B. Participants in the Santa Fe Watershed Climate Change Workshop on March 6, 2012

First	Last	Company	City
Joni	Arends	Concerned Citizens for Nuclear Safety	Santa Fe
Talitha	Arnold	The United Church of Santa Fe	Santa Fe
Pete	Balleau	Balleau Groundwater, Inc.	Albuquerque
Reid	Bandeen	Truchas Hydrologic Associates, Inc.	Placitas
Beth	Bardwell	Audubon New Mexico	Las Cruces
Rita	Bates	NM Environment Department, Air Quality Bureau	Santa Fe
Athena	Beshur	Seeds of Wisdom, LLC	Santa Fe
Bobbe	Besold	Littleglobe	Santa Fe
Consuelo	Bokum		Santa Fe
Claudia	Borchert	City of Santa Fe, Sangre de Cristo Water Division	Santa Fe
Angela	Bordegaray	NM Interstate Stream Commission	Santa Fe
David	Breecker	Santa Fe Innovation Park	Medanales
Felicity	Broennan	Santa Fe Watershed Association	Santa Fe
Melvin	Buchwald		Santa Fe
Elva	Busch	Santa Fe Garden Club	Santa Fe
Patty	Bushee	City of Santa Fe	Santa Fe
Darcy	Bushnell	Utton Center, UNM School of Law	Albuquerque
Mitch	Buszek	Public Advocates	Santa Fe
Nichole	Carnevale	Nambe Pueblo, Environmental and Natural Resources	Nambe Pueblo
Rick	Carpenter	City of Santa Fe, Sangre de Cristo Water Division	Santa Fe
Margaret	Chavez	Eight Northern Indian Pueblos	
Christine	Chavez	Los Alamos County Utilities	Los Alamos
Juliana	Coles	We Are People Here	Santa Fe
Betsy	Conover		Santa Fe
Jennifer	Cramer	Santa Fe National Forest	Santa Fe
Susan	Dean	Self-Employed	Santa Fe
William	DeBuys		Chamisal
Bill	Dempster	Institute of Ecotechnics	Santa Fe
Carolyn	Donnelly	Bureau of Reclamation	Albuquerque
Paul	Drakos	Glorieta Geoscience, Inc.	Santa Fe
Brian	Drypolcher	City of Santa Fe, Public Works	Santa Fe
Gary	Durrant	City of Santa Fe, Buckman Direct Diversion	Santa Fe
Dave	Englert	New Mexico Environment Department	Santa Fe
Emily	Geery	NMED, Drinking Water Bureau	Santa Fe
Pamela	Gilchrist	ElderGrace Cohousing	Santa Fe
Tim	Glasco	Los Alamos County Utilities	Los Alamos
Lindsey	Grant	Self Employed	Santa Fe
David	Gutzler	University of New Mexico	Albuquerque
Anna	Hamilton	Tetra Tech, Inc.	Santa Fe
David	Harrington	Squash Blossum Farm	La Bajada
Steve	Harris	Rio Grande Restoration	Embudo
Kathleen	Holian	Santa Fe County	Santa Fe
Alan	Hook	City of Santa Fe, Sangre de Cristo Water Division	Santa Fe
John	Horning	WildEarth Guardians	Santa Fe
Melissa	Houser	Santa Fe Conservation Trust	Santa Fe
OrorJonne	Hower	Bureau of Reclamation	Salt Lake City

Appendix B. Participants in the Santa Fe Watershed Climate Change Workshop on March 6, 2012

First	Last	Company	City
Bruce	Hutchison	Self Employed	Santa Fe
Nancy	Hutchison	Self Employed	Santa Fe
Jan-Willem	Jansens	Ecotone	Santa Fe
Richard	Jennings	Earthwrights Designs	Santa Fe
Peggy	Johnson	New Mexico Tech, NMBGMR	Socorro
Brandon	Johnson	United Church of Santa Fe	Santa Fe
Mike	Johnson	New Mexico Office of the State Engineer	Santa Fe
Aaron	Kauffman	Southwest Urban Hydrology	Santa Fe
Dave	Kite		Santa Fe
Jerzy	Kulis	NM Environment Department Hazardous Waste Bureau	Santa Fe
Judith	Lawson		Santa Fe
Amy	Lewis	ACL Consulting	Santa Fe
Mark	Licht	NMLA	Santa Fe
Andrew	Lieuwen	ABCWUA	Albuquerque
Dagmar	Llewellyn	Bureau of Reclamation	Albuquerque
William A	Loeb	OSFA	Santa Fe
Larry	Logan	Edison Electric Institute	Washington
Dale	Lyons	City of Santa Fe, Sangre de Cristo Water Division	SANTA FE
Karen	MacClune	ISET	Boulder
Ken	Margolis	GEOS Institute	Santa Fe
Marcos	Martinez	City of Santa Fe, Attorney	Santa Fe
Dominique	Mazeaud	Heartist	Santa Fe
Laura	McCarthy	The Nature Conservancy	Santa Fe
Annie	McCoy	John Shomaker and Associates	Albuquerque
Betsy	Millard	Southeast Neighborhood Association	Santa Fe
Mark	Miller	Daniel B. Stephens & Associates, Inc.	Albuquerque
Hvtee	Miller	Santa Fe County	Santa Fe
Beth	Mills	Santa Fe County, Open Trails	Santa Fe
Katherine	Mortimer	Public Utilities, City of Santa Fe	Santa Fe
Andy	Novak	retired	Santa Fe
Charlie	Nylander	EBRIF	Santa Fe
Charlie	O'Leary	Santa Fe Conservation Trust	Santa Fe
Erin	Ortigoza	Environmental Services	Santa Fe
Louise	Pape	ClimateToday	Santa Fe
Francois-Marie	Patorni	Santa Fe Watershed Association	Santa Fe
Jonathan	Phillips	City of Santa Fe, Sangre de Cristo Water Division	Santa Fe
Alex	Puglisi	City of Santa Fe, Sangre de Cristo Water Division	Santa Fe
Doug	Pushard	HarvestH2o	Santa Fe
Anna	Rael Delay	Congressman Tom Udall Office	Santa Fe
Daniel	Ransom	City of Santa Fe, Sangre de Cristo Water Division	Santa Fe
Jesse	Roach	Sandia National Laboratories	Albuquerque
Maria	Rotunda	Earthprints	Santa Fe
Steven	Rudnick	University of New Mexico	Santa Fe
Rich	Schrader	River Source	Santa Fe
Chris	Shaw	New Mexico Interstate Stream Commission	Santa Fe
Sigmund	Silber	S.Silber&Associates	Santa Fe

Appendix B. Participants in the Santa Fe Watershed Climate Change Workshop on March 6, 2012

First	Last	Company	City
Duncan	Sill	Santa Fe County Economic Development	Santa Fe
John Miles	Smith	Santa Fe Basin Water Association	Santa Fe
Dependable	Strongheart	Santa Fe Water Conservation Committee	Santa Fe
Mark	Sundin	Bureau of Land Management	Taos
Ryan	Swazo-Hinds	Pueblo of Tesuque, Environment Dept.	Santa Fe
Enid	Tidwell	Santa Fe Garden Club	Santa Fe
Karen	Torres	Santa Fe County	Santa Fe
Laurie	Trevizo	Sangre de Cristo Water Division, City of Santa Fe	Santa Fe
Kari	Tyler	ISET	Boulder
Arnold	Valdez	Santa Fe County Planning	Santa Fe
Velimir	Vesselinov	LANL	Los Alamos
Ralph	Vigil	New Mexico Acequia Commission	Santa Fe
Susan	Waterman		Santa Fe
Natalie	Wells	Santa Clara County Valley Transportation Agency	Santa Fe
Park	Williams	Los Alamos National Laboratory	Los Alamos
Neil	Williams	Watershed West	Santa Fe
Charles	Wilson	Charles R. Wilson, Consultant	Santa Fe
Stephen	Wiman	Good Water Company	Santa Fe
Robert	Wood	City of Santa Fe, Parks Division	Santa Fe
Rick	Young	S. S. Papadopulos & Associates	Albuquerque
Risana	Zaxus	City of Santa Fe, Land Use	Santa Fe

Appendix C. Summary of Speaker Presentations

Human activities are increasing concentrations of greenhouse gasses such as carbon dioxide and methane in the atmosphere, and these gases are trapping increasing amounts of heat near the earth's surface. In response, global average air temperatures are rising, oceans are warming and expanding, melting of land-based ice is increasing, sea ice is thinning and permafrost melting, precipitation patterns appear to be shifting, and plants and animals are growing, migrating, and responding in different ways, places and times. The evidence for climate change that is being documented in the world around us is concordant with the climate science and physics captured in the global modeling; there is no longer doubt that our climate is changing.

The releases of greenhouses gasses that have occurred to date commit us to a certain degree of climate change, regardless of future emissions; and, currently global emissions appear to be accelerating rather than decreasing. This means that, moving forward, in addition to working to limit future emissions, we need to adapt to existing and at least near-future climate changes.

The goal of this workshop was to introduce climate change and its potential impacts in the Santa Fe Basin to a broad group of local stakeholders, and to solicit from those stakeholders their primary areas of concern and their initial thoughts about how to take action. This summary includes a review of the climate science presented at the workshop by Dr. David Gutzler, University of New Mexico and Dr. Park Williams, LANL, explores the implications of that science for water resources in the Santa Fe Basin, and closes with a call to action delivered by Bill deBuys.

C.1 Climate Change Impacts

Climate change has already occurred as evidenced by observed temperature increases; and forecasts predict that temperatures will continue to rise. The increasing temperatures impact the circulation of moisture in the upper atmosphere, thus impacting precipitation patters. A summary of the past and future changes is provided here.

C.1.1The Earth Is Getting Warmer

The earth is getting warmer – unequivocally. Beginning with the post-World War II boom, fossil fuel burning and land use change have had a noticeable and growing impact on global temperatures. Figure C-1 illustrates global mean temperature. The period from 1000 AD to 1860, obtained from temperature reconstructions, illustrates a variable but generally stable climate with temperatures lower than the reference level (the 0^{o}C line, which is based on the 10-year average of temperatures for the years 1995–2004). The period from 1860 to 2010 reflects measured temperatures; global mean temperature began warming rapidly around 1975 and current temperatures are higher than anything seen in the past 1000 years.

These global trends have clear corollaries in New Mexico; New Mexico is getting warmer – significantly. Over the past century, climate division 2, which encompasses the Santa Fe Basin, has warmed a degree Celsius. The growing season across the southwestern states, the period when average daily temperatures exceed 5^{o}C, increased by approximately 10 days between 1965 and 2008.

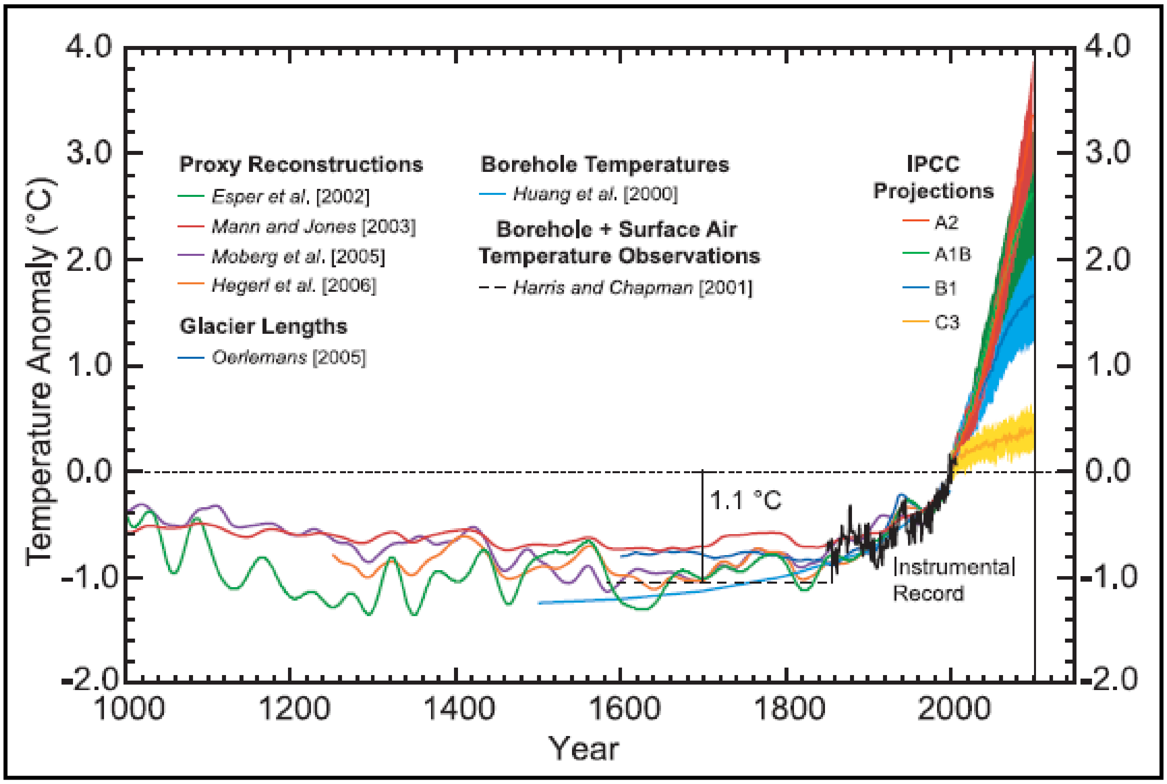


Figure C-1: ***Views of temperature change in the next century are informed by temperature changes in the past. For illustrative and educational purposes, three sets of surface temperatures have been assembled: 1000-year reconstructions of past temperature change based on proxies (tree rings, corals, etc.), glacier lengths, and borehole temperatures; the instrumental record; and Intergovernmental Panel on Climate Change (IPCC) projections for temperature change from 2000 to 2100. (Chapman and Davis, 2010)***

C.1.2 Climate Model Projections Indicate Further Warming

Climate model projections of 21st Century climate show large rates of warming. In Figure C-1, the period from 2010 to 2100 reflects global temperature projections for a variety of future land use, population, economic and emissions scenarios (C3, B1, A1B, A2) using the current suite of global circulation models (GCMs). The models illustrate that temperatures have the potential to dramatically increase in the next 100 years. Projected temperature changes under the A1B scenario are for 5.5 to 6.5 ^{o}F warming between 2000 and 2100.

However, there is a lot of uncertainty associated with the temperature projections. Uncertainty derives from:

- Which GCMs are used – each model represents earth systems with slightly different equations and divides the globe into slightly different boxes (grid cells and layers) in which to solve those equations; and,
- Which scenarios each GCM is run for – the scenarios make assumptions about population growth, energy usage, land use, and global economy to estimate emission rates. Each of

those assumptions has implications for global greenhouse gas emissions and local impacts. Theoretically, each of the scenarios is as likely as another, although we are currently following some of the higher emission tracks.

Any value within the range of possible future temperatures is as likely as another. Consequently, in working with climate projections, it is important to consider the full range of modeled projections for a region.

It is also important to remember that climate projections are generally presented as the modeled range of **average** values for a given location, and do not take into account local climate variability. Gutzler and Robbins (2010) address this for New Mexico by combining historic temperatures and precipitation variability with projected temperate trends. Results are illustrated in Figures C-2 (temperature) and 3 (precipitation).

One of the striking elements of Figure C-2 is that, by 2100, projected low temperatures, even when combined with current variability, exceed all but the highest temperatures seen in the historic record. Even by 2050, winter temperatures are close to today's average temperatures. This would have significant implications for water availability, management, and demand.

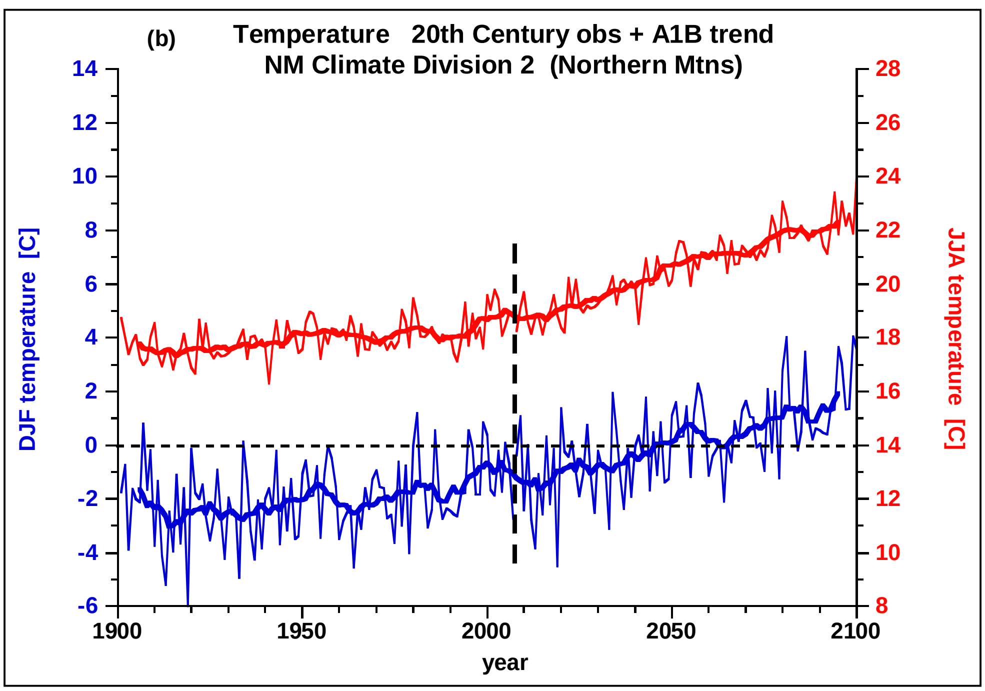


Figure C-2: Time series of annual temperature (°C) for the December-January-February (DJF) winter season (lower lines) and June-July-August (JJA) summer season (upper lines) for the twentieth and twenty-first centuries in New Mexico Climate Division 2. Thin lines show annual values; thick lines are 11-year running averages. For years 1901– 2007 (left of vertical dashed line), values are observed climate divisional data. For years 2008–2099 (right of dashed line), values are derived by adding twentieth century inter-annual variability to the twenty-first century simulated trend obtained by averaging 18 GCMs run for the A1B scenario. 21st century trends have values of +3.3°C/century in winter and +4.3°C/century in summer (Gutzler and Robbins, 2010).

Precipitation trends are less clear than temperature trends, both in the data and in model projections. Figure C-3 illustrates historic precipitation for NM Climate Division 2, and the projected precipitation under the A1B scenario, combined with historic variability. As can be seen, historic variability exceeds projected trends. Based on model results, future precipitation seasonal averages may be relatively indistinguishable from historic seasonal averages.

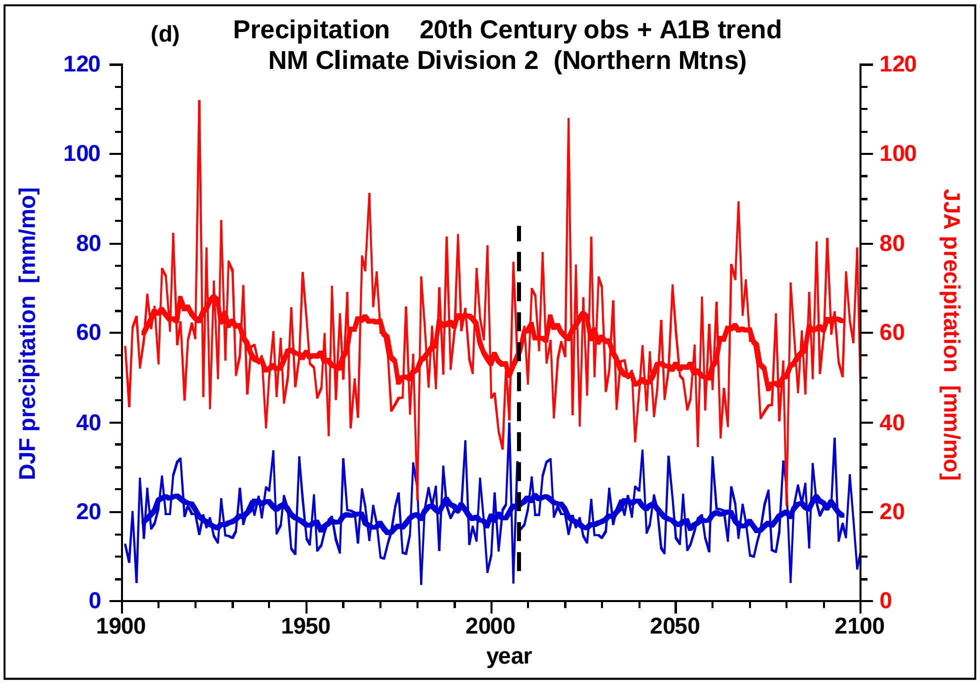


Figure C-3: Time series of annual precipitation (mm/mo) for the DJF winter season (lower lines) and JJA summer season (upper lines) for the twentieth and twenty-first centuries in New Mexico Climate Division 2. Thin lines show annual values; thick lines are 11-year running averages. For years 1901– 2007 (left of vertical dashed line), values are observed climate divisional data. For years 2008–2099 (right of dashed line), values are derived by adding twentieth century inter-annual variability to the twenty-first century simulated trend obtained by averaging 18 GCMs run for the A1B scenario. 21st century trends have values of -0.11 (mm/month)/century in winter and +1.6 (mm/month)/century in summer (Gutzler and Robbins, 2010).

This does not mean, however, that future daily precipitation will remain indistinguishable from historic precipitation events. Climate is projected to become more variable with climate change; future variability may exceed historical variability, with, for example, the lowest low temperatures remaining relatively unchanged but the high temperatures increasing dramatically. In particular, precipitation events are projected to become more intense (Figure C-4). This implies that, though seasonal precipitation totals may remain relatively unchanged, they are likely to be delivered in fewer, more intense rainfall events.

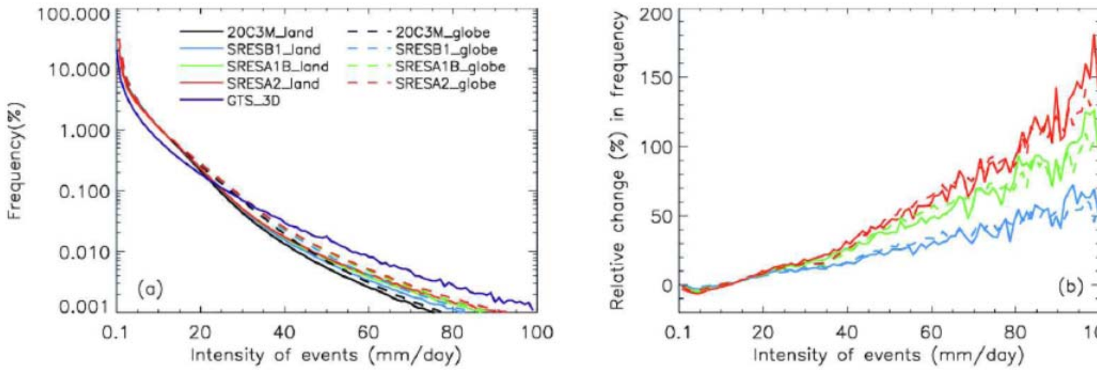


Figure C-4: Compared to simulations of current climate, global models generate fewer, but more intense, a precipitation event, averaged globally, as the climate warms up (Sun et al., 2007).

C.1.3Hydrologic Implications of Climate Change

The projected changes in temperature and precipitation will have implications for summer aridity, for winter precipitation (increasingly falling as rain rather than snow), snowmelt, and, by association, for spring melt water runoff timing and volume. Global climate models project a transition to a much more arid climate in the Southwest by the mid-21st Century, as a result of both the lack of increase in overall precipitation and the increased evaporation and evapotranspiration resulting from higher temperatures. Evaporation and evapotranspiration (E) are a strong function of surface temperature; warmer air holds more moisture. If precipitation (P) holds relatively constant, then available water (runoff and groundwater recharge), P-E, becomes consistently negative (drier surface) by the latter half of this century in model simulations. This means the dry season becomes even more intensely dry, with implications for irrigation needs for irrigated crops, and negative impacts to non-irrigated vegetation.

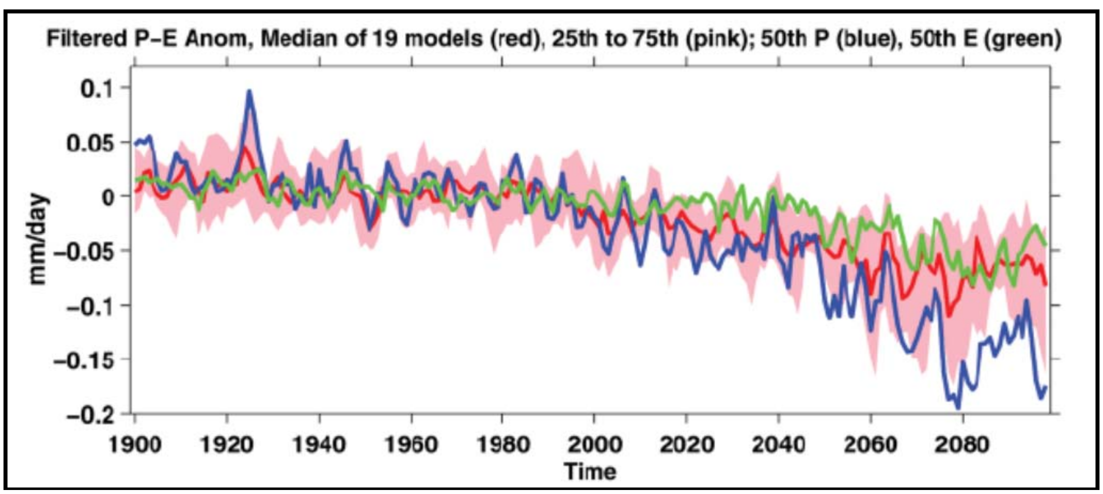


Figure C-5: Modeled change in annual mean Precipitation-Evaporation for the Southwestern US (Seager et al., 2007). The historical period used known and estimated climate forcings, and the projections used the SResA1B emissions scenario. Anomalies (Anom) for each model are relative to that model's climatology from 1950–2000. The model-ensemble mean P − E in this region is around 0.3 mm/day.

The predicted future winter climate will show changes in snowpack depth and snowmelt. Driven primarily by temperature changes, decreases in snowpack throughout the western mountains are seen in climate model simulations. The decreases are due principally to temperature change, with winter precipitation falling as rain rather than snow. By mid-century, projected changes for the Southern Rocky Mountains range from a 20 to 70% reduction in snowpack (Figure C-6).

What snow does fall will melt earlier, due to higher spring temperatures? Figure C-7 suggests that by mid-century, spring runoff could be 15 to 35 days earlier. This much earlier peak runoff date, driven by warmer temperatures, may also have lower peak flows, due to less snow. This clearly has significant implications for spring irrigation, mid- to late-summer flows, and reservoir storage.

Snowpack currently feeds a late-spring flood pulse on the upper Rio Grande and its tributaries, providing base flow for both the middle and lower river. In their 2008 paper, Hurd and Coonrod found that in the warmer climate projected for New Mexico, there would be an earlier and smaller snow-fed flood pulse, and a reduced total stream flow volume, especially in late spring/early summer. Their projected reductions in flow for the Middle Rio Grande are (Hurd and Coonrod, 2008):

- 2030: 4 - 14% reduction
- 2080: 8 - 29% reduction

Santa Fe River stream flow projections are similar to those for the Middle Rio Grande. Cox et al., in their 2011 paper, project an annual decrease in stream flow above McClure Reservoir by 2060 of 11-18%.

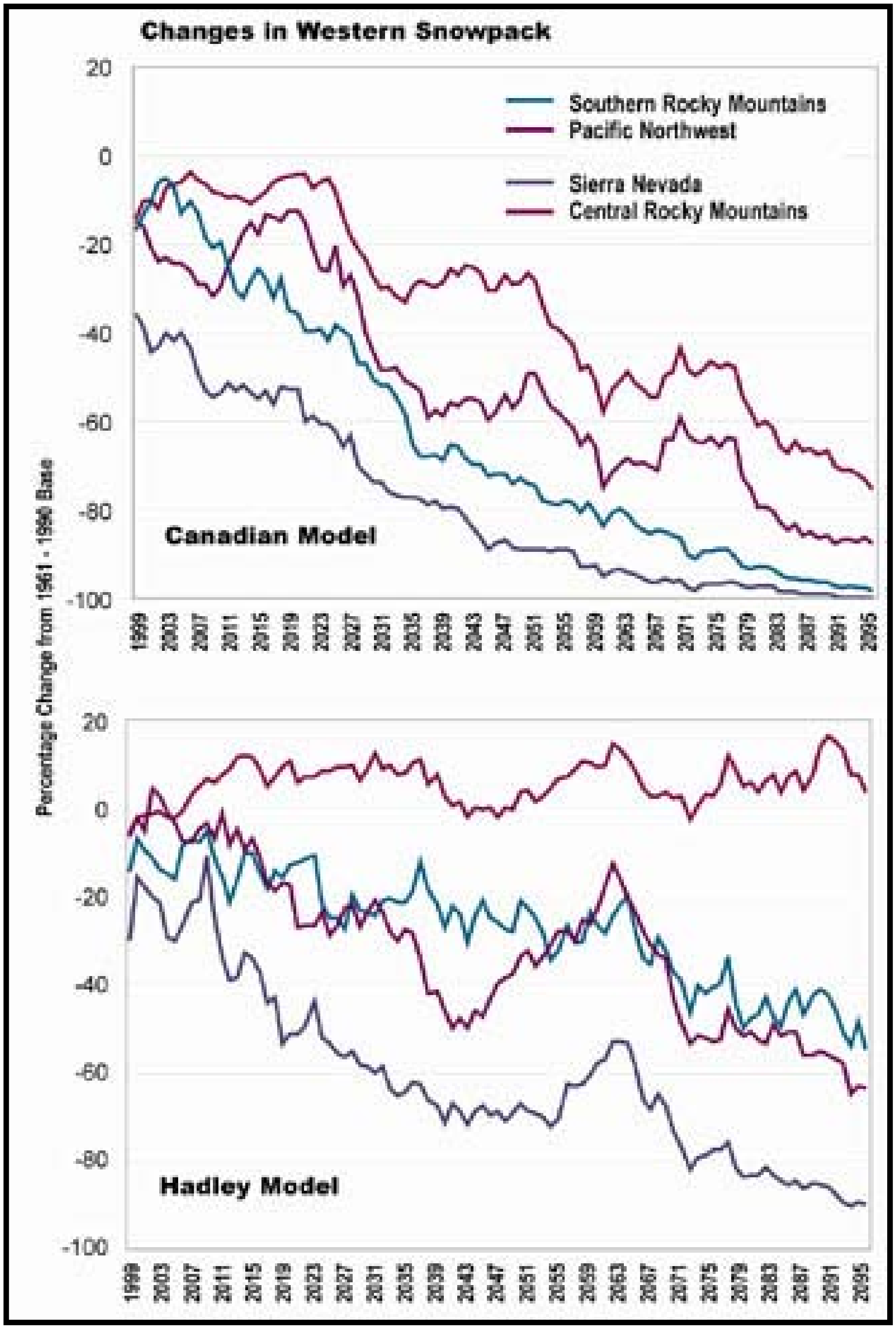


Figure C-6: Percentage change in the April 1 snowpack from the 1961-90 baseline in four areas of the western US as simulated for the 21st century by the Canadian and Hadley global circulation models. April 1 snowpack is important because it stores water that is released into streams and reservoirs later in the spring and summer. The sharp reductions are due to rising temperatures and an increasing fraction of winter precipitation falling as rain rather than snow. The largest changes occur in the most southern mountain ranges and those closest to the warming ocean waters. (NAST, 2000).

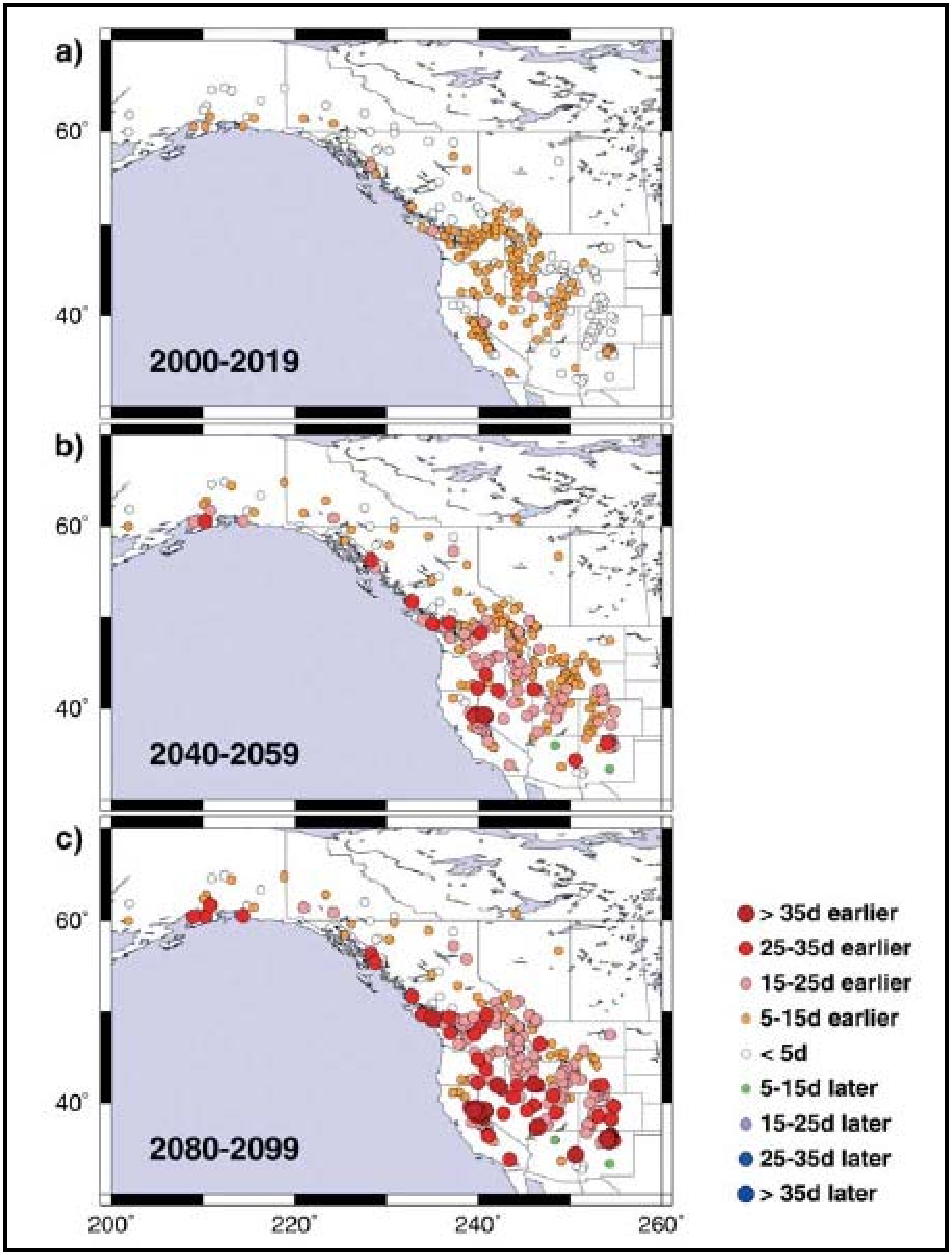


Figure C-7: Projected change in snowmelt runoff timing for western North America (Stewart et al., 2004)

C.2. Potential Secondary Effects

The temperature and precipitation projections, and their associated impacts to snowpack, snowmelt, stream flow, and P-E anomaly, have significant implications for virtually all water-related systems in New Mexico. Reservoir storage and river operations will be impacted by changes in volume and timing; these in turn will impact water availability for urban, agricultural and ecosystem use. Changes in precipitation intensity and snowpack may impact groundwater recharge rates. As a result, all systems that depend on water need to be evaluated for their vulnerability to reduced water availability, changes in the timing of water availability, and/or sensitivity to aridity and drought.

The second speaker at the workshop, Dr. Park Williams, LANL, delivered a case study on potential climate change impacts to forest ecosystems of New Mexico. This study provides significant insight into the types of cascading impacts that climate change may bring to New Mexico and the Santa Fe Basin.

C.2.1 Past, Present, and Future Impacts of Drought on Forests in the Southwestern USA

Dr. Williams initially analyzed how temperature (relative to precipitation) impacts regional forest productivity and mortality in the Southwestern USA. However, he quickly realized that temperature impacts forests via vapor pressure deficit. **Vapor Pressure Deficit** (**VPD**) is the difference (deficit) between the amount of moisture in the air and how plants draw more water from their roots. VPD has a simple, nearly straight-line relationship to the rate of evapotranspiration.

The growth of piñon pine, ponderosa pine and Douglas fir trees in New Mexico and the Southwestern U.S. is limited by moisture availability. During seasons and years of optimal climatic conditions, annual growth rings are wide; during drier years, thinner rings develop, on average with the thinnest rings during the driest years. Breaking the year down into seasons, and assessing both precipitation and vapor pressure deficit, Williams and colleagues found that winter (Nov-Mar) precipitation and summer (Aug-Oct of previous year and May-July of current year) account for 91% of the year-to-year variability in tree-ring width. Warm season vapor pressure deficit accounts for 56% of this correlation, and cold-season precipitation for 44%. Williams used this to develop a "Forest Drought-Stress Index", FDSI:

FDSI = 0.44 [zscore(cold-season precipitation)] – 0.56 [zscore(warm-season VPD)]

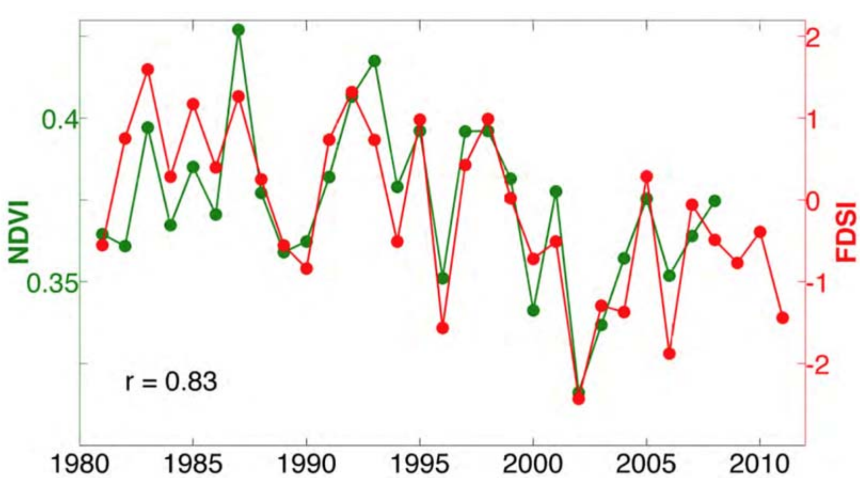
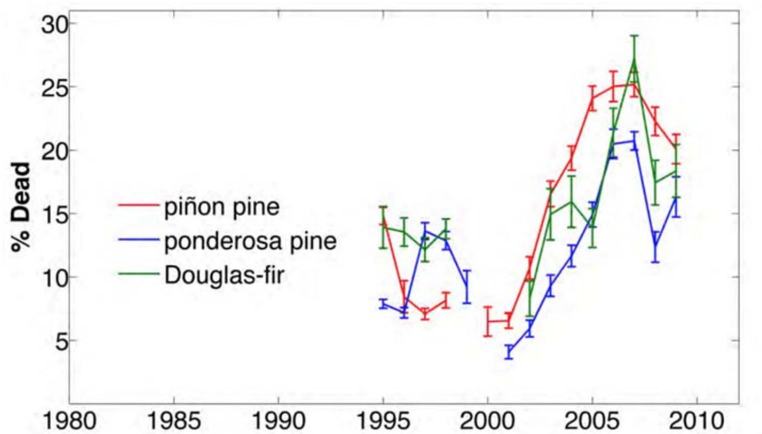


Figure C-8: Correlation between NDVI (summer vegetation greenness index derived from AVHRR satellite imagery) and the Forest Drought-Severity Index (FDSI).

The FDSI is strongly correlated (0.83) with summer vegetation greenness (NDVI) derived from AVHRR satellite imagery, as is illustrated in Figure C-8.The NDVI dropped significantly in 2002 and remained lower, for the rest of the 2000s, than in the 1980s and 1990s. This drop coincided with a period of high tree die-off in response to bark beetle outbreaks, as shown in Figure C-9. Between 1997 and 2010 bark beetles were responsible for the death of 8% of the forests in the Southwest; the number of dead trees roughly doubled between 2001 and 2006.

Figure C-9: Number of dead piñon pine, ponderosa pine and Douglas fir, USFS Forest Inventory & Analysis (FIA) data.



The bark beetle outbreaks, in turn, corresponded with drought. Drought-induced stress made trees more susceptible to beetle infestation. Figure C-10 illustrates the strong inverse correlation (0.84) between the forest area impacted by bark beetles (left axis) and the 2-year running-average FDSI (right axis; more negative values, corresponding with higher drought, are at the top of the axis).

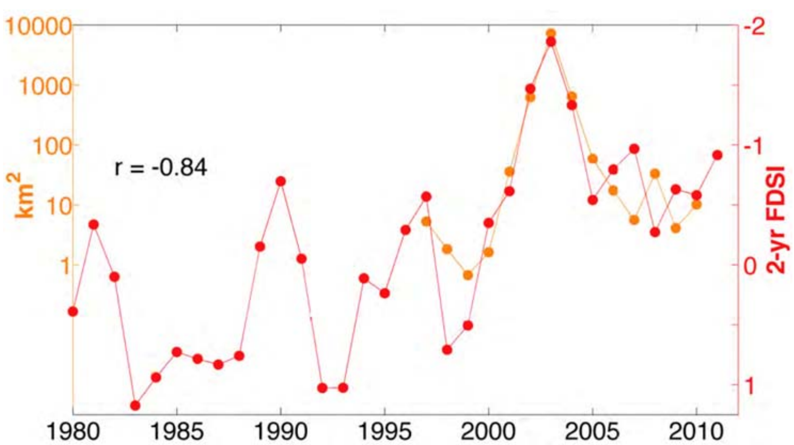


Figure C-10: Inverse correlation between forest area impacted by bark beetles (left axis; Forest Health Technology Enterprise data) and the 2-year running-average Forest Drought-Severity Index (FDSI, right axis).

Drought-induced stress also left forests more susceptible to wildfires, which further contributed to the reduction in NDVI. 2002, 2006 and 2011 all saw large areas in the Southwest burn. As with bark beetle impact, total burned area is strongly inversely- correlated with the FDSI, as shown in Figure C-11; 2002, 2006 and 2011 are all years when the FDSI was lower than -1.

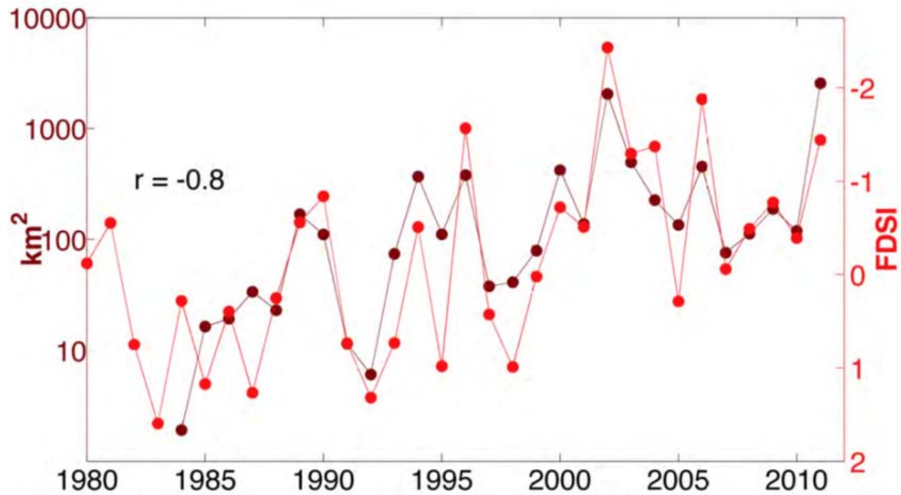


Figure C-11: Inverse-correlation between forest burned area (left axis) and FDSI (right axis). More negative values of FDSI correspond to deeper drought conditions.

Drought-induced forest mortality is normal in New Mexico. For example, tree-ring data suggest that regionally extensive droughts in the late 1200s and late 1500s caused increased tree mortality throughout the Southwestern U.S. More recently, mortality of many southwestern tree species occurred during the severe drought of the 1950s. In general, the risk of widespread tree mortality dramatically increases for FDSI values below -1. However, climate projections suggest FDSI values will become more negative in the future. By about 2050, FDSI values for even the wettest, coolest years will equal or exceed the FDSI values experienced during the 1200 and 1500 "mega-droughts" and the 1950s drought.

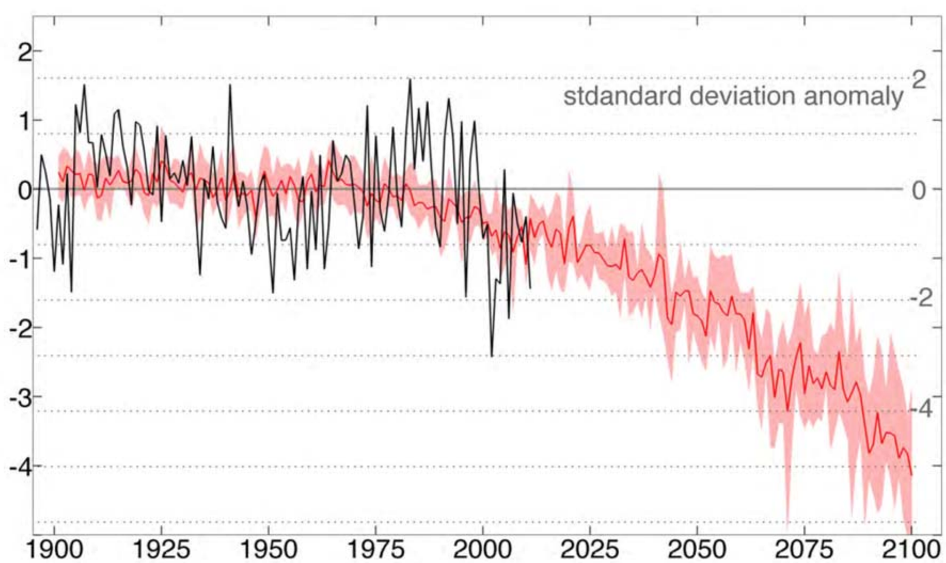


Figure C-12: Projected FDSI (dark red line is average; light red shading is range) vs. historic FDSI derived from measured data (black).

This means that, if climate models are correct, by the 2050s average drought stress will equal that of the worst drought years that the Southwestern U.S. has experienced in the past 1000 years.

C.2.2Case Study Implications

It is generally accepted that current drought and elevated temperatures have contributed to the recent increase in widespread fires and bark-beetle outbreaks in the Southwestern US. At least 8 to 11% of southwestern forest and woodland area was affected by extensive tree mortality due to bark beetles from 1997 through 2008. Another approximately 3.0% of forest and woodland area was affected by stand-replacing fire with moderate to severe burn severity from 1984 through 2006. Together, fire and bark beetles have caused high levels of mortality in 14–18% of southwestern forest areas (excluding woodlands) over the past two decades.

This suggests that, with only two more recurrences of drought/die-off similar to that of the past 20 years, Southwest forest area could be reduced by more than 50% over 1980s coverage. And, given the projections for warming and the associated increase in vapor pressure deficit and FDSI, two more recurrences similar to or worse than the past 25 years seem likely. Clearly, this is a broad simplification that ignores self-limiting effects, regeneration, and other complexities; there is considerable uncertainty about how forests will respond to increasing stress over the coming decades. Nonetheless, this science should inform the debate around how to build forest resilience.

Appendix D. Solutions Proposed At Workshop

This appendix contains the full list of climate change actions and solutions proposed at the workshop, 62 in all. Actions are divided into categories, as for sections 5 and 6 of the report, for ease in cross-referencing.

D.1 Water Supply Systems

Water: Management

1. Storm water management by neighborhood
2. Coordinated water quality / water quantity management
3. Local, community-based water board
4. Aquifer recharge/ aquifer storage and recovery: using surplus rainwater and snowmelt, landscape contouring to enhance storm water capture, arroyo catchment systems, etc.
5. Negotiate agriculture to urban water transfers of limited term with MRGCD, to be implemented in times of drought or other emergency.

Water: Demand Reduction

1. Tiered water billing - cheaper rates for those who use less
2. Strengthen water and wastewater reuse; explore cleaning wastewater to drinking water standard
3. Clearinghouse for city conservation programs

D.2 Ecosystems

1. Improve urban forests using carbon credits
2. Conduct more prescribed fires in winter
3. Thin Santa Fe River watershed (healthy forests)
4. Develop contingency plans for responding to large-scale fires in the Santa Fe watershed, including consideration of flood protection, recovery of water systems, rehabilitation of reservoirs, and budgets required to implement

D.3 Agriculture and Food security

1. Guarantee seed sovereignty
2. Buffer zones for GE crops
3. Encourage small farms in the city and county
4. Annual budget from Santa Fe County Commission to support healthy food systems
5. Urban planning to incorporate a wide variety of urban agriculture techniques, including urban farming and food-scapes in commons areas

D.4 Land Use and Quality of Life

Parks and Landscaping

1. Use compost and mulch in all commons areas
2. Plant trees w/in city limits to "cool" cities
3. Manage city parks to harvest and reduce runoff, reducing water demand

Urban Infrastructure/Green Infrastructure

1. Solar panels over parking lots to reflect heat and generate energy
2. Incentives for addressing water leaks
3. Tax incentives for green properties
4. Require pervious pavement
5. Free green-waste bin and city/county composting
6. Close 4-corners coal plant

Zoning/Development

1. Improve zoning to: preserve agricultural land, foster urban infill, and foster small (~150 people) neighborhoods
2. New development - zero-runoff requirement for storm water
3. Moratorium on new construction that draws from groundwater
4. Connect land and water planning
5. Explore policy options to address the tension between locals and second-homers – does Santa Fe want to encourage or discourage the growth of 2nd homes.

D.5 Energy Systems

1. Electric coop and/or municipal energy company
2. Create incentives to use renewable energy
3. Greater incentives for energy efficiency, coupled with funding help for individual households

D.6 Sociological Systems/Public Engagement/Policy Change

1. Start now: do what you can with what you have where you are
2. Provide more incentives for actions that address climate change
3. Highlight models of successful projects happening now
4. Foster inclusive discussions incorporating all components of community
5. Eliminate corporate personhood, starting locally and using this to leverage state and national change
6. Break down solutions between those that do and do not require financing
7. Open discussion of uncomfortable topics such as population growth
8. All citizens work annually for city water system, in exchange for a tax credit, to create more awareness

9. Build task force to manage conserved water to enhance resilience, avoid demand hardening or dedication to growth (task force to preserve/protect water freed up by conservation so that it doesn't go to support growth)
10. Create sacred space around water, including at meetings

D.7 Education

1. Free birth control, sex education in schools, and education on impacts of overpopulation
2. Free classes on growing food and composting
3. Conservation classes, participation rewarded through tax incentives
4. Xeric demonstration gardens
5. Demonstration rainwater harvesting systems
6. Install rainwater catchment systems in all schools, linked to gardens, food gardens, and trees
7. Require middle school water education and green education
8. Lessons learned – put into school buildings and curricula
9. Tours of WWTP to educate residents and school children on where waste-water goes
10. Tours of Buckman Direct Diversion (recognize cost)
11. School challenges to decrease carbon footprint within classrooms and school-wide, including quantification
12. Increase water resource outreach and education for all citizens

D.8 Visionary

1. Make imagination and possibility more seductive than scarcity and fear
2. Artist in Residence dedicated to Santa Fe River
3. Make conservation, both at individual and community level, a ritual
4. Water-free day each year to demonstrate how integral it is to our existence
5. "Year of water" – poets manage water for a year

D.9 Implementation

1. Regional governance – connect government agencies across whole watershed
2. More communication and collaboration across government levels, beginning with the city and county
3. A diversity of decision-makers, coupled with deep community engagement

Photo descriptions:

View of sunset from Santa Fe, June 2009. Photo by A. Lewis

One year after Las Conchas Fire, May 16, 2012. Photo by A. Lewis

Bill deBuys at Santa Fe River Climate Change Workshop, March 6, 2012. Photo by A. Lewis.

Santa Fe River Climate Change Workshop, March 6, 2012. Photo by A. Lewis

Breakout session during the Climate Change Workshop, March 6, 2012. Photo by A. Lewis

Blue gramma grass near Santa Fe, August, 2006. Photo by A. Lewis

High water use toilets on route to the landfill after being replaced through the City of Santa Fe's toilet retrofit program, December, 2006. Photo by A. Lewis

Las Conchas fire and fireworks, July 4, 2012. Photo by A. Lewis

Results of forest treatments in the Santa Fe Watershed near Nichols Reservoir, September, 2011. Photo by A. Lewis

Rangeland near Santa Fe, August 2007. Photo by A. Lewis

Domestic garden near Santa Fe, August, 2007. Photo by A. Lewis

Green chili roasting in Santa Fe, September, 2011. Photo by A. Lewis