THE IMPACT OF CLIMATE CHANGE ON NEW MEXICO'S WATER SUPPLY AND ABILITY TO MANAGE WATER RESOURCES

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EXECUTIVE SUMMARY

Governor Bill Richardson, recognizing that the biggest impact of climate change on New Mexico will be its affect on the State's water resources, in his Executive Order 2005-033 directed "The Office of the State Engineer to work with other state agencies, with local and federal agencies, and with the State's research institutions to prepare an analysis of the impact of climate change on the State's water supply and ability to manage its water resources. A report summarizing findings shall be completed no later than July 2006." This report will therefore address only water issues, although it is important to consider it along with the New Mexico Environment Department's December, 2005 report on the impacts of climate change throughout New Mexico.

Global warming and climate change are increasingly understood because a growing number of researchers internationally are contributing to the body of scientific knowledge and to modeling capacity. Although to date little modeling is available that is specific to New Mexico, results from global climate models (GCMs) were utilized for the projections reported in Section II. The impacts to the State are anticipated to be significant for water managers and users, with changes to both supply and demand including:

---temperatures have already risen in New Mexico and are predicted to continue to increase;

---changes in snowpack elevations and water equivalency;

---changes in available water volumes and in the timing of water availability;

---increasing precipitation in the form of rain rather than snow due to increasing temperatures;

---smaller spring runoff volumes and/or earlier runoff that will impact water availability for irrigation and for ecological and species needs;

---milder winters and hotter summers, resulting in longer growing seasons and increased plant and human water use;

---increased evaporative losses from reservoirs, streamflows and soils due to hotter, drier conditions;

---increased evapotranspiration by agricultural and riparian plants;

---an increase in extreme events, including both drought and floods.

Incorporating climate change into water planning has historically been challenging due to the continued level of prediction uncertainty, coupled with the myriad additional pressures faced by water resource planners. Climate change needs to be added as "another pressure" along with population growth, changing demographics, existing climate variability, increasing water demand and availability challenges, land use, species protection and other ecosystem demands. Adaptive management strategies will need to be devised that are robust and flexible enough to address climate change.

Most of the strategies, policies and tools necessary to manage water resources in the context of climate change have probably already been identified. Incorporation of climate change into New Mexico's water planning may require new modeling and scenarios, and may lead to adjusted priorities and revised timelines, including acceleration of "no regrets" strategies that will also ameliorate the other pressures on the State's water resources.

The State Water Plan (SWP) and many of the State's regional plans already provide a policy framework in which to address climate variability and incorporate many of the policies and strategies that need to be re-evaluated in the context of climate change. Mainstreaming climate vulnerabilities and adaptation strategies into water resource management will be required for comprehensive planning for sustainable development. While the literature on adaptation strategies is still quite limited, there are a variety of recommendations that include both new and revised components of strategic plans and appropriate management strategies. The report outlines some of these as a starting point for discussion of New Mexico's options for addressing climate change:

1. Strategic planning within all water-related plans that includes climate change scenarios while recognizing the uncertainties inherent in these predictions and maintaining flexibility within the planning environment to accommodate new modeling and data as it becomes available. Good strategic planning will require:
   a. improved federal and state water data gathering activities to support sound decision-making;
   b. increased transdisciplinary and collaborative stakeholder participation in planning and strategy design; and
   c. integrated regional water planning.

2. Highly adaptive management capacity at the watershed scale with particular attention to rangelands, agricultural systems, and aquatic ecosystems.

3. Assessing infrastructure vulnerabilities and capacities; improving existing infrastructure and management systems; expanding water supply through new technologies; and developing new approaches to storage.

4. Enhanced demand management, conservation and efficiency measures, with special attention to the water/energy nexus.

5. Addressing statutory, regulatory and institutional barriers.

6. Addressing the role of climate change in meeting the economic, social and environmental goals of sustainable development.

Climate change will likely have a significant impact on the availability of and demand for New Mexico's water during the next century. The key to successful adaptation is a robust planning structure that incorporates highly certain predictions (such as temperature increases) as well as less certain forecasts (such as precipitation changes) into scenarios that can direct implementation of flexible management strategies. The State Water Plan (SWP) and the regional plans provide a policy framework to which climate change can be added as an additional pressure, albeit a potentially more threatening one. Doing so will better position the State's water resource managers to meet objectives that might otherwise be compromised by changing climatic conditions, while waiting for improved climate predictions may compromise the State's ability to anticipate and capture potential benefits and avoid potential negative impacts.

Adapting to climate change will not be a smooth process and will require multiple management tactics rather than a one-time solution. Given the latest scientific research and modeling on the impacts of climate change, New Mexico could gain substantial benefits from anticipatory stoking of its water management toolbox with proactive policies and clearly beneficial "no regrets" strategies that also alleviate the additional pressures to the State's water resources.

> ***"In the Southwest, water is absolutely essential to our quality of life and our economy. Addressing climate change now, before it is too late, is the responsible thing to do to protect our water supplies for future generations."***
>
> ***Governor Bill Richardson***

I. GOALS, OBJECTIVES, SCOPE AND LIMITATIONS OF THIS REPORT

a) Introduction

Governor Bill Richardson has implemented an aggressive climate change initiative for New Mexico. His Executive Order 2005-033 [www.governor. state.nm.us/orders/2005/EO_2005_033] directed that the New Mexico Environment Department (NMED) provide a report on the impacts of global warming on New Mexico by December 31, 2005. That report is available at www.nmenv.state.nm.us/aqb/cc/Potential_Effects_Climate_Change. The E.O. also calls for a Climate Change Advisory Group (CCAG) to develop a comprehensive program to identify sources and decrease New Mexico's contribution to emissions of greenhouse gases. That will be completed by the end of 2006, and further information about that process can be found at www.nmclimatechange.us.

Recognizing that the biggest impact of climate change on New Mexico will be its affect on the State's water resources, the E.O. also directed:

> **"The Office of the State Engineer to work with other state agencies, with local and federal agencies, and with the State's research institutions to prepare an analysis of the impact of climate change on the State's water supply and ability to manage its water resources. A report summarizing findings shall be completed no later than July 2006."**

This report will therefore address water only, although it is important to consider it along with the NMED report which includes additional information about both water and ecosystem impacts that may not be covered in this document. It has also benefited from the input of an informal work group created to assist with its development. (See Appendix A) It was developed from information gleaned through published reports as well as informal discussions with water resource managers, planners, modelers, climate experts, and others contemplating the implications of climate change on water resources. As such, it represents a compilation of existing data and educated, scientific opinion on this issue. It does not purport to be an in-depth analysis of the issue, primarily because there is not a substantial amount of research specific to New Mexico available on the topic. Nor does it include new research. It is, instead, an initial review of the available information on the impact of climate change on New Mexico's water resources that can be expected based on existing research and analysis.

Global warming and climate change are increasingly understood because a growing number of researchers are contributing to the body of scientific knowledge and to the capacity for models to generate good predictions. However, with few exceptions, very little attention has been paid to the implications of climate change for water policy and management. The report's final section thus includes only a preliminary overview of those areas discussed in the existing literature in which adaptive management strategies will likely be required to limit the extent and severity of adverse and severe consequences from climate change. It is intended to create a framework for dialogue within which policy makers, water managers and the public can begin to incorporate climate change into strategic plans for the State's water future.

b) *Why is this an important issue?*

Water is so critical to the New Mexico's quality of life and economic vitality that any impacts to our water resources reverberate across the social, economic and environmental fabric of the State. The anticipated impact of climate change is particularly important since New Mexico is highly dependent on climate-sensitive natural resources (e.g. snowpack, streamflow, forests) and on natural-resource based economic activities (e.g. agriculture, recreation and tourism).

The pressures on water resources in New Mexico are already substantial.

> "In the Western United States, the availability of water has become a serious concern for many communities and rural areas. Near population centers, surface-water supplies are fully appropriated, and many communities are dependent upon ground water drawn from storage, which is an unsustainable strategy. Water of acceptable quality is increasingly hard to find because local sources are allocated to prior uses, depleted by overpumping, or diminished by drought stress. Some of the inherent characteristics of the West add complexity to the task of securing water supplies. The Western States, including the arid Southwest, have the most rapid population growth in the United States. The climate varies widely in the West, but it is best known for its low precipitation, aridity, and drought. There is evidence that the climate is warming, which will have consequences for Western water supplies, such as increased minimum streamflow and earlier snowmelt events in snow-dominated basins. The potential for departures from average climatic conditions threatens to disrupt society and local to regional economies." [Anderson, 2005]

In WATER 2025, the Bureau of Reclamation described the realities facing water managers in the Western U.S.: explosive population growth, existing water shortages that will (and already are) resulting in conflict, and aging water facilities that limit management options, noting that crisis management will not be enough to meet these challenges. WATER 2025 called for proactive management of scarce water resources and suggested guiding principles and key tools to address systemic water problems, many of which are relevant to the discussion of managing in the context of climate change. [USDOI, 2005]

The NEW MEXICO STATE WATER PLAN (SWP) created a framework for water management in the State. [www.ose.state.nm.us/water-info/NMWaterPlanning/state-water-plan] The policies and strategies that it established include many that will be useful in addressing climate change. The SWP already recognizes that New Mexico's climate varies a great deal. Climate change models indicate that such variation can be expected to continue, but that the rate and variation of these changes may be even less predictable and more extreme than in the recent past. The SWP includes multiple responses to climatic variability and change such as active water management, water conservation, urban growth management, development of new water supplies, and watershed and ecosystem protections, all of which often have many more general benefits and can promote longer-term economic and environmental stability for the State. [Meridith, 2002]

Climate change will thus present an additional challenge to management of the State's water resources. Along with population growth, economic development, existing climate variability, recurring drought, and the unpredictable impacts of international geopolitical events, it injects another layer of uncertainty and complexity into the arena in which strategic planning and water policy development occur. "By taking climate forecasts into account and adjusting operational practices to reflect potential conditions, resource managers are better positioned to meet resource management objectives that might otherwise be compromised as a result of different climate conditions. Climate forecasts may also enable managers to anticipate and capture the benefits associated with possible climate conditions. In both cases, the lead-time provided by the forecasts gives managers the opportunity to anticipate and plan for potential climate-induced changes." [Climate Impacts Group, 2005]

II. OBSERVED AND PREDICTED IMPACTS OF CLIMATE CHANGE ON NEW MEXICO'S WATER SUPPLIES

Thanks to the following individuals who contributed to this section: Prof. David Gutzler, University of New Mexico; Dr. Gregg Garfin, Climate Assessment for the Southwest, University of Arizona; Dr. Bernard Zak, Sandia National Laboratories.

a) Introduction

In the 20th Century global temperature increased by about 1°F, with much of the warming occurring after 1970 [IPCC, 2001]. An increasing body of evidence indicates that much of the increase in temperature is associated with anthropogenic inputs of carbon dioxide (CO_2), methane (CH_4), and other atmospheric greenhouse gases (henceforth GHGs). The GHGs are trace gases (present in small amounts in Earth's atmosphere) that actively absorb infrared radiation but are much less effective at absorbing solar radiation. Thus GHGs allow sunlight to pass through the atmosphere to the surface, but absorb and re-emit radiant heat emitted from the surface and "recycle" some of that heat back downward. Recycling of infrared radiation creates the "Greenhouse Effect" that keeps the Earth's surface significantly warmer than it would be in the absence of an atmosphere.

Although significant uncertainties remain concerning many aspects and predicted impacts of current climate change, there is no longer any serious debate about several fundamental results [IPCC, 2001; summarized by Gutzler, 2000]:

1) Earth's climate is warming rapidly, as can be seen in the worldwide retreat of glaciers, pack ice and snowfields during the 20th Century, continuing today.
2) Ice core records show that several principal atmospheric greenhouse gases are now present in concentrations higher than at any time in the last half-million years. The abrupt rise in the concentrations of these gases since the Industrial Revolution is due without doubt to human activities. The concentrations of each of these anthropogenic greenhouse gases continues to increase rapidly; in this century it seems inevitable that CO_2 will reach a concentration more than double its pre-industrial value.
3) The direct radiative effect of GHGs is very well understood. There is no doubt that the direct effect of increasing the atmospheric concentrations of GHGs is an increase in Earth's surface temperature.

Similar trends in temperature over the past few decades are clearly in evidence across New Mexico; indeed, warming trends across the American Southwest exceed global averages by about 50%. Since the 1960s, wintertime statewide average temperatures have increased by nearly 1.5°F (Fig. II-1).

It is important to keep in mind that the ongoing warming of global and regional climate is taking place in the context of shorter term weather and climate variability, as well as demographic factors that may increase our vulnerability to climate change. The American Southwest is subject to recurring severe multi-year drought episodes, which occur on average several times per century, as determined from tree ring records spanning the last thousand years (Fig. II-4). These pronounced drought episodes, which seem to be a natural component of regional climate, are expected to continue as the climate warms. Meanwhile human population is increasing rapidly in New Mexico, and across the southwestern U.S. and northern Mexico, despite the limited water supply in this arid region.

b) Overview of climate trends and predictions for New Mexico and the Southwest

In the American Southwest, the impacts of climate variations on water supplies are easily recognizable by simply observing snowpack, reservoir and stream flow levels. Both Global Climate Models (GCMs) and historical trends in temperature, precipitation, and snowpack can be used to assess the recent and potential future effects of climate change on water resources across the Southwest and New Mexico. GCMs indicate that by the end of this century, the American Southwest, and more specifically New Mexico, can expect a significant increase in temperature, resulting in a decrease in snowpack. Precipitation predictions are far less certain, as will be shown in sections II(d) and II(e). The models suggest that even moderate increases in precipitation would not offset the negative impacts to the water supply caused by increases in temperature. Predicted changes in climate variability could also result in more frequent and extreme flooding [Nash and Gleick, 1993].

i) Temperature

Climate models predict that increases in temperature in the 21st Century will be greater in the Southwest than the global average, as part of a general tendency for continental interiors to warm up more than oceans or coastal regions [IPCC, 2001]. In the northern part of New Mexico, the largest increases in temperatures over the past several decades have occurred in the winter months, resulting in recent annual average temperatures more than 2º F above mid-20th Century values [Figure II-1]. Recent model simulations suggest accelerated summertime warming in the future [Figs. II-8 and II-11], as will be described below.

ii) Snowpack

Climate models predict a trend toward higher freezing altitude and reduction in Western snowpack [Fig. II-2] over the coming decades as a result of rising temperatures [U.S. GCIRO, 2005]. The anticipated higher temperatures discussed above will have several major effects: delay in the arrival of the snow season, acceleration of spring snowmelt, and therefore a shorter snow season, leading to rapid and earlier seasonal runoff [Gleick, 2000]. Annual average temperatures have been rising in the mountainous areas of New Mexico during the winter and early spring [Fig. II-1], which supports model-based projections that snowfall will begin later and total snowfall will decrease, even if winter precipitation stays the same or increases [Lettenmaier, 2004].

Snowpack has been below average for 11 of the past 16 years in the Colorado River Basin and 10 of the past 16 in the Rio Grande Basin [RMCO, 2005]. After one winter of exceptionally abundant snowpack in 2004-05, this trend continued in the winter of 2005-06. Snowfall in New Mexico was far below average last winter and snowpack observations ranged from 40% of average in the upper Rio Chama basin to less than 10% of average over most of the state [SWCO, 2006].

The recent observed decrease in snowpack in the Southwest has coincided with the warming trend. Climate models predict that snowpack in the Southern Rocky Mountains will continue to decline through the 21st Century [Figs. II-3 and II-13]. Increasing temperatures may deplete the water resources in the Colorado River Basin by as much as 40% by the end of the century [Lettenmaier, 2004].

iii) Precipitation

Climate models predict a marked decrease during the 21st Century in the ratio of rain to snow in winter precipitation [IPCC, 2001]. The largest percentage increases in precipitation falling as rain are likely to be in the Southwestern U.S. [Felzer and Heard, 1999]. Recent model simulations also predict a decline in total winter precipitation across New Mexico (Figs. II-9 and II-12), but large uncertainties surround these precipitation predictions. Other models show modest increases in winter precipitation. However a recent study concluded that a 7°F increase in temperature in the Colorado River Basin would require precipitation increases of 15-20% above current averages to mitigate the decrease in flows experienced from evaporative losses [Nash and Gleick, 1993]. Additional research has also shown that increases in precipitation along with increased temperatures can result in decreases in runoff [Wolock and McCabe, 1999].

iv) Drought

Increasing temperatures, earlier snow melt, and decreasing soil moisture lead to an increase in summertime evaporation, thereby decreasing recycled moisture availability and creating a cycle that perpetuates the “increased intensity, frequency and duration of drought” [WCRP, 2003]. Tree ring-based reconstructions of western droughts over the last millennium show a correlation between warm temperatures and drought, indicating that long-term warming trends could lead to extreme aridity over the western United States [Cook et.al., 2004]. Another reconstruction dating back to 1512 indicates that long-term annual flow in the Colorado River was likely 10% less than the average annual flows measured from1906 to 2000 [Lettenmaier, 2004].

A representative precipitation history derived from old trees in northern New Mexico [Fig. II-4] shows that recent decades (light blue and green lines) have been relatively wet compared to the long term climatic average (black line). Note that the 1950s drought (red line), the most severe drought in New Mexico in the instrumental record, shows up as a severe episode but is by no means the worst drought in the past 1000 years. This long record, like other reconstructions from different parts of the Southwest, shows that intermittent decade (or longer) droughts have been a recurring feature of Southwest climate for many centuries. These droughts are currently not predictable, but New Mexicans should assume that severe droughts (like the 1950s, or worse) will continue to occur in the future.

v) Flood events

Warming trends will result in shifts and changes in the magnitude of runoff peaks that depend on overall precipitation [Gleick, 2000]. As discussed above, warming at high elevations will decrease winter snowfall and snowpack, increase winter rainfall, and accelerate spring snowmelt, causing probable increases in winter runoff and decreases in summer streamflow [Gleick, 2000]. Increases in summer surface temperatures will likely result in reduced atmospheric stability, increased convection, and a more vigorous hydrologic cycle, resulting in a climate conducive to more intense (but possibly less frequent) storms [Carnell and Senior 1998, Hayden 1999], thereby leading to an increase in flood events. Springtime peak flows could increase significantly and flood events could be earlier and more extreme.

c) Global Climate Model (GCM) Predictions

GCMs of several kinds have been developed over the past half century to aid in evaluating what the impacts would be on future climate of various societal choices regarding the use of fossil fuels. The starting point for the use of such models is the definition of "scenarios" for carbon dioxide and other GHG emissions -- effectively, different guesses as to how society might respond to trends in the availability of current fuels (e.g. petroleum) and the potential threat of climate change. The Intergovernmental Panel on Climate Change (IPCC) began its work in 1988, and came out with its first assessment report in 1990 [IPCC, 1990]. In support of its first report, the IPCC defined 6 such emissions scenarios. In support of its third assessment report in 2001, IPCC expanded the number of scenarios considered to 40, categorized by different assumptions about global economic and population growth, as well as global energy policy. Of these, 6 "marker scenarios" were chosen by the IPCC to represent the whole range of potential futures [IPCC, 2001].

Coupled ocean-atmosphere GCMs (CGCMs) running on fast supercomputers represent the state of the art for climate modeling science. Within this category of GCM, more than a dozen models exist, developed and used by various research groups around the world [Meehl et al., 2005]. A suite of such models yielded the results presented in Section II(d). Although they agree on warming in the presence of increasing GHG, each model predicts the evolution of global climate a little differently even when forced by the same GHG emissions scenario. To go from any one of these global simulations to useful regional predictions that take topography into account, it's necessary to couple CGCM results to a higher resolution regional climate model. Results from such a simulation are described in Section II(e).

In considering the effect of climate change on water resources in New Mexico, if one were to follow the IPCC approach, one would run a suite of different CGCMs on the selected IPCC marker scenarios, and couple each run to one (or more) regional model(s). The results could reasonably be expected to span the range of future climate uncertainty. That's well beyond the scope of the present study. However, there was a recent model-based study of the impact of climate change on water resources in the West that took a more limited but nonetheless in depth look at the issue [Barrett, 2004]. Although it did not focus specifically on New Mexico, the state was included in the modeling domain so useful information can be gleaned from that study. Called the Accelerated Climate Prediction Initiative (ACPI), the Jan-Feb 2004 issue of the journal *Climatic Change* was dedicated to ACPI results.

In ACPI, a single GCM (the NCAR/DOE Parallel Climate Model [PCM]) was forced by a single emissions scenario, a "Business as Usual" (BAU) scenario, for the 21st century. The BAU scenario was developed before the IPCC 2001 scenarios, but it's close to the mean of emissions assumed in those scenarios. The PCM results were "downscaled" to the western region [Leung et al., 2004] using the Penn State/NCAR (National Center for Atmospheric Research) mesoscale model (MM5). For selected river systems, the results were then used to drive the Variable Infiltration Capacity (VIC) macroscale hydrology model to produce stream flow sequences. For the Colorado River basin (including all of Arizona and parts of California, Nevada, Utah, Wyoming, Colorado and New Mexico), annual predicted runoff was 10% lower for simulated 1995 conditions than for historical averages for 1950-1999. For the periods 2010-2039, 2040-2069 and 2070-2098, simulated annual runoff was 14%, 18% and 17% lower than the historical average [Christiansen et al., 2004]. However, because of the timing of the melt (earlier in the spring) and increased evaporation due to higher temperatures, the Colorado River Model used by the USGS predicts that the cumulative total basin storage in reservoirs for these three periods could be reduced by 36%, 32% and 40% respectively [Figure II-5a].

A very similar approach could be used for the Rio Grande using the PCM and MM5 model runs already done, applying the VIC hydrologic model to this different region, and interpreting the results using a Rio Grande rather than a Colorado River model. Such an effort would be far more relevant to New Mexico. In the absence of such research, however, the work already done on the Colorado is at least indicative. It should be pointed out that the average predictions for the focus periods give no indication of the extremes that might occur. Thus droughts could occur that are far more serious than the averages would suggest. Nor do the results bar extremes on the other end of the spectrum -- floods. Some indication of the range of possible variation can be obtained from the historical record. Between 1906 and 2000, Colorado River annual flow varied between 5.5 million acre feet (MAF) and 25.2 MAF, with an average of 15.3 MAF [Figure II-5b]. Longer term paleoclimate records suggest that the range of possible variation could be much greater yet [Woodhouse et al., 2006].

This section wouldn't be complete without some reference to a climate change scenario which is very different from that discussed above. Model studies have indicated that increasing warming could cause the global ocean currents to reach a "tipping point," and quite suddenly (within a decade or so) cause a drastic change in global climate. The paleoclimatic records from Greenland and Antarctic ice cores indicate that such "flips" have occurred more than 20 times during the last 100,000 years [NRC, 2002]. There is at most an ambiguous indication that such a flip might occur within the planning horizon for water resources in New Mexico [Shiermeier, 2006]. Much less is known about the climate and its potential impact on water resources that might result from such a flip than from the warming scenarios discussed here.

d) Climate predictions for New Mexico using IPCC global climate models

Climate predictions using GCMs from the forthcoming IPCC AR4 assessment [http://www.ipcc.ch] were used to examine potential changes in temperature and precipitation in New Mexico in the 21st century. The models used the Special Report on Emissions Scenarios (SRES) A1B GHG emissions scenario [Nakicenovic et al. 2000; http://www.grida.no/climate/ipcc/emission/index.htm]. The A1B scenario assumes a future world of very rapid economic growth; global population that peaks in mid-century (at approximately 9 billion) and declines thereafter; and rapid introduction of new and more efficient technologies. The A1B scenario has total CO_2 emissions peaking at more than 16 gigatonnes/year (Gt/yr) at mid-century, declining somewhat by the end of the century (Fig. II-6). This results in more than a doubling of pre-industrial atmospheric CO_2 levels by the end of the century. The model experiments included radiative forcing by natural factors, such as changes in solar irradiance and volcanic eruptions, in addition to human-influenced factors such as changes in greenhouse gases and aerosols. The human-influenced factors start with observed data and vary through the course of the 21st century based on the assumptions of the aforementioned A1B scenario.

The average of eighteen GCMs forced by the A1B GHG scenario was used in the projections presented here. As discussed in the previous section, there is no way of determining which models best represent the future. The use of a broad average of many GCMs preserves the richness of variability in the complete suite of models, rather than relying on a subset of models that might show faithful representation of present conditions. The GCMs provide projections at rather coarse spatial resolution, depending on the individual model. Spatial resolutions ranged from 1°-3° in latitude and longitude, or approximately 275 km (170 mi.) per side of grid box at 45°N. The entire state of New Mexico is covered by no more than a dozen (often fewer) grid cells in these models.

Averaging the projections required harmonizing the variety of spatial resolutions in the GCMs by downscaling (statistically interpolating) the data to NOAA climate divisions (http://www.cdc.noaa.gov/USclimate/map.html) for the entire United States. Data were kindly provided by Martin Hoerling and Jon Eischeid of the NOAA Earth System Research Laboratory. The climate division data were then combined to create New Mexico statewide temperature and precipitation averages. Specifics regarding the fourth assessment models and projections can be obtained from the Program for Climate Model Diagnosis and Intercomparison (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php).

The 18-GCM New Mexico statewide average temperature and precipitation projections (henceforth, *GCM statewide averages*) exhibit some biases compared to observed climate records (Table II-1). The GCM statewide precipitation averages are greater than observed overall, particularly in winter. Water year temperatures are slightly warmer, due to relatively high summer temperatures, despite cooler than observed winter temperatures. The model predictions (below) are presented in comparison to the benchmark of the GCM statewide 1971-2000 averages; however, the aforementioned biases indicate model uncertainties that must be taken into consideration. Moreover, as has been shown by others, GCM temperature projections show greater consistency than precipitation projections (Cayan et al., 2006; Dettinger, 2005).

The GCM NM statewide averages suggest substantial increases in temperature by the end of the century (Table II-2), particularly in summer. Projected GCM NM statewide average temperature increases of over 3°C (more than 5°F) are far greater than temperature increases experienced during the period of instrumental record [Fig. II-1b]. Figures II-7 and II-8 show steady long-term upward trends in annual, winter, and summer temperatures. Trends of as little as 0.04°C/year in summer add up to a considerable overall warming by the end of the 21st century. Increases in summer temperature may impact evapotranspiration and soil moisture, as well as energy demand for cooling. The impacts of recurring drought will undoubtedly be exacerbated by temperature increases, as demonstrated during the relatively warm drought of the late 20th century [e.g., Breshears et al., 2005].

Annual precipitation, though characterized by greater uncertainty, is projected to decline by 4.8% (29.3 mm) per year by the end of the 21st century (Table II-2; Fig. II-9). Increases in summer precipitation (up to several mm/yr by mid-century) are more than compensated for by decreases in winter precipitation (and presumably spring and fall precipitation). Precipitation projections for both winter and summer (Fig. II-10) show multi-decadal fluctuations characteristic of ocean-driven variability in the instrumental and paleoclimate records [Brown and Comrie, 2004; Gutzler et al., 2002; Grissino-Mayer and Swetnam, 2000; Ni et al., 2002]. Even given the high uncertainty in precipitation projections, GCM NM statewide temperature changes are probably substantial enough to have a bearing on the overall composition of winter precipitation – snow versus rain. As in other parts of the West, increasing temperatures may also shift the peak of snowmelt-driven streamflow to earlier in the year, with ramifications for the reliability of water resources [Stewart et al., 2005; Jain et.al., 2005].

The aforementioned temperature projections, though expressed at a coarse spatial scale, are reasonably compatible with estimates from the National Assessment of the U.S. Global Change Research Program [USGCRP, 2000]. However, the overall decrease in annual precipitation [Fig. II-9] is at odds with results from the two models selected by the USGCRP. The steep decline in winter precipitation, especially toward the end of the 21st century [Fig. II-10] may reflect a shift in the El Niño-Southern Oscillation phenomenon, due to GHG-induced perturbations in ocean-atmosphere dynamics [e.g., Vecchi et al. 2006]; or it may indicate a tendency for a few overly dry models (e.g., the Australian model; Ron Neilson [Oregon State University] personal communication) to pull the 18-model average down. Given the poor representation of North American monsoon processes in most GCMs [Gutzler et al., 2005], the precipitation projections must be viewed with caution.

e) Climate predictions for New Mexico using a regional climate model

The global models used in the previous section provide large-scale guidance for potential climate change based on a particular choice of future GHG forcing. As noted, global models typically feature relatively coarse horizontal resolution. Section II(c) outlined a strategy for using higher resolution regional models to improve the description of climate change over limited areas. Diffenbaugh et al. [2005] carried out a climate change simulation by embedding such a regional model, called RegCM3, within the NASA FV-GCM global model [Atlas et al., 2005].

This simulation was forced by a different GHG emissions scenario, denoted A2 in Fig. II-6. The A2 and A1B scenarios differ primarily in emissions late in the 21st Century. Of course, both of these scenarios represent guesses and many other scenarios are possible, as discussed in Section II(c). All realistic scenarios include significant increases in GHG concentrations in this century, so the principal qualitative difference in the climate change results is simply timing. Scenarios with higher GHG emissions levels generate faster warming trends and more severe climate changes. Therefore the selection of an emissions scenario mostly affects the dates by which a certain level of warming (or snowpack decline, etc.) is reached.

In the Diffenbaugh et al. [2005] simulation, RegCM3 covers the contiguous 48 United States with a horizontal resolution of 25 km. RegCM3 was run for two time periods: 1961-1985, to represent recent climate, and 2071-2095, to represent climate at the end of the 21st Century associated with the A2 GHG scenario. Selected RegCM3 output fields across New Mexico and southern Colorado for these two time periods were kindly provided by Noah Diffenbaugh of Purdue University. Each of the plots shown here depicts the simulated difference between recent climate (1961-1985) and late 21st Century climate (2071-2095).

Fig II-11 shows the change in temperature across the state of New Mexico for

(a) annual mean conditions,

(b) the summer season (June-August), and

(c) the winter season (December-February).

In this model, the A2 scenario generates annual temperature change between 3°C and 5°C (Fig. II-11a), with the magnitude of temperature change increasing inland (toward the north). Recall that observed 20th Century temperature change across the state since the 1960s has been about 1.5°F (Figs. II-1 and II-2), which is somewhat less than 1°C. Therefore this simulation indicates that the relatively rapid warming observed over the past several decades will continue at a greatly accelerated rate during the 21st Century. Spring season results are similar to winter, and fall season is similar to summer (these results not shown).

Precipitation changes for the annual mean, summer and winter (Fig. II-12) are modest compared to temperature changes. The annual average change is generally not statistically significant (Fig. II-12a). The near-zero annual mean change in this simulation results from a slight decrease in summer rainfall (Fig. II-12b) and an offsetting increase in winter precipitation (Fig. II-12c). Other model simulations of 21st Century climate show precipitation changes of different sign, as discussed in Section II(d). Thus, the most predictable climate change in New Mexico forced by increasing GHG is a strong temperature trend toward warmer conditions, not a systematic change in total precipitation one way or another.

As shown in Fig. II-11b, the greatest warming in this simulation occurs in the summer season (consistent with the global model predictions shown in Fig. II-8), with temperature change exceeding 5°C in northeastern New Mexico. Winter warming is considerably less (between 2° and 4°C in Fig. II-11c), with greatest warming in northwestern New Mexico. One consequence of pronounced summer temperature increase is an increase in both the magnitude and length of extreme heat waves, as described by Diffenbaugh et al. [2005]. In this report we emphasize the effects of climate change on water resources, assuming broadly that precipitation variability from year to year is similar to the current climate, including intermittent drought episodes. Water resources in New Mexico would be greatly affected by the warming trend illustrated in these RegCM3 (and other) simulations, even in the absence of significant precipitation change, because more winter precipitation falls as rain instead of snow, and soil moisture decreases, especially in spring and summer.

The magnitude of winter warming has profound consequences for snowpack throughout the interior of western North America. Fig. II-13 shows the change in snowpack (expressed in mm H_2O content, commonly referred to as "Snow Water Equivalent" or SWE in observed data) for:

(a) New Mexico, March 1 average,

(b) New Mexico, April 1 average, and

(c) eastern Utah/western Colorado, April 1 average.

The current average date of maximum snowpack in southern New Mexico is around March 1, while snowpack in northern New Mexico and southern Colorado typically reaches its maximum around April 1. Examination of the mean snowpack fields from the model (not shown here) indicate that the solid blue color across New Mexico in climate change panels (a) and (b) can be interpreted to mean that spring snowpack is, on average, nonexistent south of about 36°N in the late 21st Century. In other words, the late 21st Century climate in this simulation includes no sustained snowpack south of Santa Fe and the Sangre de Cristo range.

Snowpack remains in far northern New Mexico and southern Colorado (the headwaters region of the Rio Grande), but is greatly reduced in mass by the end of this century. The April 1 climate change in Fig. II-13c shows reductions in April 1 SWE of 50-200 mm H_2O, compared to an average in the 1961-1985 simulation of 100-300 mm H_2O across the San Juan mountains, i.e. a decrease in water mass between one-third and one-half. Some of this decrease results from earlier snowmelt, and some from higher freezing altitude (snow line) during the winter. Spring runoff into rivers and reservoirs is likely to be drastically reduced by the late 21st Century.

Soil moisture changes are most pronounced in the spring (March-May) season, shown in Fig. II-14. The largest changes are seen in northwest New Mexico, where the upper layer soil moisture content decreases by 5 mm H_2O or more, a decrease of about 20% relative to the 1961-1985 simulation. This change is associated with the decrease in snowpack in the springtime. Soil moisture in the summer season also decreases but less in absolute terms, because soils are dry then even in the current climate.

Evaporation from the surface decreases in the summer season (June-August) in this simulation, shown in Fig. II-15. The red colors represent increased rates of evapotranspiration (ET) of 0.5 mm/d, which is a reduction of 25% or more relative to current ET rates simulated by the model. This is the result of drier soils and less summer rainfall, and (as noted by Diffenbaugh et al. [2005]) produces a positive feedback on summer temperature increases by reducing the surface cooling effect of evaporation. Interpretation of evaporation changes in this model must be tempered with a significant caveat: the model does not include interactive vegetation, so long-term changes in vegetation that may result from significant climate change are not included in the results [Diffenbaugh et al., 2005].

There are several points worth noting concerning the evaporation changes simulated by the model. First, as discussed above, reduced summer ET simulated by the model is associated with drier surface conditions. Where the surface is not dry (such as the water surface of a reservoir), evaporation rates are certain to *increase*, not decrease, under the 21st Century climatic conditions simulated by this model. Thus depletion of water resources by evaporation from reservoirs would increase. Second, the change in average climate simulated here would greatly increase New Mexico's vulnerability to recurring drought episodes. Drought conditions (such as the state experienced in the winter and spring of 2006) exacerbate the surface dryness that RegCM3 simulates as a mean condition in the late 21st Century. Warmer temperatures, more extreme heat waves, and a drier surface would make drought episodes more extreme in the changed climate.

The regional climate changes simulated by RegCM3, if realized, would have profound, seasonally varying consequences for the hydrologic cycle across New

Mexico. In the cold season (winter and spring), snowpack would be reduced drastically even if total precipitation stays the same or increases somewhat -- and model predictions include the possibility of a reduction in winter precipitation. In the warm season, warmer temperature and drier land surface conditions would raise evaporation rates off open water surfaces and increase vulnerability to drought cycles. These statements remain valid despite continuing uncertainty concerning long-term climatic trends in total precipitation rates in both winter and summer.

Acknowledgements. Jon Eischeid and Martin Hoerling (NOAA Earth System Research Laboratory) provided the IPCC projection data (Fig. II-7 to II-10) and shared insights regarding global climate model output. Ben Crawford (Climate Assessment for the Southwest, University of Arizona), put together several of the IPCC projection figures. Noah Diffenbaugh (Purdue University) generously provided regional model projection figures (Figs. II-11 to II-15).

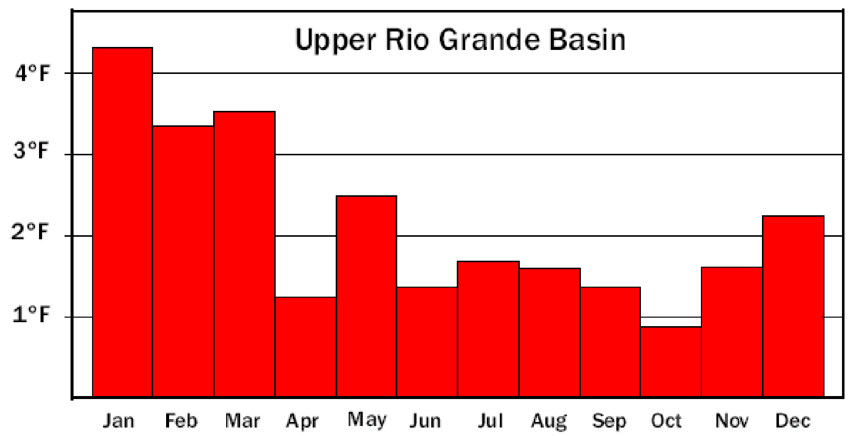
Table II-1. Differences between observed (Obs.) and 18-model average temperature (TEM) and precipitation (PPT) for the water year (WY; October-September), winter (DJF; December-February), and summer (JJA; June-August), for the period 1971-2000.

Variable	Obs (in./°F)	Obs (mm/°C)	Model (mm/°C)	Bias (mm/°C)	Bias (in./°F)
WY PPT	14.5 in.	368.6 mm	601.0 mm	232.4 mm	9.1 in.
WY TEM	53.5°F	11.9 C	12.2°C	0.3°C	0.5°F
DJF PPT	2.0 in.	51.8 mm	127.9 mm	76.1 mm	3.0 in.
DJF TEM	36.1°F	2.3°C	0.7°C	-1.6°C	-2.9°F
JJA PPT	6.1 in.	156.0 mm	191.4 mm	35.4 mm	1.4 in.
JJA TEM	71.4 F	21.9°C	24.1°C	2.2 C	4.0°F

Table II-2. Changes in temperature and precipitation between the 30-year model reference period (1971-2000) and projections for 30-year periods.

	1971-2000	2001-2030 (change)	2031-2060 (change)	2061-2090 (change)
WY TEM (°C)	12.2	13.1 (+0.9)	14.3 (+2.1)	15.5 (+3.3)
DJF TEM (°C)	0.6	1.4 (+0.8)	2.3 (+1.7)	3.4 (+2.8)
JJA TEM (°C)	24.1	25.2 (+1.1)	26.5 (+2.4)	27.8 (+3.7)
WY PPT (mm)	601.0	590.0 (-11.0)	589.4 (-11.6)	571.7 (-29.3)
DJF PPT (mm)	127.9	127.0 (-0.9)	125.8 (-2.1)	122.4 (-5.5)
JJA PPT (mm)	191.4	189.6 (-1.8)	195.5 (+4.1)	193.0 (+1.6)

Figure II-1a: Average Monthly Temperatures in 1995-2004 in the Upper Rio Grande Basin, compared to 1961-1990 average values. [RMCO 2005]



Data from the climate division series, National Oceanic and Atmospheric Administration. Analysis by the Rocky Mountain Climate Organization. Historical average monthly temperatures are from the period 1961-1990.

Figure II-1b: Five-Year Average Temperatures, 1895 to 2004, compared to Historical Averages [RMCO 2005]

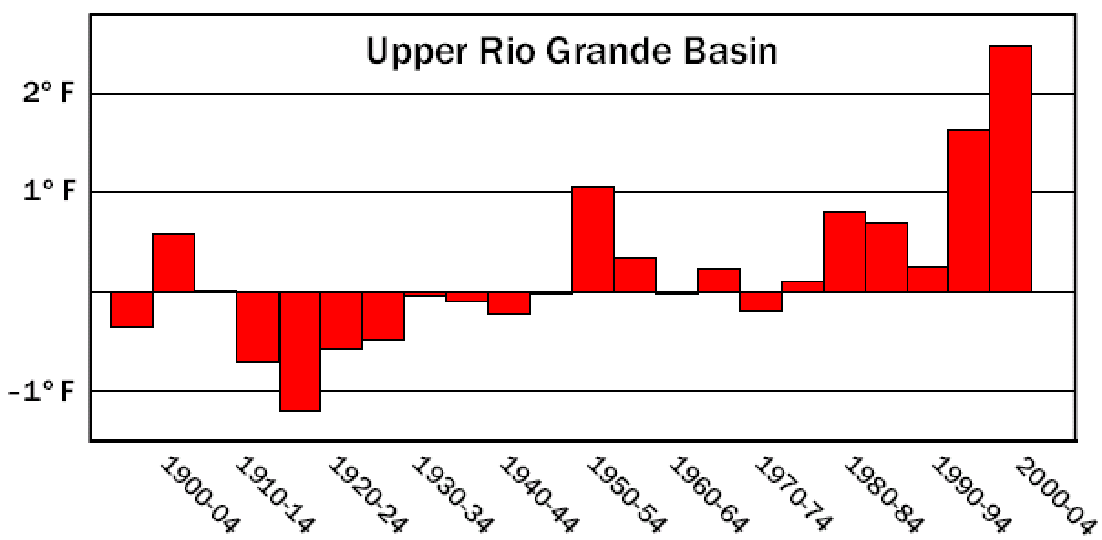


Figure II-2: Possible effects of warming on snowline in higher elevations [Gleick et al., 2000].

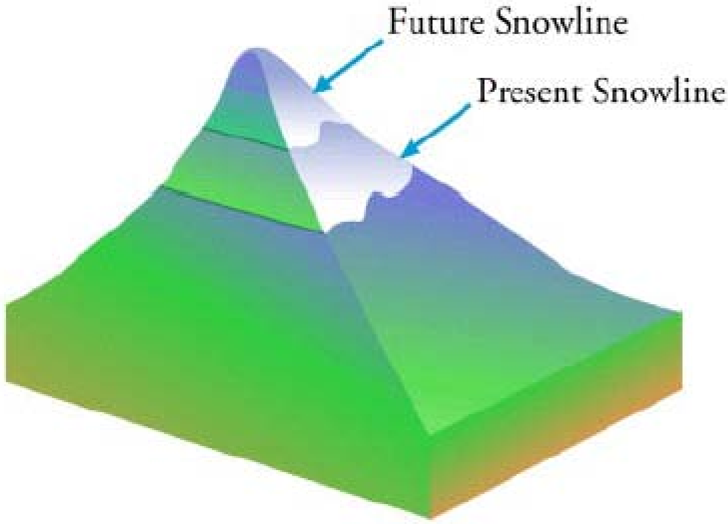


Figure II-3: Percentage change from the 1961-90 baseline in the April 1 snowpack in four areas of the western US as simulated for the 21st century by the Canadian and Hadley models. [USGCRP, 2000]

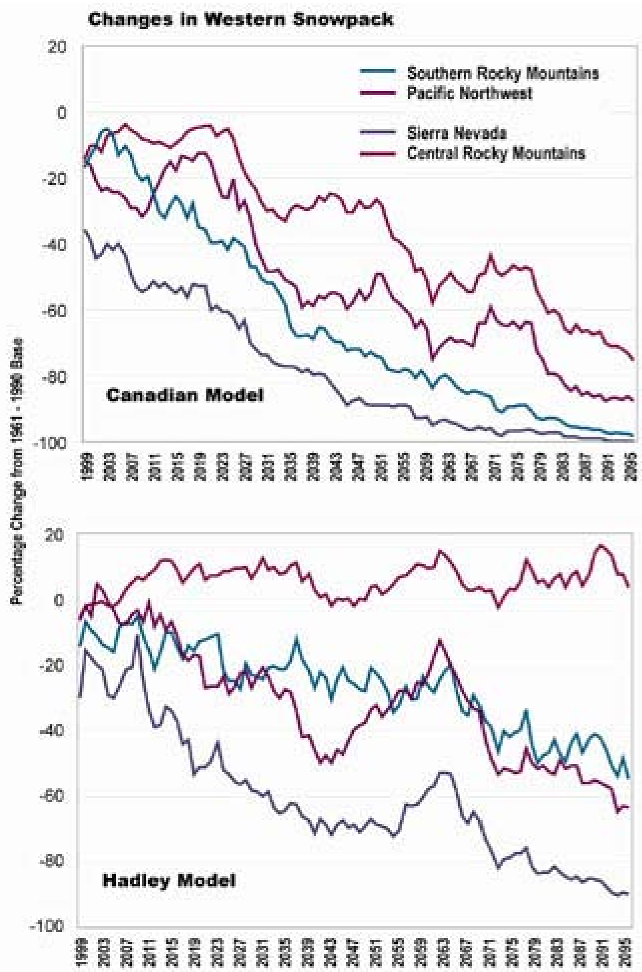


Figure II-4: Precipitation time series for the past millennium for New Mexico Climate Division 2 (north central New Mexico, including the upper Rio Grande Valley). The time series is based on tree ring data within Division 2, and values are expressed as percentage departures from the 1000-year average (thick black line). Average values for three recent decades -- 1983-1993 (a wet period), 1946-1956 (a dry period), and 1996-2006 (the most recent decade) -- are shown as light blue, red, and green lines, respectively.

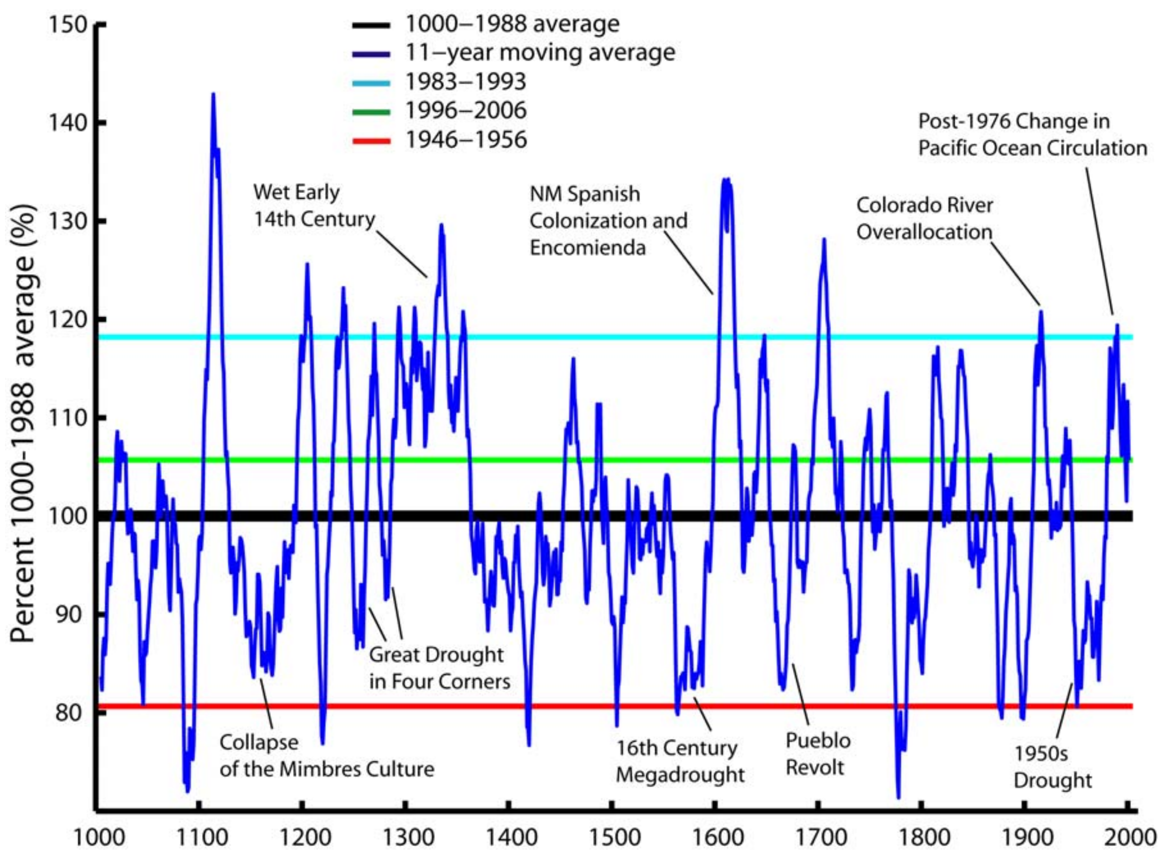


Figure II-5a: Projected changes in average total Colorado River Basin reservoir storage, for downscaled climate simulations of the U.S. Department of Energy/National Center for Atmospheric Research Parallel Climate Model (PCM) based on projected 'business-as-usual' (BAU) greenhouse gas emissions and a control climate simulation based on static 1995 greenhouse gas concentrations, and an ensemble of three 105-year future climate. Simulations for three time periods, and a comparison with observed historical (1950–1999) climate.

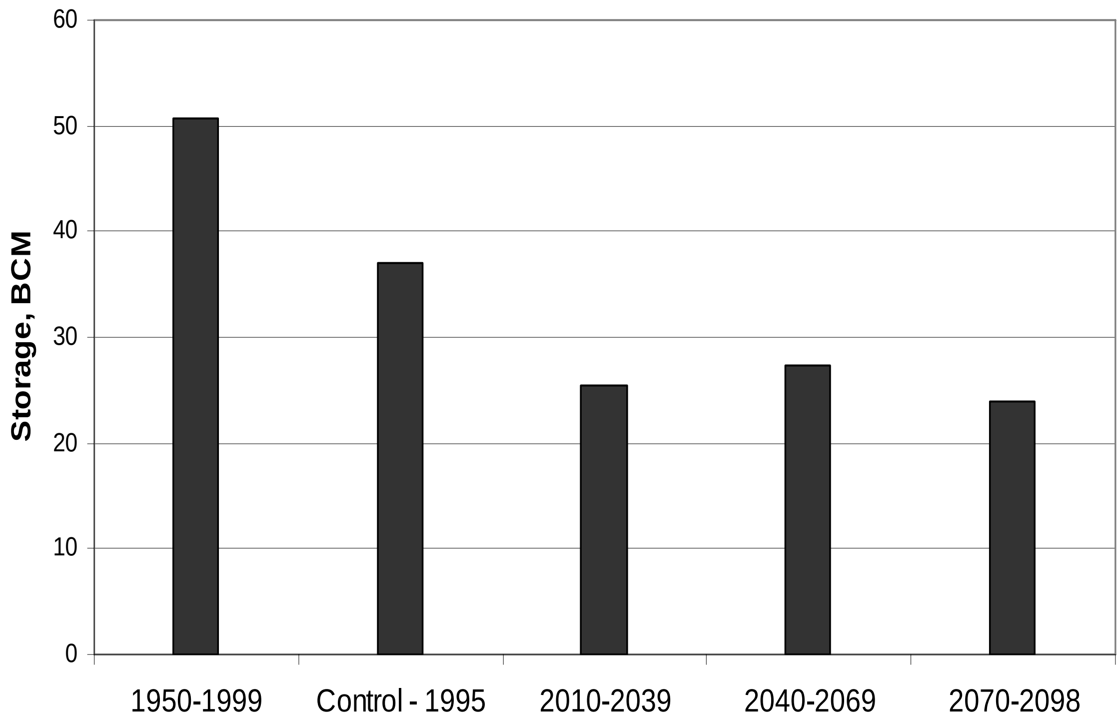


Figure II-5b: Colorado River Basin water year (October-September) annual flow, 1906-2000. Average flow for the period is 15.3 million acre-feet (MAF). The lowest flow in the record is 5.5 MAF in 1977 (Oct. 1976-Sept. 1977); the highest flow in the record is 25.2 MAF in 1984 (Oct. 1983-Sept. 1984). Data courtesy of Dave Meko (University of Arizona) and Jim Prairie (U.S. Bureau of Reclamation).

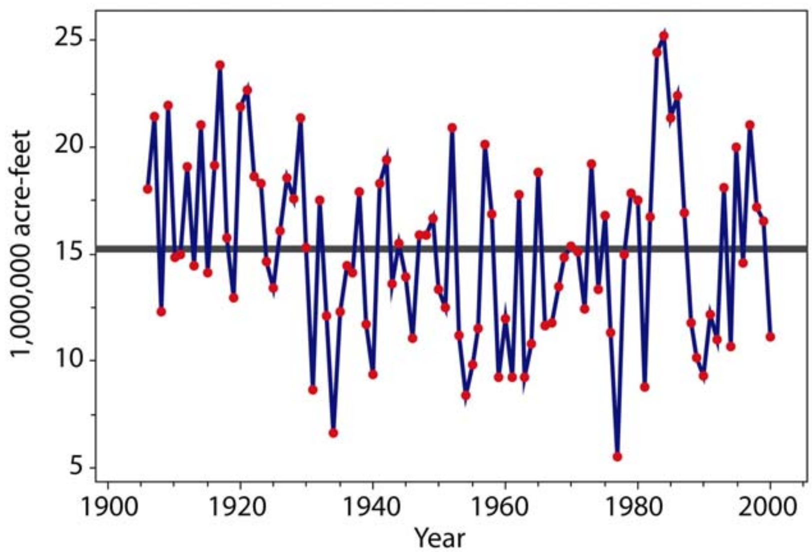


Figure II-6: IPCC Special Report on Emissions Scenarios CO_2 assumptions for the 21st century. The atmospheric CO_2 concentrations associated with particular emissions scenarios, shown in this plot, are generated by a carbon cycle model. SRES A1B (green line), the scenario used in IPCC 4th Assessment Report projections shown in this section, describes a future world of very rapid economic growth; global population that peaks in mid-century and declines thereafter; new and more efficient technologies are rapidly introduced. SRES A2 (red line), used in the regional model simulation described in section II(e), is similar during the first half of the 21st Century but assumes a higher emissions rate late in the century. Other scenarios (such as B1, the blue line shown here) provide different guesses for 21st Century GHG emissions. Still other, unrealistic scenarios (such as the orange curve assuming no increase at all in CO_2 concentration in the future) are developed by the IPCC for comparison purposes.

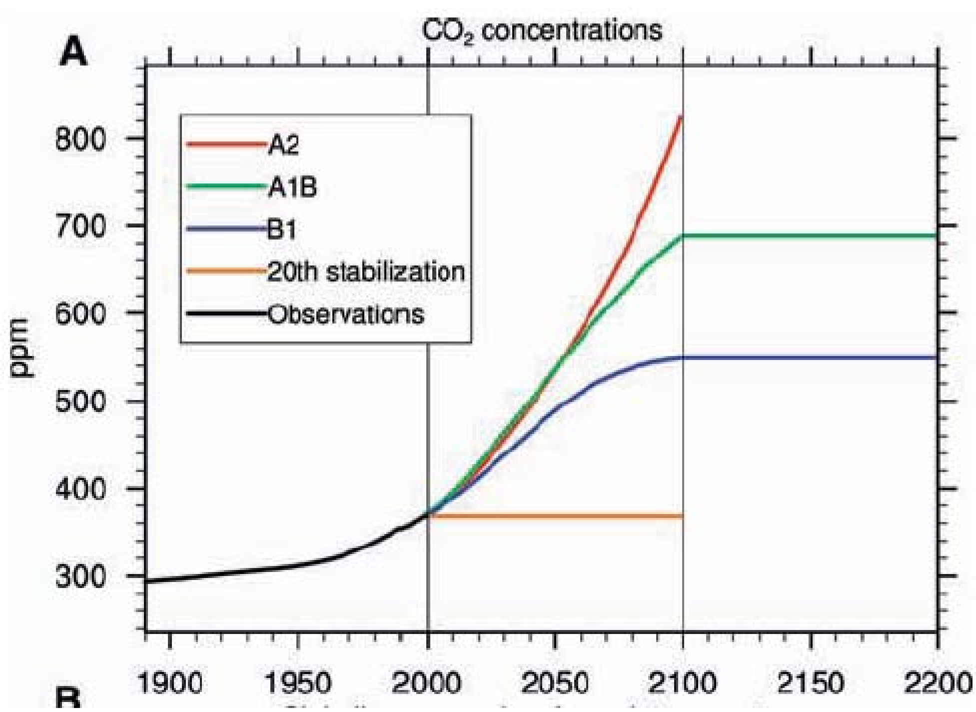


Figure II-7: New Mexico water year (October-September) annual temperature projections compared with model climatology (1971-2000).

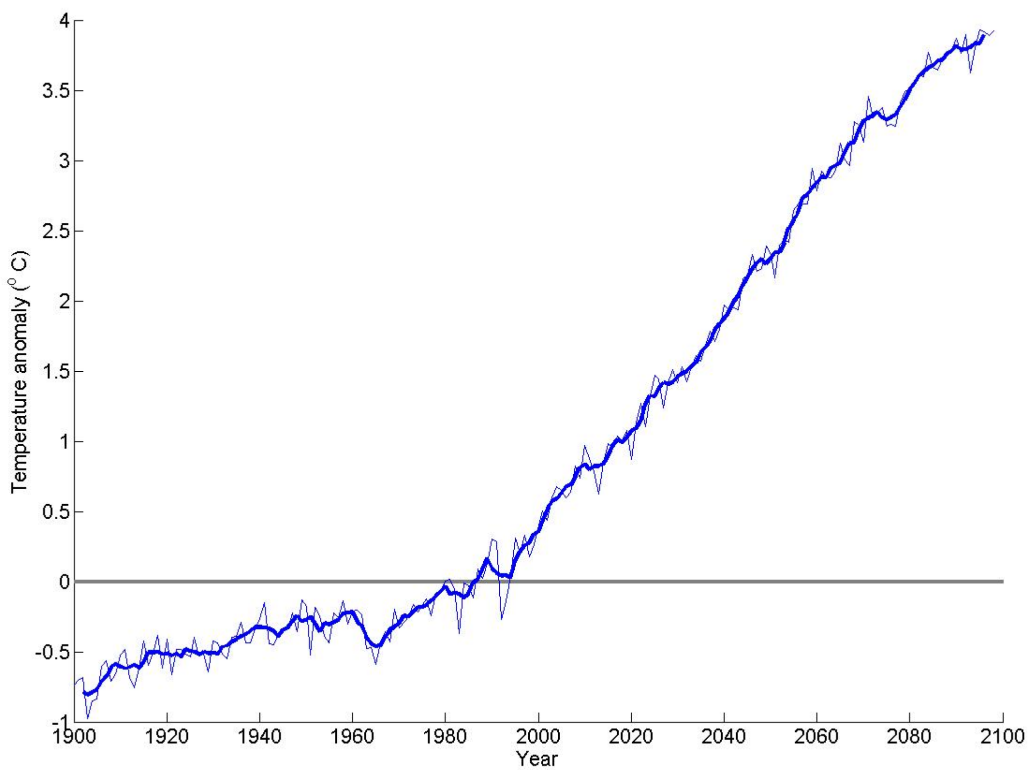


Figure II-8: Simulated New Mexico seasonal temperature changes in the 21st Century for summer (red line; June-August) and winter (blue line; December-February), compared with model climatology (1971-2000).

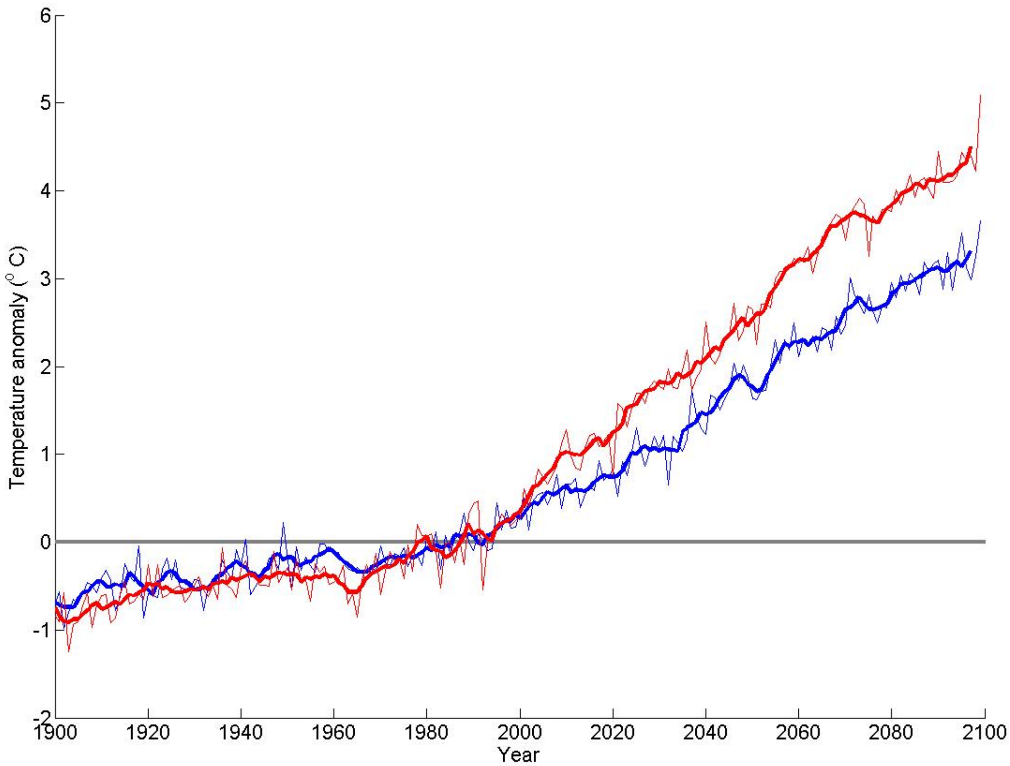


Figure II-9: New Mexico water year (October-September) annual precipitation projections compared with model climatology (1971-2000).

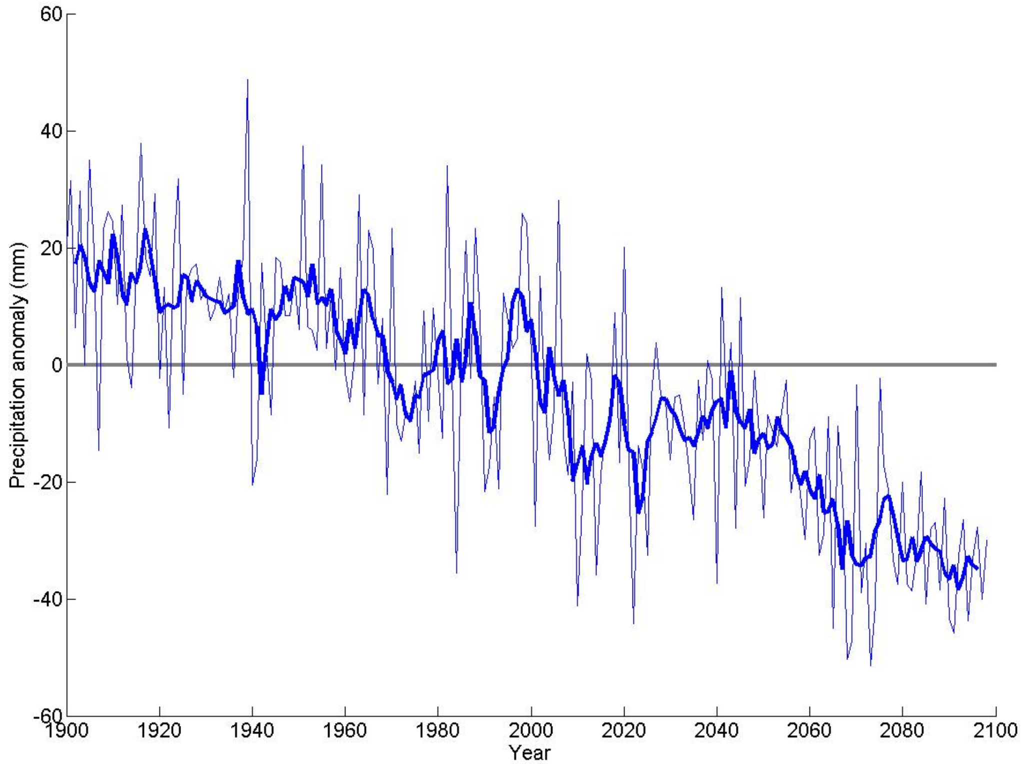


Figure II-10: Simulated New Mexico seasonal precipitation changes in the 21st Century for summer (top, red line; June-August) and winter (bottom, blue line; December-February), compared with model climatology (1971-2000).

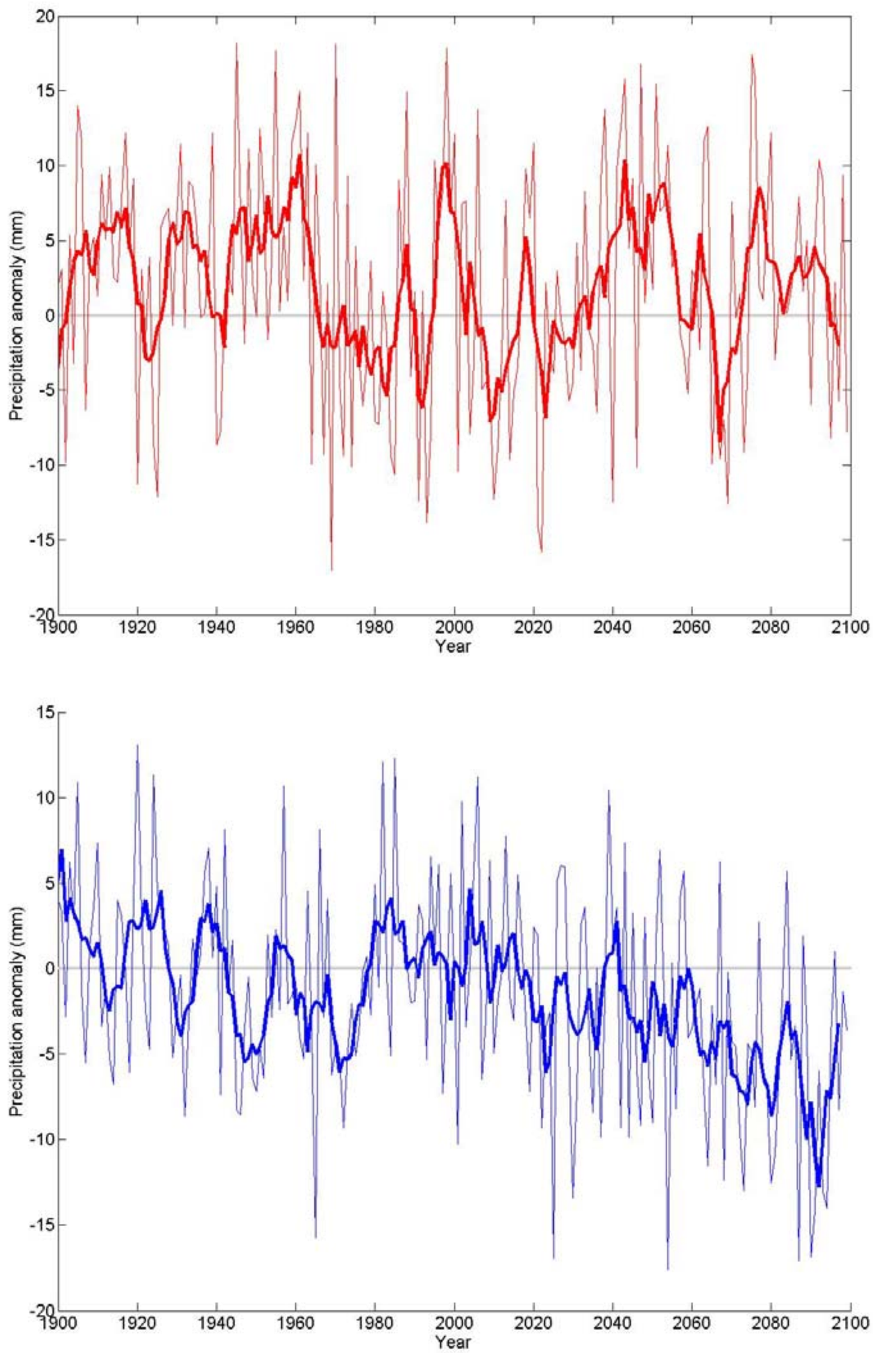


Figure II-11: Simulated change in temperature (°C) from 1961-1985 to 2071-2095 across New Mexico for (a) annual mean (b) summer (June-Aug) (c) winter (Dec-Feb). [Diffenbaugh et al., 2005]

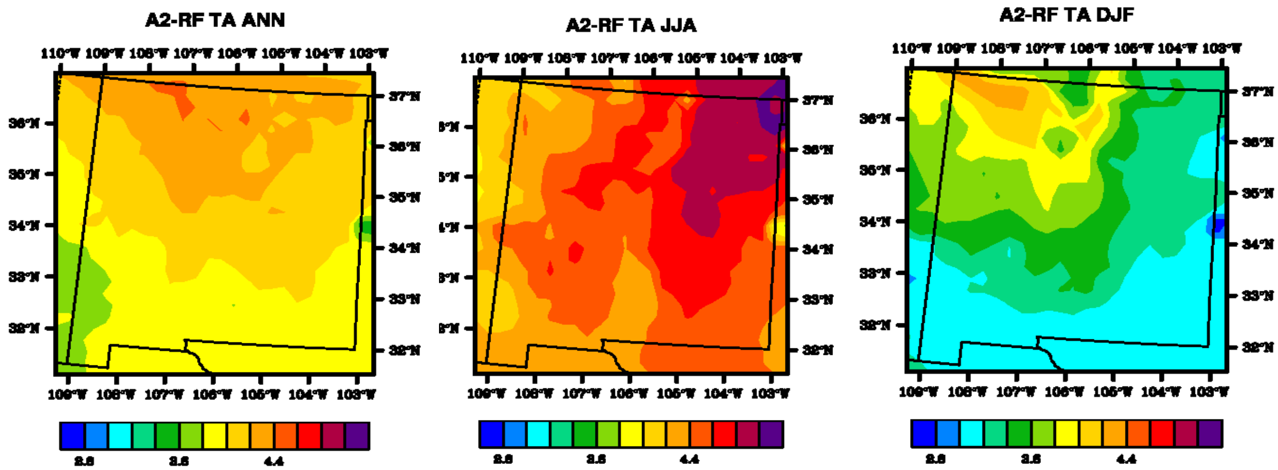


Figure II-12: Simulated change in average precipitation rate (mm/day) from 1961-1985 to 2071-2095 across New Mexico for (a) annual mean (b) summer (June-Aug) (c) winter (Dec-Feb). [Diffenbaugh et al., 2005]. Note that a change of 1 mm/day corresponds to about 14 inches of precipitation accumulated over the course of a year (panel a) and about 3.5 inches for an individual season (panels b and c)

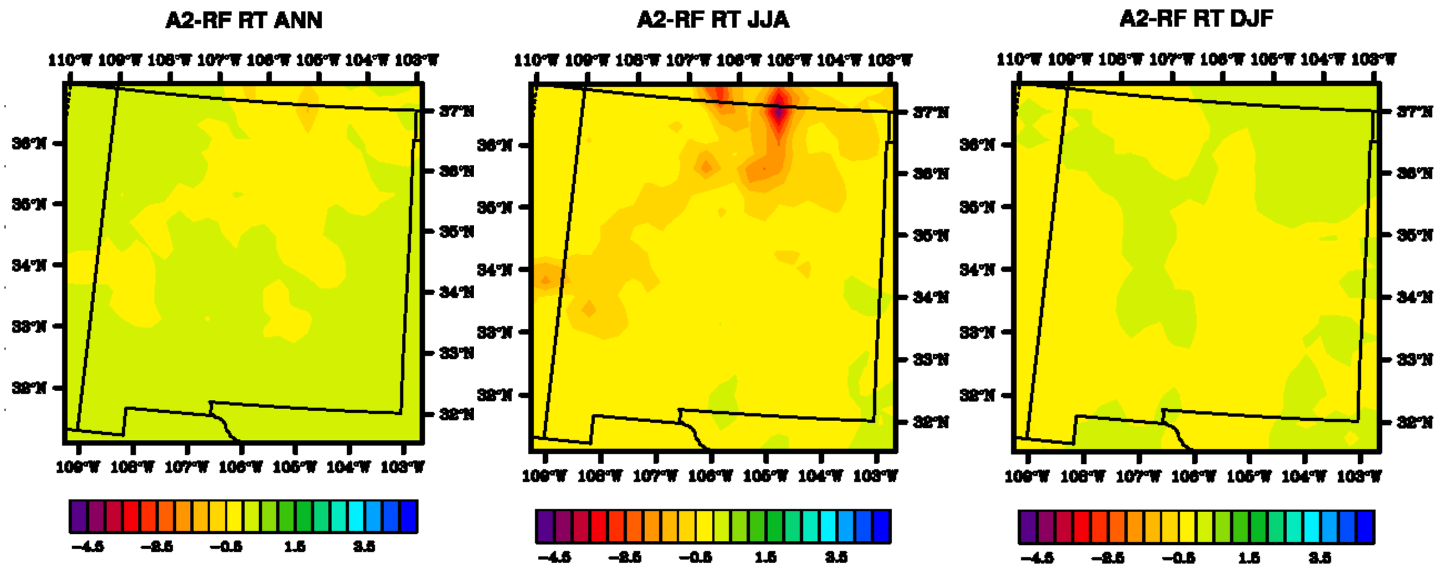


Figure II-13: Simulated change in average snowpack (mm water content in snow) from 1961-1985 to 2071-2095 [Diffenbaugh et al., 2005] for

(a) state of New Mexico on March 1 each year

(b) state of New Mexico on April 1 each year

(c) eastern Utah/western Colorado/southwestern Wyoming on April 1 each year.

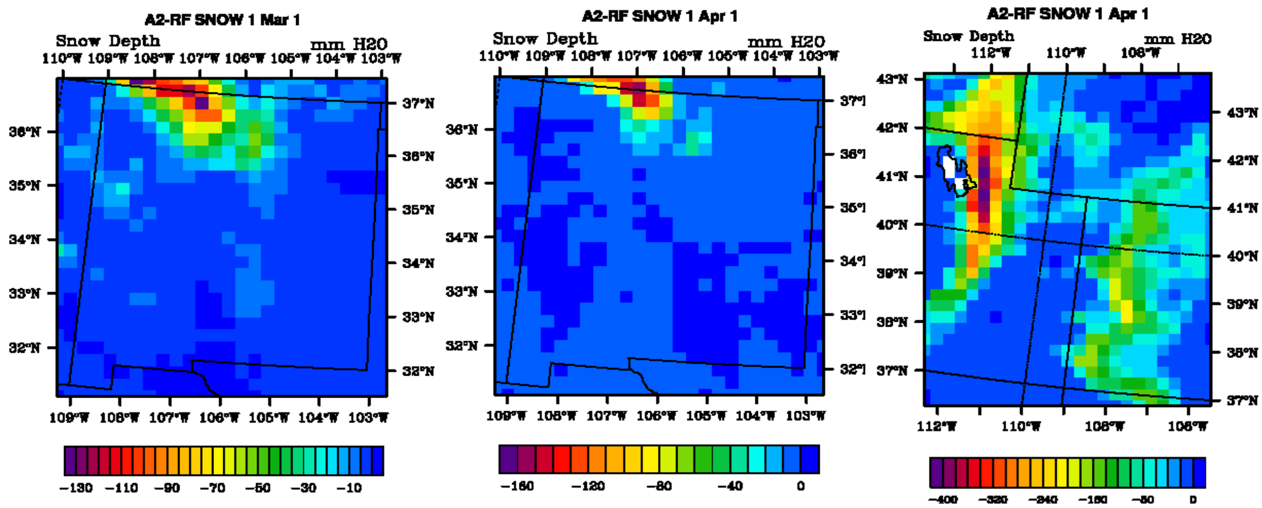


Figure II-14: Simulated change in spring season soil moisture (mm water content in soil averaged from March through May), from 1961-1985 to 2071-2095 [Diffenbaugh et al., 2005].

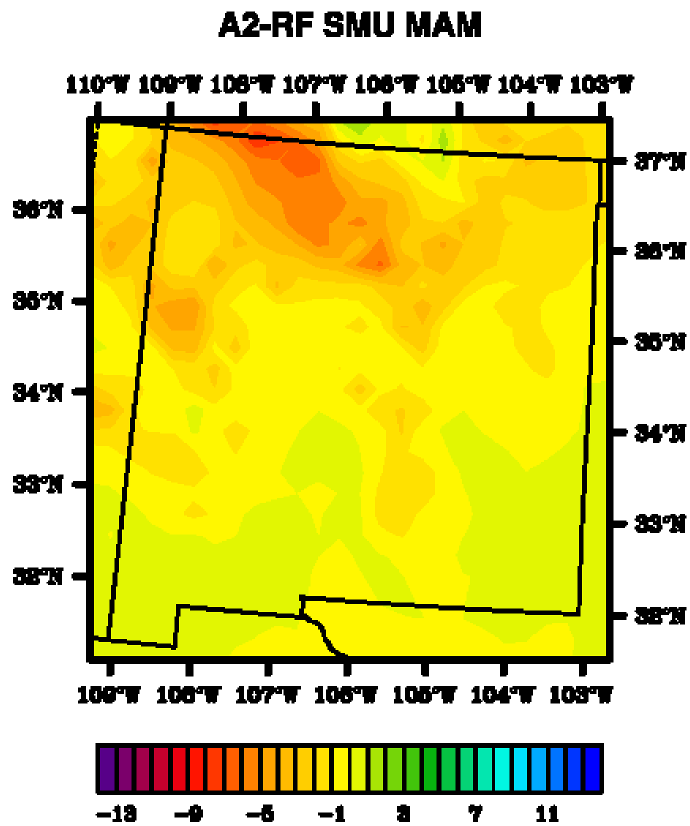
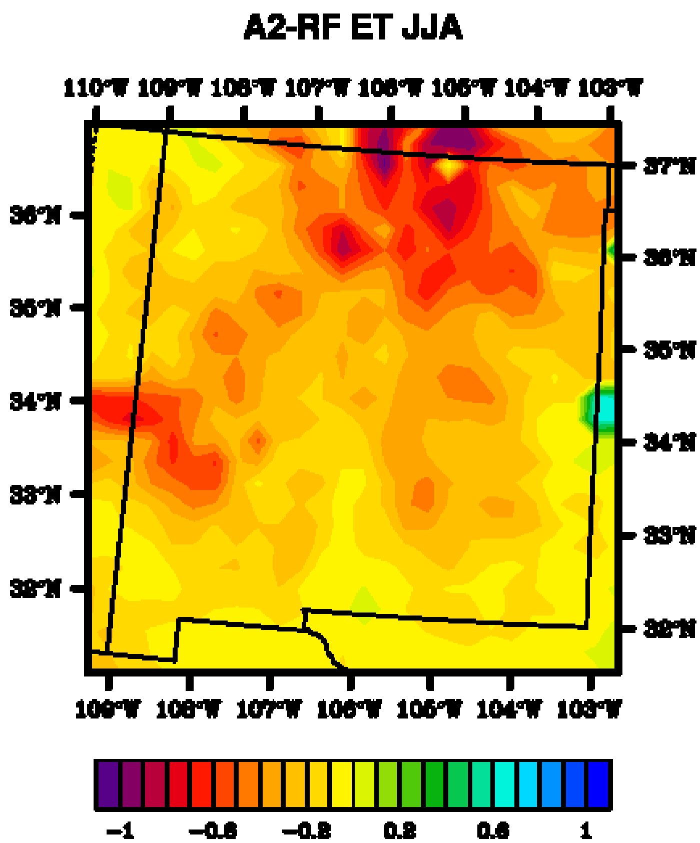


Figure II-15: Simulated change in summer season soil evapotranspiration (mm/day averaged from June through August), from 1961-1985 to 2071-2095 [Diffenbaugh et al., 2005].



III. INTEGRATING CLIMATE CHANGE INTO WATER RESOURCE MANAGEMENT

a) Introduction

Climate change has been discussed primarily at the global scale, and the primary focus of public attention and policy efforts has prudently been on the urgent need for GHG emissions reduction (mitigation) strategies. However, "recognition is increasing that the combination of continued increases in emissions and the inertia of the climate system means that …even if extreme measures could be instantly taken to curtail global emissions, the momentum of the earth's climate is such that warming cannot be completely avoided." [Easterling, 2004] Therefore, even if CO2 emissions were halted tomorrow, warming will likely persist throughout this century and some degree of adaptation will be necessary. While ***mitigation*** strategies are necessary to reduce the likelihood or severity of adverse conditions, ***adaptation*** strategies will be a necessary compliment to reduce the severity of potential impacts.

b) Climate change and water planning

Climate change has historically had difficulty getting on the agenda of many public and private institutions. The challenge of uncertainty (addressed below) with the resulting difficulty in assessing vulnerabilities, and the limited research and modeling available at the regional or watershed scale, has also been a disincentive. [Climate Impacts Group, 2005] Down-scaling techniques are improving the specificity and accuracy of smaller scale impacts and should support planning at the local level, where the impacts will be felt most acutely and at which adaptive management strategies will need to be designed and implemented. [Hurd, 2006]

Policy makers and managers are also constantly juggling multiple issues of immediate importance and have limited time and resources to take on what appears to be a "new" issue. Climate change is often viewed as one of those issues that can be addressed later when there is more certainty about what is really happening. However, many of the adaptive strategies required to address impacts of climate change will require years to plan and implement, and delaying may increase both vulnerability and ultimately the costs of mitigating those impacts. Often the tools needed to develop adaptive capacity for climate change are the same or similar to those used in current management practices. [Gleick, 2000]

To date, only a few states and local governments in North America have begun to address the impact of climate change on water resources, primarily in the Pacific Northwest due to the predicted dramatic decrease in snowpack coupled with rising ocean levels and potential salt water intrusion. British Columbia has a comprehensive climate change plan that includes both strategies and resource allocation. [British Columbia, 2004] Seattle has a strong climate protection initiative [www.seattle.gov/environment/climate_protection], as does Portland [Palmer, 2002]. California has also taken a very aggressive approach to climate change. Its 2005 State Water Plan update addresses climate change “qualitatively,” with the stated intent to address it quantitatively in the 2010 update as well as to provide regular updates to the Governor and Legislature. [California Department of Water Resources, 2005 and 2006] While these planning efforts incorporate climate change models and assess impacts, adaptation strategies are essentially still in the developmental stage.

New Mexico’s STATE WATER PLAN (SWP) does not specifically address climate change. However, the SWP does comprehensively describe at the policy and strategy level many of the tools that will be needed to manage the State’s water resources under a variety of conditions, including those resulting from climate change. WATER 2025 also identifies the most promising tools for dealing with the challenges to western water management, many of which are similar to or will be exacerbated by climate change. [USDOI, 2005] Thus the foundation has already been laid for incorporating climate change as an additional element to the planning process.

c. The challenge of uncertainty and confidence bounds

> *“Prediction is very hard, especially when it’s about the future.”*
> *Yogi Bera*

Climate change is impossible to predict with certainty, as is the weather or severity or durations of drought. “Climate varies for multiple reasons, all operating at once, many of which we do not understand well, some of which we may only suspect, and others that we simply don’t know…[which have] to be disentangled all at once from a relatively short record of 50 years of good three-dimensional observations and a little over a century of surface observations.” [Redmond, 2002] Climate is based on land and atmospheric interactions that create a chaotic system, where feedbacks are highly variable and the processes that affect the system at times behave in a non-linear manner. Uncertainties arise from attempts to predict exactly what climate changes will occur in various local areas of the Earth, and what the effects of clouds will be in determining the rate at which the mean temperature will increase. [CaEPA, 2006] “Paradoxically, to understand the driest climates in North America…we cannot fully understand the climate of the Southwest, and how and why it varies, unless we understand the climate of the entire world.” [Redmond, 2002]

Tree ring data also indicates that the Southwest has in the past experienced climate swings, including long- term severe drought. [Redmond, 2002] “Future unexpected, large and rapid climate system changes (as have occurred in the past) are, by their nature, difficult to predict. This implies that future climate changes may also involve ‘surprises’. In particular, these arise from the non-linear, chaotic nature of the climate system...” [IPCC, 1995]

“Reducing uncertainty in climate projections also requires a better understanding of the non-linear processes which give rise to thresholds that are present in the climate system. Observations, palaeoclimatic data, and models suggest that such thresholds exist and that transitions have occurred in the past … Our knowledge about the processes, and feedback mechanisms determining them, must be significantly improved in order to extract early signs of such changes from model simulations and observations.” [IPCC, 2001]

Uncertainty is inherent to the climate system and cannot be eliminated. However, delaying until all uncertainties are resolved is not viable because some uncertainties will always remain. For example, the degree of impact greenhouse emissions will have on future climatic conditions depends on future decisions and actions by governments and individuals.

“When uncertainty precludes conventional scientific analysis, yet quantitative estimates are needed for use in analysis, it is sometimes possible to obtain the judgments of experts in the form of probability distributions.” [NRC, 1999]

---*Quantitative* assessments of confidence levels [Figure I.1] are representations of researchers’ degree of belief in the validity of conclusions, based on collective judgment, observational evidence, modeling results, and theory examined [Gleick, 2000].

---In providing *qualitative* assessments on the state of knowledge, researchers evaluate the level of scientific understanding supporting a conclusion and utilize four classifications: Well-Established, Established but Incomplete, Competing Explanations, and Speculative.

Figure I.1. Confidence Levels for Assessing the Validity of Research

Very High	95% or greater
High	67-95%
Medium	33-67%
Low	5-33%
Very Low	5% or less

Source: Gleick, 2000.

These quantitative and qualitative assessments of confidence levels can be incorporated by users depending on the specifics of each decision making situation. [Hartmann et. al, 2003] While this environment of uncertainty is complex, climate scenarios developed from modeling are the best available scientific information about the probable effects of global warming. These tools, coupled with confidence assessments, provide information to support water resource managers and policy makers in the decision making process.

The uncertainty acknowledged by modelers and researchers when projecting climate change includes difficulties in forecasting forcing scenarios, modeled responses to forcing scenarios, and uncertainty caused from missing or misrepresented physical processes in models. Research has shown that better prediction information is developed through feedback between predictions and experience rather than from introducing more sophisticated predictive methods [NRC, 1999]. The processes involved will be iterative, where modelers provide information to decision makers, feedback assessments on the effectiveness of decisions will be provided to both the decision makers and modelers by water managers. It is through adaptive adjustments during this interchange that water managers can document improvements and provide decision makers and researchers with better information.

d) Risk management

The every day decisions made by water managers are based on conscious or unconscious risk assessment, where risk is defined in terms of the probability of a particular climatic outcome multiplied by the consequences of that outcome. Consequences will not necessarily vary in direct proportion to the magnitude of climate change due to the possibility of abrupt changes. While New Mexicans are experienced in dealing with climate variability, human-induced climate change is likely to take us outside the range of previous experience and thus require new strategies to cope with emerging situations that cross over previous management thresholds. Decision-makers are regularly called upon to make decisions based on uncertainty (e.g., assumptions about population growth or economic development) with an overall goal of managing future risk from a variety of different factors. Given the scientific uncertainties about the magnitude, timing, rate and local/regional consequences of climate change, water managers will need to determine appropriate responses within a framework that allows for adaptation to new data and changing conditions. [USCRS, 2006]

Climate forecasting raises ethical and legal issues for scientists that relate to risk management. Ethical questions can relate to when and how to issue forecasts, how to deal appropriately with uncertainty, how forecast skills should be developed to achieve an appropriate distribution of benefits, and how ethical beliefs (e.g, concerning the rights of nonhuman species or equity among human populations) do and should affect the development, presentation, and dissemination of forecast information. Legal research questions include assessing case law regarding responsibility for climate, weather, and analogous forecasts as well as the treatment of scientific uncertainty in the legal system, the relationship between impacts and liability settlements, and the role of legal institutions (e.g. water and property rights) in coping with climatic variability and climate forecasts [Stern,1999]

With respect to the onset of global climate change, two schools of thought have emerged regarding the adaptive capacity of water resources and water systems. The first believes that water managers already have the necessary tools to cope with climatic change and argue that key responses to climate change are virtually the same as to existing variability: that is, to upgrade supply-side and demand-side measures and add flexibility to institutions to better cope with social and environmental changes. [Schilling and Stakhiv, 1998]

The other school, however, attaches greater significance to the changing fundamentals being introduced to the climate system. A shift in the climate ‘paradigm’ increases the uncertainty. No longer can the historical record be relied upon to guide the design, construction, and planning of water projects. This school has less confidence that sufficient time and information will be available prior to the onset of significant or irreversible impacts. Proponents of this view argue that “complacency on the part of water managers may lead to the failure to anticipate impacts that could be mitigated or prevented by actions taken now.” [Gleick, 2000]

Policy and managerial responses need not (and should not) wait for better climate predictions. It is already clear that temperatures are rising and that extreme events are becoming more common, so assessing the vulnerabilities of existing management strategies and resource availability given those impacts can proceed without certainty about changes in precipitation. A close look at risk, even without firm quantification, can often lead to optimal solutions that may not be immediately apparent and that may avoid expensive missteps. [Orange County, 2004] Water resource managers already operate within a context of uncertainty about economics, demographics, water supply availability, and other conditions. Climate change is thus not a stand alone issue. It will add an additional layer of uncertainty to the complexity of water resource management in addition to population growth, land use, economic development, species protection, ecosystem demands, and other “change drivers” including peak oil. Managers will thus need robust and resilient planning scenarios and processes, and highly adaptive management structures, to adapt to changing predictions. [Hurd, 2006]

e. Adaptive management

Adaptive management strategies are appropriate to consider across the range of sectors potentially affected by changes in water resource conditions. Furthermore, these strategies can take different forms depending on the degree to which they either take a ‘wait and see,’ reactive stance or an anticipatory perspective in which potential future conditions are taken into account in system planning and design.

In considering the nature and extent of possible climatic changes, reacting to changed conditions can be ultimately more costly than making forward-looking responses that anticipate likely future conditions and events. This is an important consideration, especially with respect to long-lived assets, infrastructure, and institutions such as bridges and dams, settlement and development in water-stressed regions, interstate compacts, urban water reuse and recycling capacity etc., which may be subject to catastrophic consequences as a result of inadequate consideration in design and planning. Such a reactive, “wait-and-see” approach would be particularly unsuccessful in coping with:

- Long-lived investments and infrastructure that may be costly or prohibitive to change in response to climate change;
- Irreversible impacts, such as species extinction or unrecoverable ecosystem changes; and

- Unacceptably high costs and damages, for example, inappropriate development that exposes lives and property to intense weather or drought events. [Smith, 1997]

Proactive adaptation, unlike reactive adaptation, is forward-looking and takes into account the inherent uncertainties associated with anticipating change. Successful proactive adaptation strategies are designed to be flexible and effective under a wide variety of potential climate conditions, to be economically justifiable (i.e., benefits exceed costs), and to increase adaptive capacity (that is how and how well a system adjusts to realized or anticipated environmental changes). [Hurd, 2006]

IV. TOOLS, POLICIES, AND STRATEGIES FOR ADAPTING WATER MANAGEMENT TO CLIMATE CHANGE.

Most of the strategies, tools and policy responses for managing water resources during climate change are not novel to this issue and have probably already been identified. Generally, responses are needed that will increase management flexibility, develop new supplies, reduce demand, and reallocate water. Accomplishing these goals implicates a variety of strategies and actions including engineering/ technology improvements, coordination among water purveyors, legal and pricing reforms, and robust demand management, to list a few. The incorporation of climate change into the State's planning for water resource management will require new modeling and scenarios, and may lead to changing priorities and revised timelines, especially the accelerated implementation of "no regrets" strategies and possible changes to statutory and institutional structures that will also ameliorate other pressures on the State's water resources.

The discussion in the literature about adaptation strategies is still quite limited, but the emerging literature suggests that there is a clear and defined role for public policy interventions to reduce vulnerabilities and protect natural resources. [Tompkins and Adger, 2005] Throughout the discussions of climate change impacts and potential responses, there are a variety of recommendations for incorporating climate change into strategic planning and for developing adaptive management strategies. Comments at various climate change conferences revolve around the need to take a comprehensive approach and to create multiple planning and adaptation strategies: while there is clearly no silver bullet, there may be "silver buckshot"!

Mainstreaming climate change vulnerabilities and adaptation strategies into water management, disaster preparedness, emergency planning, land use and development planning, and institutional/organizational design will be necessary to integrate climate change adaptation into comprehensive planning for sustainable development. [Agarwala, 2005; Burton and van Aalst, 1999] This section will provide a cursory and by no means complete discussion of some of the strategies and tools for addressing climate change, and will hopefully provide a starting point for discussion of New Mexico's options for incorporating climate change into its water planning and management agenda.

1. Strategic planning

The Western Governor's Association, on the recommendation of the Western States Water Council, recently adopted a set of policy recommendations for addressing climate change and other water issues. [WGA, 2006] The general recommendation suggested that, while recognizing the uncertainties inherent in climate prediction, western states and water managers should expand water-related plans to include climate change scenarios and should coordinate with local governments and water purveyors in developing responses.

Lester Snow, Director of the California Department of Water Resources, described this new approach to state water planning in his comments upon the release of California's Water Plan Update 2005, which addressed climate change qualitatively with plans for improved quantitative analysis over the next several years: "This …represents a fundamental change in the way state government needs to be involved with local entities and interest groups to deal with water issues in the state. The way we manage California's water resources is changing. We need to consider a broader range of resource management issues, competing water demands, new approaches to water supply reliability, and … to develop regional water plans that are more integrated…to ensure sustainable water uses and reliable water supplies in the face of uncertainty and change." [WSWC, 2005]

The ability to manage through the uncertainty of climate change will depend on good planning based on good data and modeling scenarios, and on utilizing and expanding the large portfolio of tools and systems in place that allow for robust and easily adaptable management. [Easterling, 2004] Identifying ***vulnerabilities*** to water supplies, clearly articulating the causes of those vulnerabilities, determining how climate variability and extremes might exacerbate those vulnerabilities, and establishing an analytic framework to identify the best options to correct those vulnerabilities should become part of state, regional and watershed-level water management plans.

a. Integrate predictions into planning to generate multiple future scenarios for risk analysis, both probability and consequence.

Current modeling, coupled with observed changes over the past decade, provides substantial certainty about temperature increases. While predictions about precipitation cannot be made with the same certainty, it does appear that there will be changes in precipitation patterns due to temperature increases, along with continued high persistence of variability. (See Section II for more detail on predictions for New Mexico.) This will result in changes to the hydrologic cycle (such as increased elevations for snowfall, with resulting decreased snowpack and changes to runoff patterns) which, though not yet specifically predictable, should be incorporated into management planning.

It is critically important to bridge the gap between scientists, policy makers, and water managers so that new climate change model results can be incorporated quickly into both policy and management options. The science and research community will need to prepare assessment and synthesis products to support informed discussion and decision-making about climate variability and change. Improving predictions is likely to depend not only on more sophisticated predictive methods but also on feedback, so that processes are iterative and modelers can improve their ability to provide usable and useful data and results to policymakers and water managers. [NRC, 1999]

b. Increase federal and state water data gathering activities to serve as the basis for sound decision-making.

To fully understand Southwest climate variations, a more dense network for systematic observation is necessary to identify the smaller scale effect of differences between mountains and adjoining valleys which govern the origin of most streamflow. Supporting expansion of federal data gathering programs, including the National Integrated Drought Information System (NIDIS) [www.nws.noaa.gov/ost/climate/NIDIS] as well as improving state water resource databases is prerequisite to sound decision-making. [Redmond, 2002; WGA 2006]

In addition, inadequate data is available about water availability at national, regional and local levels. “National water availability and use has not been comprehensively assessed in 25 years” according to a U.S.G.A.O. report in 2003. [Whitney, 2006] New Mexico has substantial water usage and demand data that was developed for the state and regional plans, but there are considerable gaps in knowledge about the State’s water resources (especially aquifers).

c. Increase transdisciplinary and collaborative stakeholder involvement in strategic planning.

A common element of many water supply challenges facing New Mexico are the conflicting needs of people, cities, agriculture, and the environment. Success will always require a collaborative effort among stakeholders, based on recognition of the rights and interests of stakeholders, to maximize the opportunity for innovation and creativity. [USDOI, 2005] The SWP already calls for interagency collaboration and substantial public involvement, to which could be added a public education component that interjects climate change into the discussion about state water policy.

In addition, enhancing ongoing collaboration between state water managers, scientists, federal agencies, universities, and others will insure that the science of climate change is fully understood and incorporated into planning. Conversely, an improved dialogue between scientists and water managers and users is critical to scientists’ understanding of data and research needs and to water managers ability to provide feedback loops to scientists to improve predictive capabilities and response analysis. [NRC, 1999]

d. Improve integrated regional water planning.

The integrated regional water planning (IRWP) paradigm calls for involvement of "myriad water users, purveyors, agencies, governments, organizations and universities to integrate diverse water-related programs that include watershed management, agricultural and urban water conservation, ground water recharge, dam rehabilitation, land use planning, water importation, reuse and recycling, desalination of brackish water supplies, and system interties." [WSWC, 2005] New Mexico has already taken several steps in this direction:

---16 regional water plans are either completed or nearing completion, and efforts to integrate these plans into the SWP are underway;

---the FOREST AND WATERSHED HEALTH PLAN and the NON-NATIVE PHREATOPHYTE/WATERSHED STRATEGIC PLAN together form the basis of an integrated approach to watershed management;

---a water and waste water system collaboration initiative has generated substantial interest in regionalization of those systems, and the Technical Team created to support this initiative has begun to address land use and watershed management and source protection issues.

The overall objective of IRWP is to address issues that individual entities cannot resolve; promote cost effective solutions; leverage investments in existing infrastructure; integrate water management with land use, energy and other resource management issues; and address drought and flooding which are expected to result from climate change. [British Columbia, 2004] Water planning thus needs to become part of a total resource management approach. [World Conservation Union, no date]

2. Implement highly adaptive management capacity at the watershed scale

Using climate change science, despite its inherent uncertainties, will require that water planning incorporate vulnerability assessments and utilize an approach that builds increasing resiliency to climatic extremes. States will need to maintain multiple water-related plans, including not only state water plans, drought plans, reservoir management plans, flood plans, and the like, but also forest management, energy, and economic development plans which include water-related concerns. States will also need to coordinate more closely with local governments and water purveyors, which are playing an increasingly important role in water management through land use policies, development of new water supplies, water transfers, and implementation of demand management and water use efficiency programs. [WGA, 2006] This will create increasingly complex planning environments involving multiple stakeholders to enhance ways to manage all water supplies, including groundwater, surface water, and effluent, in a sustainable manner.

Watershed-scale management, such as the State Engineer is implementing through Active Water Resource Management (AWRM), is assuming increasing importance, and devising watershed management plans can not only secure sustainable clean water but also help resolve conflicts during both drought and floods. [British Columbia, 2004] Managing at this scale is also important for resolving the demand for water to support critical ecosystem services. [Whitney, 2006]

Given the importance of agriculture to the State's economy, ecology and heritage, special attention will be required to address the challenge of climate change to the State's rangelands and farming. Similarly, the implications of climate change are more threatening for natural systems, particularly aquatic ecosystems, because it will be difficult for many species to change behavior or migrate, decreasing resiliency and potential for successful adaptation. [Easterling, 2004]

Rangelands: Rangelands are an important part of New Mexico's ecology, economy and heritage, occupying over two-thirds of the surface area of the state with grasslands, shrublands, and savannas. Ranching is nearly $1 billion industry in the State. [USEPA, 1998] New Mexico's rangelands are managed by a wide variety of people and institutions with many and varied objectives. While livestock grazing currently dominates the decision making on most rangelands, they also perform other valuable ecosystem services such as climate regulation, wildlife habitat, open space, and energy production infrastructure. It is uncommon for any rangeland to be managed for only one use. Rangelands also cover much of New Mexico's watersheds, and can enhance or detract from efficient hydrologic cycle functioning and therefore affect both water supply and quality.

In general, predictions about climate change in the Southwest focus on three major changes over the next several decades: increased temperatures, shifts from summer to winter precipitation, and increased variability in both temperature and precipitation within and across seasons [IPCC, 2001]. These changes in the existing climatic regime will alter the geographical extent, the plant composition, and the ecological processes of rangelands, requiring active management approaches for land managers to remain successful in meeting both commercial and ecosystem needs. [USEPA, 2002]

Managing the State's rangelands effectively during climate change will require an adaptive management approach at all levels that emphasizes monitoring rangeland conditions and flexibility in managerial responses. Adaptive management is a well developed and proven process that has shown positive results in both economic and ecological attributes when correctly implemented. [Easterling, 2004] The State has already created two plans that provide the direction for this new management approach: the FOREST AND WATERSHED HEALTH PLAN and the NON-NATIVE PHREATOPHYTE/ WATERSHED STRATEGIC PLAN. This is especially critical given the demonstrated historical linkages between atmospheric conditions and regional fire activity: increased temperatures with changing precipitation patterns are often precursors to increased regional fire activity, which will place additional stress on water resources. [USGCRP, 2000]

Evaluating the complete range of ecosystem services derived from rangeland management, both public and private, is an important requirement for adaptive watershed management. In addition to the services already mentioned above, it is important to note that increasing temperatures and drought will present challenges to rangeland health. These include likely shifts of plant dominance and structure that are not easily reversed and often result in an increase in invasives as ecological conditions change, as well as the potential for rangeland degradation leading to an increase in blowing dust, detrimental to health and problematic for the State's highway drivers. [USGCRP, 2000] Devising strategies, tactics and operations that will best maintain a full range of services may require such tactics as redirecting conservation program incentives to support and maintain ecosystem services that provide public interest benefits at the expense of short-term economic performance. Those currently managing rangelands and/or deriving their livelihood therefrom will need to be involved early and consistently in discussions about maintaining and improving rangeland health during climate change, and additional resources will likely be required to support the management approaches required to enhance the ecological functioning of these lands. [Brown, 2006]

Farming: Crop production in New Mexico is a $500 million industry. A warmer climate, with less snowfall, more winter rain, and an earlier spring runoff could mean decreased ability to store water for use later in the summer when demand peaks, as well as increased evaporation. Farmed acres in the State could decrease as much as 25% due to these pressures. [USEPA, 1998]

Agricultural systems are managed, so farmers have multiple adaptation options including revised plant/harvest schedules, crop rotations or changes, and different tillage practices. However, agricultural systems display high sensitivity to extreme climatic events (floods, wind storms, drought) and to seasonal variability (frost dates, rainfall patterns). Increased rainfall intensity can increase soil erosion, along with degraded water quality from increased movement of agricultural chemicals and waste into water bodies. Coupled with increased temperatures, it can result in increases or changes in pests and invasive species. [Adams, 1999]

Agricultural policies will need to address both the challenges and opportunities of climate change while also adapting to other pressures. Although the role of soils and crops in carbon sequestration is not yet fully understood, it should play a role in farming techniques as well as crop selection. The opportunity for New Mexico's growers to provide feedstock for production of ethanol and biodiesel may open new markets to support changing crop patterns. [Ebinger, 2006]

Policies will also need to address the impact of the peaking of world oil production, which will result in higher oil prices and a liquid fuels problem for the transportation sector. [Hirsch, 2005] The agricultural sector is heavily dependent upon diesel fuel: for transportation of fertilizers and pesticides (most of which are produced from petroleum), and for transportation of products to markets. U.S. consumers are also heavily dependent upon petroleum for transportation of food. The combined challenge of "peak oil" and food production has increased interest in the development of local food production and urban agriculture, and calls for careful evaluation of pressures to move agricultural water to other uses.

Aquatic ecosystems: Aquatic and wetland ecosystems display high vulnerability to climate change. Changes in water temperature and shifts in timing of runoff will change aquatic habitats, resulting in species loss or migration as well as novel and unpredictable interactions of new combinations of species. [Fish, 2005] Stream management practices will have to accommodate these new threats to aquatic species, increasing Endangered Species Act (ESA) and threatened species challenges. [Poff et. Al, 2002]

3. Infrastructure and technology options

The SWP includes a policy and strategies for improving the use of and for enhancing water supplies through continued improvements in technology. Many western universities, as well as the national laboratories, have research programs that could be focused on practical applications of new and existing technologies to improve water management and expand water supply. [WGA, 2006] Climate change will add an additional pressure to the other variables that already challenge water managers dealing with aging infrastructure and distribution demands.

There are three major areas in which science and technology should play a major role in addressing this and other U.S. water challenges [Whitney, 2006]:

a. Improving use of existing infrastructure: Increased application of management systems (such as Supervisory Control and Data Acquisition, or SCADA; meter telemetry) will improve the efficiency of infrastructure management, in addition to providing the feedback loops and quick response time required for adaptive management.

b. Expanding supply through new technologies for water reuse, desalination, weather modification and expanded use of lower quality water: Implementation of new technologies may require regionalization in order to achieve the scale necessary to justify investments, and additional research will be necessary to determine effectiveness and feasibility (for weather modification, for example). A comprehensive study of untapped but impaired water supplies in the State could focus development in those locations with a high probability of water demands exceeding supplies, as well as those most likely impacted by climate change. [U.S.D.O.I., 2005] Costs for many of these are decreasing, while experience from implementing new technologies is providing direction for more efficient and effective use in the future. NOTE, however, that both increasing energy costs and the need to decrease greenhouse gas emissions are major considerations in determining an appropriate role for these new technologies. (see Part 4 below)

c. Developing new approaches to water storage: New Mexico already loses a substantial amount of water through evaporation. Improving both surface and groundwater storage alternatives, including aquifer storage and recovery, are key areas for technological advancements.

Infrastructure vulnerability assessment: Safe engineering design depends upon a probability analysis of historically observed hydrologic events. One of the anticipated impacts of climate change is an increase in extreme hydrologic events, both flood and drought. [Groisman et. al., 2001] Rain has increased in the U.S. by 7% in three decades; heavy rain events of more than 2 inches a day have increased 14%, and storms dumping more than 4 inches a day have increased 20%. [Epstein, 2006] Historic records may therefore not reflect the magnitude of future events. The "return period" for hydrologic events is also based on the average, historically-observed elapsed time between occurrences of different magnitudes, and this may also change significantly with climate change. Assuring that existing infrastructure will withstand both more extreme and greater frequency events will require vulnerability analysis and possibly cautionary retrofit. Engineering manuals that provide design standards for hydrologic analytical methodologies will need to be revisited and revised to insure that anticipated changes in the magnitude of hydrologic events are incorporated into designs for new infrastructure. [Hernandez, 2006]

Reservoir management: Warming and loss of snowpack will impact operations of many of the state's reservoirs. More precipitation as rain, coupled with the retreat of snowpacks to higher elevations, will increase reservoir inflows during the winter and early spring months, resulting in empty flood control space previously maintained during winter months being filled earlier with runoff. Especially with the potential for extreme flood events, more annual runoff is likely to go through reservoirs earlier in the year, decreasing the amount available for hydropower and irrigation uses later in the year. Reservoir managers will need to search for physical, regulatory, and operational flexibilities to accommodate these changes. [CaDWR, 2006]

4. Demand management, conservation, and efficiency

The IPCC, in each of its assessments to date, has noted that water demand management and institutional adaptation are primary components for increasing flexibility to meet the uncertainties of climate change. [IPCC 1995, 2001] Innovative water conservation practices could decrease water use, and management innovations could increase efficiency with limited environmental impact. [CaDWR, 2006] Most agricultural irrigation water delivery systems were built in the early 1900s. Lining or enclosing of canals where appropriate, rehabilitation of irrigation system infrastructure, and application of new automated and remote-controlled water management technologies using low-cost solar-powered components, while requiring significant initial investment, can modernize existing systems and improve efficiency of water delivery, often with substantial savings. [USDOI, 2005]

Most urban (i.e. non-agricultural; the term "urban" will be used for the municipal, domestic, commercial, industrial and institutional sectors) water systems were built in the middle of the last century. A combination of aging infrastructure and increasing demand is generating need for replacement or upgrading of systems, providing the opportunity not only for decreased conveyance loss but also for integrated regional water and waste water system design that can incorporate such opportunities as use of pre-treatment water for golf courses and other non-potable demands, thereby optimizing the use of and extending the existing water supply.

Urban sector: The fastest growing demand for water is the urban sector, with water supplies limited and water rights at a premium. The majority of New Mexico's drinking water systems are rural, and much of the population depends upon community water systems or domestic wells. Climate change, particularly long term drought, can result in loss of water sources, as well as a rise in turbidity and in levels of contaminants regulated by the Safe Drinking Water Act (SDWA). It will also exacerbate existing challenges, including uncertain future demand, changing demographics, unanticipated treatment costs, changing quality regulations, infrastructure maintenance and upgrades, and developing new water supply options. [Palmer and Hahn, 2002] Some of the climatic events that are most disruptive to water systems will be compounded by climate change: high temperatures and drought (which increase demand); high winds and electrical storms (that cause electrical outages); and heavy precipitation and flash floods (that may cause breakage or exposure of infrastructure, overload the capacity of waste water systems, and impact water quality and turbidity). [Carter and Morehouse, 2003]

Confronting the additional pressure of climate change with existing challenges is already leading to collaboration among small water systems. Regional planning and infrastructure development will need to integrate drinking water, waste water, source water protection, new supply development, and demand management for sustainability. A State water conservation plan for this sector would establish policies and strategies to decrease both domestic and commercial use, along with appropriate State programs to facilitate and accelerate implementation of practices with the greatest potential for successful reduction of water use. Such a plan should include such accepted strategies as metering; per capita usage goals; subdivision, development and construction code changes to encourage water efficiency and grey water reuse; and land use guidelines to encourage water-efficient development landscaping. The State's "Our Communities, Our Future" initiative has developed a multi-pronged approach that includes many policies and statutory/regulatory recommendations to support sustainable water supplies. [Hughes, 2006]

Agricultural sector: Most irrigation systems are already implementing some efficiency and conservation techniques. [King,2005] Resources for such improvements could be targeted to areas where additional water is needed for environmental or other purposes. Re-evaluation of current farming technologies and cropping patterns, particularly perennial crops such as orchards, will need to be done in the context of climate change to assist farmers with appropriate adaptations.

Water/Energy nexus: "Water and energy are interdependent," according to Mike Hightower of Sandia National Laboratories. Much of energy production requires water, and water pumping and treatment require a lot of energy. [WSWC, 2006] Increased demand for energy (for cooling, anticipated with temperature increases) leads to increased demand for water that is unlikely to be offset by decreases to winter demand (from reduced heating). [Smith and Tirpak, 1989; Sailor and Pavolova, 2003] Increased demand for potable water leads to increased demand for energy.

Providing water for multiple purposes is also energy-intensive. The California Energy Commission estimates that providing water to the State results in an average of 44 million tons of carbon dioxide emissions. End uses of water, including heating for domestic, commercial and industrial operations, also consume energy, as does waste water treatment. Consequently, any reductions in energy consumption related to water will decrease GGEs. [CaDWR, 2006]

There is thus a strong link between energy and water conservation, with opportunities to achieve both through collaboratively planned projects. Including energy savings can improve the economic justification for water conservation projects and may be one of the best ways to reduce energy use and therefore emissions. Water conservation can lower energy use and energy bills. Water recycling is a highly energy efficient water source. Both water and energy policymakers should give water conservation higher priority as a mutual benefit. [Cohen et. al, 2004]

5. Statutory, regulatory and institutional barriers.

"States should evaluate and revise as necessary the legal framework for water management to the extent allowable to ensure sufficient flexibility exists to anticipate and respond to climate change." [WGA, 2006] WATER 2025 also identified that water management could be improved through removal of institutional barriers. [USDOI, 2005] An extensive literature on the important role of institutional capital to plan, facilitate, implement, monitor, and sustain adaptations to climate change has noted that appropriate institutional mechanisms may be absent and that long-lived institutions may be unable to accommodate the restructuring necessitated by adaptations. [Young, 2002; Easterling, 2004] In the Colorado River Basin, for example, measurements of the economic effects of hypothetical changes in climate and precipitation indicate that much of the total damages result from the current inflexibility of the Colorado River Compact. [Loomis et.al., 2003] The Endangered Species Act (ESA) and the National Environmental Policy Act (NEPA) may limit habitat management options; river restoration and species protection may not be compatible or synergistic; and managing aquatic ecosystems in arid lands with climate uncertainties may be compromised. [Cowley and Sallenave, 2006] Water policies, including pricing and inadequate quantification of water rights as well as related issues such as land use, can inhibit conservation and limit valuable flexibility in market-oriented transfers. [Easterling, 2004]

While certain to send a shudder through water attorneys, managers, and multiple stakeholders, pressures on water resources (drought, increased demand, changing regulatory requirements, sustainable development) have already highlighted areas where new approaches are required. Climate change will add to that pressure and call for re-evaluation of existing structures.

6. Sustainable development.

Sustainability is often defined as “meeting the needs of the present without compromising the ability of future generations to meet their own needs.” Sustainable development involves a comprehensive integration of economic, social and environmental goals that will need to incorporate the impacts of climate change. [Robinson et.al, 2006] Climate change will add an additional pressure, and an unpredictable variable, to those already faced by New Mexico in meeting its water needs. However, climate change and sustainable development policies can reinforce each other; for example, the reduction of non-renewable energy consumption and conservation practices that also reduce greenhouse gas emissions. [Swart, 2003]

While the published literature on the impacts of climate change is substantial, that on the links to sustainability is still scarce. That on adaptation strategies is also limited, other than general descriptions of options and opportunities briefly described in this report. However, much of the response to climate change will necessarily be local, because that is where the impacts will be felt. [Easterling, 2004]

V. CONCLUSION

"I have found that plans are useless, but that planning is priceless."
President Dwight Eisenhower

New Mexico's water future will be determined by water demand and availability of our water resources. Climate change will likely have a significant affect on both. Continued and exacerbated variability, coupled with changes in amount, form (rain vs. snow), location, and intensity/duration of precipitation events are anticipated results of climate change, and these changes will have serious consequences for water managers. [Smith, 2006]

There is a clear and defined role for public policy intervention in adapting to climate change. [Tompkins and Adgar, 2005] The key to successful adaptation is a robust scenario-based planning structure. The STATE WATER PLAN provides a policy framework to which climate change can be added as an additional pressure, albeit perhaps a potentially more dangerous one. It and the State's regional plans already include many of the strategies required to address climate change. Identifying likely changes and quantifying the range of potential impacts will allow the State to identify and evaluate adaptation options, and to compare costs and benefits against both "no action" risks as well as strategies already in place to meet additional demands. It will set the stage for moving forward with those "no regrets" strategies that clearly address both climate change and other challenges, while continuing to investigate other pathways that may be less clear.

Building the adaptive capacity required to manage climate impacts before they occur is the ultimate objective of such planning. Building such capacity will evolve over time as new modeling results become available and additional defendable adaptation opportunities become evident. Water resource planners and managers will need to incorporate monitoring, re-evaluation and adjustment of policies and strategies into management activities to respond to climate changes and additional pressures and demands. Doing so will better position water resource managers to meet objectives that might otherwise be compromised by changing climate conditions. [Climate Impacts Group, 2005]

Adaptation is not likely to be a smooth process or free of costs, and it is by definition on-going rather than a one-time solution. [Easterling, 2004] Planning need not and should not wait for "perfect" climate predictions on precipitation---action can be initiated now based on what is known: that temperatures are increasing with resulting changes in precipitation and that extreme events are likely to become more common.

Given the latest scientific research on the impacts of climate change, it appears that there would be some urgency as well as substantial benefits from stoking New Mexico's adaptive capacity with proactive policies and strategies in anticipation of what is likely to come. As Governor Bill Richardson said on February 28, 2006, when announcing the Arizona/New Mexico collaboration on the Southwest Climate Change Initiative, “In the Southwest, water is absolutely essential to our quality of life and our economy. Addressing climate change now, before it is too late, is the responsible thing to do to protect our water supplies for future generations.”

APPENDIX A: CLIMATE CHANGE WATER IMPACTS WORK GROUP

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