POTENTIAL EFFECTS OF CLIMATE CHANGE ON NEW MEXICO

AGENCY TECHNICAL WORK GROUP
STATE OF NEW MEXICO
December 30, 2005

CONTENTS

EXECUTIVE SUMMARY

This report has been prepared by state agency personnel pursuant to Governor Richardson's Climate Change and Greenhouse Gas Reduction Executive Order 05-033, issued June 9, 2005 (Richardson 2005). The purpose of the report is to assess the potential impacts on New Mexico of climate change that could be brought about by global warming in the 21st century. The Executive Order also directs state agencies and stakeholders to develop recommendations for measures to reduce New Mexico's emissions of greenhouse gases; more information on this process may be found at www.nmclimate.change.us.

Human activity is changing the global climate by increasing the concentration of carbon dioxide, methane and other greenhouse gases in the atmosphere. These gases trap heat near the earth's surface. The greatest human-caused contribution to the increased greenhouse effect is the large amount of carbon dioxide produced by burning of carbon-based fuels such as coal, oil and natural gas. Other human-caused sources of greenhouse gases include land use changes, cement production, and other industrial processes.

Increased warming of the earth's surface changes the complex interactions of air, land, water and ice, and the circulations of winds and ocean currents that make up the global climate system. Computer models of the climate system are used to estimate global patterns of future climatic conditions under various scenarios of future greenhouse gas concentrations. Some projected changes, such as significant warming and decreased snow and ice cover in Arctic regions, appear to have already begun in the last few decades.

Climate models project substantial changes in New Mexico's climate over the next fifty to one hundred years, if no measures are taken to reduce global greenhouse gas emissions. Projected climate changes by mid- to late-21st century include: air temperatures warmer by 6-12°F on average, but more in winter, at night, and at high elevations; more episodes of extreme heat, fewer episodes of extreme cold, and a longer frost-free season; more intense storm events and flash floods; and winter precipitation falling more often as rain, less often as snow. Some climate models project that average precipitation will increase, while others predict a decrease. However, recurrence of a severe multiyear drought like that of the 1950s is likely some time during this century, regardless of human-caused climate change. When such a drought does recur, higher evaporation rates because of warmer temperatures will exacerbate effects of drought, and will at least partially offset the effect of any increase in precipitation that might occur due to climate change.

Water Resources

Water resources are vital to New Mexico, and many areas of the state are already facing potential shortages in meeting the needs of our growing cities, agriculture, and manufacturing. Because of the importance of water to New Mexico, the Executive Order directs that a separate report addressing the potential impacts of climate change on water resources be prepared under the direction of the Office of the State Engineer and issued by July 2006. However, the present report does address water resources in general terms because so many other potential impacts are dependent on water.

Warmer temperatures will reduce mountain snowpacks, and peak spring runoff from snowmelt will shift to earlier in the season. A longer and hotter warm season will likely result in longer periods of extremely low flow and lower minimum flows in late summer. Water supply systems which have no storage (e.g., many acequia systems) or limited storage (e.g., small municipal reservoirs) may suffer seasonal shortages in summer. Large reservoir systems may also suffer shortages from a reduction in average runoff. Recurrence of a multiyear severe drought like that of the 1950s would have greater impacts on the water resources and the economy of the state than in the 1950s because of the warmer temperatures, as well as the great increases in population and demand for water since the 1950s.

Infrastructure

Infrastructure systems sensitive to climate include those for flood control and drainage, climate control in buildings (e.g., air conditioning), electrical power distribution, sewage, water supply, and transportation. A potential increase in flash flood intensity may impact flood-sensitive structures such as flood control and drainage systems, including roadway and railroad bridges and culverts. Water use restrictions may adversely affect the functioning of sewage systems. Design standards for infrastructure systems may have to be revised to cope with a changing and uncertain future climate. Existing systems may need to be retrofitted, modified or replaced to cope with warmer temperatures, more intense storms, and drought.

Agriculture

Climate change impacts on agriculture are highly dependent on whether precipitation increases or decreases. Increases in precipitation would increase yields of rainfed and irrigated crops and would tend to improve forage availability on rangelands. Warmer temperatures will lengthen the frost-free growing season. Severe drought coupled with warmer temperatures would adversely affect crop and rangeland production. Higher atmospheric carbon dioxide concentrations will tend to increase yields of some crops, if water and nutrients are not limiting. On rangelands, however, higher carbon dioxide levels may favor woody plants over grasses, which would reduce grazing capacity. Major uncertainties are the impacts of intense rainfall events, pests, weeds, and pathogens. Warmer conditions may affect pest populations, requiring new strategies for pest control. Farmers can use a number of adaptation strategies to lessen potential yield losses.

Natural Systems

Climate change is likely to have significant impacts on the ecosystems of New Mexico's forests, grasslands, deserts, lakes and streams. Predicting the specific impacts is difficult because of the complexity of natural systems, with each species responding in its own way to the physical environment and with multiple interactions among species. As each species responds individually to its changed environment, existing plant or animal communities will likely change as new assemblages of species form. Changes in ecosystem structure and functioning will often be abrupt rather than continuous and gradual.

Aquatic systems are particularly vulnerable to climate change because they will be impacted not only by warmer temperatures but also by changes in the timing and amount of water. Climate change is expected to result in a significant loss of aquatic habitat. Habitat suitable for coldwater fish (e.g., trout) is expected to shrink, with replacement by warmwater fish species. Extinction rates of many endemic species of the eastern plains is expected to increase. Riparian ecosystems are expected to experience losses and decline, with a reduction in species diversity.

Change in terrestrial ecosystems will include shifts in the timing of seasonal life history events such as breeding of birds, insects or amphibians, and flowering of plants. Geographic ranges are expected to shift to the north and to higher elevations. Some species trapped on isolated mountain ranges could become locally extinct if the mountain is not high enough to provide suitable alternative habitat and the species cannot disperse across intervening deserts to other mountaintops. Invasions of non-native species are likely, but species diversity may be reduced. Shrubs such as mesquite and creosotebush are likely to further invade grasslands. Forests are likely to experience more catastrophic wildfires, and more massive dieback due to drought stress and insect outbreaks. Alpine meadows may largely disappear from New Mexico.

Outdoor Recreation and Related Tourism

Reduced opportunities for outdoor recreation will not only impact the quality of life for New Mexicans, but will likely harm the state's economy because outdoor activities are a major attraction to tourists. Warmer winter temperatures are likely to severely reduce opportunities for snow sports, and ski resorts will suffer economically. Lower water levels in lakes and rivers will adversely impact water sports such as boating, angling, and whitewater rafting. Periods of high fire hazard may further restrict access to wildlands for picnicking, camping, hiking, hunting, birdwatching and other outdoor activities. The attractiveness of our scenic vistas may be diminished by more air pollution episodes.

Environmental Quality and Health

Climate change is likely to increase air pollution in New Mexico. Warmer temperatures and more air stagnation episodes are projected to increase ozone (smog) levels. Wildfires and dust storms associated with drought are likely to increase particulate air pollution. Episodes of extreme heat are expected to become more severe and much more frequent, resulting in increases in heat-related illness and mortality. Disruption of ecosystems and natural controls may lead to outbreaks of infectious diseases that are transmitted by, or have reservoirs in, rodents, birds or insects. Such diseases include hantavirus, plague, dengue fever, and arboviruses such as West Nile virus. Warmer temperatures and increased dust storm activity may result in greater incidence of coccidiodomycosis (Valley Fever), which is caused by a soil fungus and is currently more common in Arizona than in New Mexico.

Environmental Justice and Native Peoples

The potential impacts of climate change will disproportionally affect communities of color and low-income communities, thereby raising issues of environmental justice. These communities have limited resources available to adapt and cope with additional impacts.

Traditional Native American subsistence systems (farming, grazing, hunting) are likely to be severely impacted by climate change. Local extinctions of plants and animals integral to the cultural and spiritual life of Native American communities will be highly disruptive to their cultural identity.

INTRODUCTION

This report has been prepared pursuant to Governor Richardson's Climate Change and Greenhouse Gas Reduction Executive Order 05-033, issued June 9, 2005 (Richardson 2005). In addition to other measures, this Order directs representatives of state agencies to prepare a report on potential impacts of global warming on New Mexico, for presentation to the Climate Change Action Council. The Climate Change Action Council, also created by the Executive Order, is an advisory group of state officials charged with reviewing and providing recommendations to the Governor's Office regarding climate change policy.

Executive Order 05-033 also calls for creation of a stakeholder group, the Climate Change Advisory Group, charged with developing proposals for measures that will reduce New Mexico's greenhouse gas emissions to specified future target levels. Development of these proposals is currently in progress (see www.nmclimatechange.us). Consideration of the effects of future measures to reduce greenhouse gas emissions, whether in New Mexico, in other states, nationally, or internationally, is beyond the scope of this current report.

This report was prepared by a technical state agency working group convened by representatives of the Environment Department, and includes contributions from representatives of the following Departments: Game and Fish, Agriculture, Transportation, Regulation and Licensing (Construction Industries Division), and Health. This review of published reports and climate change impact assessments portrays the broad scope of potential climate change impacts on New Mexico, and highlights issues of particular concern for state and local governments and other decision-makers. Preparation for this coming century of rapid climate change will require a better understanding of potential impacts as New Mexico makes decisions on how to mitigate and adapt to unprecedented changes.

Global Warming

There is scientific consensus worldwide through the Intergovernmental Panel on Climate Change, and nationally through the National Academy of Sciences and other scientific professional associations, that the human modification of the global climate is occurring and that the climate is warming (IPCC 2001a, Oreskes 2004, Cicerone 2005).

Human activity is changing the climate by changing the chemical balance in the air. Certain gases in the atmosphere, called 'greenhouse gases', absorb outgoing longwave radiation and re-emit back to the surface heat that would otherwise escape to space. The atmospheric concentrations of several greenhouse gases emitted by human activities, including carbon dioxide and methane, are increasing dramatically. Because these gases are causing the atmosphere to recycle heat and hold in more warmth, the average temperature at the surface of the planet is going up. The rate of increase has accelerated in the last 50 years, and significant further increases are expected in the next century and beyond.

Small amounts of carbon dioxide and methane occur naturally in the atmosphere. Before the industrial revolution began in the mid-1700s, their concentrations were fairly stable because there was a balance between natural processes that produce these gases and processes that remove them from the air. But since the industrial revolution began, the carbon dioxide concentration in the air has increased 31%, and the methane concentration has more than doubled (IPCC 2001a). Most of this increase has occurred in the last century.

The greatest human-caused contribution to the increased greenhouse effect is the large amount of carbon dioxide produced by burning of carbon-based fuels such as coal, oil and natural gas. Greenhouse gases are also released during manufacturing processes, oil and gas production, and as a result of deforestation and agricultural practices.

Higher global mean air temperatures are already being measured. The global average surface temperature has increased over the 20th century by about 0.6°C (1.0°F), and is projected to rise by an additional 1.4 to 5.8°C (2.5 to 10.4°F) over the 21st century, depending on future emissions of greenhouse gases (IPCC 2001a). Eight of the ten warmest years since 1880 have occurred in the last decade, and the three most recent complete years (2002, 2003 and 2004) were the second, third and fourth warmest years on record (National Climatic Data Center 2005). Based on 11 months of data, 2005 is on track to be the second warmest year on record (NOAA 2005). Mountain glaciers are disappearing, spring is occurring earlier, and Arctic permafrost (permanently frozen ground) and sea ice are melting (Cayan et al. 2001, IPCC 2001a, NSIDC 2005, Overpeck et al. 2005).

Changes in the global temperature are changing global and regional climates because heat in the atmosphere drives the climate system. The climate system is a complex interaction of air, land, water, and ice, with winds and ocean currents controlling the movement of heat and water around the globe. Even slight changes in average temperature are associated with significant changes in the climate system.

The effects of climate change will not be the same everywhere. Warming is predicted to be greatest over land, at high latitudes, at higher elevations, and in winter and early spring. The Intergovernmental Panel on Climate Change (IPCC 2001a) projects the following changes in extreme weather events and climate during the 21st century:

Very Likely (90-99% chance)

- Higher maximum temperatures and more hot days over nearly all land areas;
- Higher minimum temperatures, fewer cold days and frost days over nearly all land areas;
- Narrower daily temperature range over most land areas;
- Increase of heat index (a combination of temperature and humidity that measures effects on human comfort) over most land areas;
- More intense precipitation events in many areas;
- Larger year-to-year variations in precipitation over most areas where an increase in mean precipitation is expected;
- Continued decrease in northern hemisphere snow and ice cover;
- Continued rise in mean sea level.

Likely (66-90% chance)

- Increased summer drying and risk of drought over most mid-latitude continental interiors;

- Increased risk of drought and floods occurring with El Niño events;
- Increase in tropical cyclone (hurricane) peak wind intensities in some areas;
- Increase in tropical cyclone mean and peak precipitation intensities in some areas.

Many of these trends are observable in 20th century climatic records (IPCC 2001a).

Late 21ST Century Climate of New Mexico

Projections of the future climate of New Mexico can be derived from global or regional climate models (IPCC 2001a, NAST 2000, Stainforth et al. 2005, Meehl et al. 2005, Diffenbaugh et al. 2005, Smith et al. 2005). In evaluating the projections of climate models for New Mexico, which has diverse topography and is at the junction of different climatic zones, it is also useful to consider historical climate variability and its causes (Sheppard et al. 1999, Grissino-Mayer et al. 2002, Stohlgren 2003).

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

<u>Temperature</u>

- Average air temperature substantially warmer by 6-12°F (3.3-6.7°C)
- Greater warming for winter, nighttime minimum temperatures, and higher elevations
- More episodes of extreme heat
- Fewer episodes of extreme cold
- Longer frost-free period

<u>Precipitation</u>

- Changes in average precipitation are uncertain, could increase or decrease
- More extreme events (torrential rain, severe droughts)
- Continuation of historical patterns of wet and dry cycles, including likely recurrence of multiyear drought (like 1950s)
- Winter rain instead of snow at all but highest elevations

Assessing Potential Impacts of Climate Change

The impact studies cited in this report have used a variety of different projections of future climate, depending on the climate model and emission scenario. All the projections are consistent with the general trends described above, but some of the earlier studies were based on somewhat smaller estimates of temperature increase. Climate models have given inconsistent predictions of future precipitation in New Mexico, with some models projecting a significant increase, others a significant decrease, and some projecting increases in some areas of the state and decreases in others. Although confidence in the ability of models to project future climate has improved (IPCC 2001a), some uncertainties remain, particularly for precipitation and for changes at the sub-regional scale.

Assessing the impact of a given future climate entails additional uncertainty because it requires an understanding of the functioning of the complex systems being impacted. Our understanding of these complex systems is often based largely on variations under "normal" or historical conditions, and there are limits to our confidence in the validity of projections to a novel climatic condition. Furthermore, the rapidity of climate change in the coming century presents even greater difficulty in predicting responses of natural and human systems.

Surprises are inevitable. New evidence from paleoclimatic records now show that climate changes (Alley et al. 2002) and ecosystem responses (Peteet 2000) are not always gradual, but can occur abruptly over a few decades or less. Complex human and natural systems often respond in a nonlinear manner to increasing stress. That is, they change gradually or not at all until a threshold ("tipping point") is reached, and then they change dramatically. Positive feedbacks can amplify the impacts of small changes into enormous effects, such as when a wildfire grows slowly until it begins creating its own winds and "blows up" catastrophically (Peters et al. 2004).

Given these uncertainties, projected impacts should be viewed not as predictions, but as a vulnerability analysis. Our best estimates of what could happen, with some degree of likelihood, can serve as a useful guide for a range of precautionary measures, the foremost of which is an effort to reduce emissions of greenhouse gases.

Uncertainty about climate change impacts does not mean that impacts may or may not occur, it means that the risks of a given impact are difficult to quantify (Schneider and Kuntz-Duriseti 2002, IPCC 2004, Congressional Budget Office 2005).

WATER RESOURCES

Water is crucial to New Mexico's growth and economic development, and water resources are already generally overallocated in some of New Mexico's larger river basins, such as the Rio Grande. Therefore, the Governor's Executive Order calls for the Office of the State Engineer to lead the preparation of an analysis of the climate change on the State's water supply and ability to manage its resources. The report is due July 2006, and is still in preparation. Since the State Engineer's report will cover the issue in much greater detail, here we present only a brief and general summary of some potential impacts of climate change on New Mexico water resources.

Some changes related to water resources are direct consequences of the projected changes in temperature and precipitation described above:

- greater evaporative loss from lakes and reservoirs;
- greater evaporative loss from soils and plants (evapotranspiration);
- less runoff and more soil drought for a given amount of precipitation;
- smaller mountain snowpacks;
- earlier snowmelt; and
- reduced groundwater recharge.

Specific impacts on water resources in any particular watershed will depend on the physical characteristics of the watershed (e.g., size, elevation, soils), the storage and conveyance infrastructure, and on constraints on water storage, use and distribution imposed by water law.

Runoff is sensitive not only to precipitation, but also to temperature, because higher temperatures cause more evapotranspiration. Therefore, even if annual precipitation does not change, the effect of projected increases in temperature would be less runoff and therefore less flow in streams and rivers and less water in storage reservoirs. For example, it has been projected that a mean annual temperature increase of 4°C (7.2°F) would reduce runoff by 10 to 20% in the Colorado River Basin (Nash and Gleick 1991, 1993). This means that the effect of substantial increase in precipitation could be largely or completely eliminated by the projected increases in temperature. Albuquerque is planning to obtain much of its future municipal water supply through the San Juan-Chama Project. This water will come from the San Juan Basin, which is part of the Colorado River Basin. Climate change is projected to increase the likelihood of shortages in meeting compact obligations (Christensen et al. 2004), potentially jeopardizing this source of water for Albuquerque.

A recent analysis of climate model output projects that runoff in the midlatitude western United States, including much of New Mexico, could decrease by more than 10% in the mid-21st century (Milly et al. 2005).

Because of warmer spring temperatures, there has been a general trend to earlier spring runoff from snowmelt over western North America in the 20th century, and this trend is projected to accelerate with continued global warming (Hamlet et al. 2005, Stewart et al. 2005, Dettinger 2005). This trend in snowmelt timing has not been as strong and consistent in New Mexico as in the Pacific Northwest and California because of differences in snowpack elevation and continental versus maritime climate, but the trend is likely to become widespread in New Mexico and the southern Rocky Mountains with continued warming. Earlier snowmelt increases the risk of winter and spring flooding and summer shortage of water if the runoff cannot be captured and stored (USEPA 1998, Smith 2004). Reservoir systems with a large capacity relative to mean annual inflows, such as the Colorado River and Rio Grande systems, are not very sensitive to the seasonal pattern of runoff (Christensen et al. 2004). However, earlier runoff timing may cause problems of spring overflow and summer shortages for smaller snowmelt-fed water storage systems in New Mexico.

INFRASTRUCTURE

The "built environment" includes housing, commercial and industrial buildings, schools, hospitals, places of worship and recreation, roads, airports, railroads, and systems for water supply, sewer collection and treatment, flood control, electrical and natural gas distribution, and communications.

Design Standards

Infrastructure systems have been designed to cope with weather extremes that could be anticipated on the basis of historical climate. These systems may become inadequate or even fail under a new climate, especially if weather extremes change more than averages, as projected (IPCC 2001a). Engineering design standards are currently based on the assumption that climate is stable; for example, that today's "100-year flood" will be the same 20, 50, or 75 years from now. But the projected rate of climate change might mean that 50 years from now, today's "100-year flood" can be expected to recur about every 20 years. It will be a challenge to design long-lived systems under conditions of rapidly changing climate (Smith and Tirpak 1989).

Modern societies rely on these systems for their health and safety, economic well-being, and quality of life. Because these systems fail so infrequently, we tend to take their continued functioning for granted. The course of events when Hurricane Katrina devastated New Orleans, and in the aftermath as the city tries to recover, illustrate how interdependent these systems are, how much we depend on them, and how costly they are to upgrade, repair, or rebuild.

Transportation Systems

The impacts from climate change on transportation systems have been significantly less researched than impacts on natural systems. The potential impacts described in this section are largely taken from papers presented at a workshop hosted by the U.S. Department of Transportation (US DOT) in 2002. The US DOT completed case studies in several geographic areas, which did not include the Southwest. Thus, possible impacts in other regions were selectively applied to New Mexico's transportation system where deemed likely and appropriate.

New Mexico's diverse climatic zones will be affected differently. For example, a hotter and drier climate will create additional maintenance demands for asphalt surfaces in the southern regions of New Mexico, while in northern regions the same climatic trend may lead to reduced maintenance costs by reducing the need for snow and ice removal. The possible impacts presented here are those most likely to have the greatest impacts on New Mexico's transportation infrastructure. The following environmental changes are listed with their likely possible impacts.

Some of the possible impacts that could result from longer, hotter summers are:

- increased traffic on northern interstate route to avoid heat of southern interstate route;
- increased maintenance of asphalt surfaces on southern routes due to deformation of the roadway from heat (Pisano et al. 2002);

- increased probability of damage to roadways due to increased brush fires in heavily vegetated areas;
- increased risk of heat stress to maintenance employees;
- airport delays or accidents due to loss of lift in hot, low density air (Pisano et al. 2002) and/or possible need to reduce aircraft payloads or lengthen runways to compensate for loss of lift;
- damage or accidents due to warping of rail lines (Rossetti 2002); and
- blowing dust that would create hazards for travel on roadways, rail lines and airports (Rosetti 2002).

Some of the possible impacts that could result from shorter, milder winters are:

- decrease in number and intensity snow/ice removal events (Pisano et al. 2002);
- decrease in damage to road surfaces and road beds from freeze/thaw cycles;
- increased mowing maintenance because of longer growing season for vegetation; and
- changes in animal migration and roadway crossings.

Some of the possible impacts that could result from an increase in storm intensity are:

- increase in erosion in right-of-way;
- roadway flooding from insufficient drainage (Mills and Andrey 2002);
- damage from flood scour of bridge footings and piers (Mills and Andrey 2002); and
- airport delays due to turbulence from convective cells (Pisano et al. 2002).

Some of the possible impacts that could result from an overall decrease in rainfall leading to continuing severe drought conditions are:

- increase in number of dust impaired visibility areas;
- excessive groundwater pumping causes subsidence and creates fissures under roadways and rail lines;
- decrease in mowing maintenance, from decrease in vegetation in right-of-way; and
- increase in right-of-way erosion from lack of vegetation.

In addition to the above environmental impacts to the state's transportation infrastructure, there will be constraints placed on NM Department of Transportation projects in the planning stage. Federal and State laws and executive orders may dictate moderate to fundamental changes in how the transportation needs of the state are met. Restrictions on vehicle emissions may lead to a decrease in the number of vehicles on state highways and create increased demand for state-funded intermodal transportation alternatives. These may include additional rail and bus lines and the enlargement and improvement of many regional airports across the state.

Urban Infrastructure and Systems

Higher temperatures, more intense storms and droughts would impact infrastructure systems in New Mexico and result in extreme demands on our energy systems.

Cooling systems would need to cope with warmer weather. However, existing power systems may be unable to keep up with the power demand resulting from a marked increase in air conditioning. Furthermore, expanding the use of the conventional means of supplying power could result in significant increases in greenhouse gas emissions. Potential solutions include retrofitting existing cooling systems with more energy efficient systems, and developing new energy efficient technology (including alternate methods of cooling) which minimize energy use, and designing buildings to stay cooler.

Aging drainage infrastructures may be designed for minimal overflow. Excessive surface water during more intense rainfall events can overwhelm catchment and drainage systems, especially in urban areas, resulting in flooding. Increased flows could result in structural damage and safety hazards. The changing flow patterns from more intense rainfall events, especially when combined with cyclical drought conditions, would also increase sediment transport and deposition. As a result, water runoff drainage systems in urban areas may need to be modified to cope with changing rainfall patterns. Beyond an evaluation of capacity, solutions can include development of systems that better optimize active storage capacity, and changes in the use and density of urban areas.

Existing buildings and landscaped areas (e.g., yards, parks) in urban areas would need to be adapted to function under new climatic conditions and extremes that cannot be predicted with certainty. New buildings would need to be designed and built to function under a range of possible future climate conditions, and existing buildings would have to be retrofit to cope with emerging climate conditions. Continued urban growth and recurrent drought will likely necessitate new water usage regulations. Adaptation will require researching and utilizing new technology to build water and energy efficient buildings and landscaped areas.

Sewage treatment systems may malfunction when water flow is reduced by water usage restrictions or water conservation practices. This can require designing sewer systems that operate with less water. However, such systems must also be able to cope with sudden increases resulting from more intense rainfall events; drainage of surface water combined with foul water during intense storms can result in sewer system overflows, which normally discharge to receiving waters.

AGRICULTURE

Overview

Agriculture can be defined as the science, art, and business of cultivating the soil, producing crops, and raising livestock. Agriculture in New Mexico is an integral part of the state's lifeblood, culture, history and economy.

The following summarizes the current understanding regarding the potential impacts of climate change on U.S. agriculture (Adams et al. 1999):

Crops and livestock are sensitive to climate changes in both positive and negative ways. Understanding the direct biophysical and economic responses to these changes is complicated and requires more research. In addition, indirect effects, such as changes in pests and water quality and changes in extreme climate events, are not well understood.

The impact of climate change on U.S. agriculture is mixed. The emerging consensus from modeling studies is that the net effects on U.S. agriculture associated with a doubling of CO_2 may be small, but regional changes in production may be significant. Patterns of regional change are uncertain because changes in regional climate cannot be predicted with a high degree of confidence. Beyond a doubling of CO_2, the negative effects are more pronounced both in the United States and globally.

Agriculture is a sector that can adapt, but there are some factors not included in assessments that could change this conclusion. Changes in the incidence and severity of agricultural pests, diseases, soil erosion, and ground-level ozone levels, as well as changes in extreme events such as droughts and floods, are largely unmeasured or uncertain and have not been incorporated into estimates of impacts. These omitted effects could result in a very different assessment of the true impacts of climate change on agriculture. If the rate or magnitude of climate change is much greater than anticipated, adaptation could be more difficult and impacts could be greater than currently expected.

The Regional Impacts of Climate Change: An Assessment of Vulnerability (Watson et al. 1997) reports that the productivity of food and fiber resources of North America is moderately to highly sensitive to climate change and that production could be affected in the following ways:

- Warmer climate scenarios (4–5°C increases in North America) have yielded estimates of negative impacts in eastern, southeastern, and corn belt regions and positive effects in northern plains and western regions.
- More moderate warming produced estimates of predominately positive effects in some warm-season crops.
- The ability to adapt may be limited by information gaps, institutional obstacles, high economic, social, and environmental costs, and the rate of climate change.

Rangelands and Ranching

New Mexico's production agriculture is a $1.6 billion annual industry, two-thirds of which comes from livestock, mainly cattle (USEPA 1998). The vast majority of ranching operations in New Mexico depend completely on the range to support their cattle. Success in ranching depends on the natural vegetation accessible to grazing animals. Variability in precipitation and temperature can directly affect grazing material (Southwest Regional Assessment Group 2000). Rainfall is critical in maintaining the quality and quantity of rangeland vegetation (Southwest Regional Assessment Group 2000).

Availability of water on federal and private lands is often the single most important factor determining the value of land for grazing. Without rain, ranchers may face higher costs in supplemental feed, water hauling, and cattle relocation. The decline in western water availability suggested by several studies would seriously decrease the economic viability of grazing on these lands (USEPA 2000). Livestock production would be adversely affected if summer temperatures rise significantly and conditions become significantly drier. Under these conditions, livestock tend to gain less weight and pasture yields decline, limiting forage (USEPA 1998). If ranchers are unable to reduce their herds quickly enough, or to provide needed supplemental feed or water, they run the risk of severely damaging the range ecosystem upon which they depend (Southwest Regional Assessment Group 2000).

Within existing rangelands, elevated levels of carbon dioxide may induce a shift from grasses toward shrubs and other woody plants (USEPA 2000).

Water Availability

Water is the fulcrum in the delicate balance of life in the Southwest. The continued availability, delivery, management, and demand of this precious resource are climate-dependent. Even if climate conditions remain relatively stable compared to the present, the expected increase in the human population alone would create a water shortfall (Southwest Regional Assessment Group 2000).

Lowered water supplies would likely mean higher water prices. Higher prices and lowered supplies could have severe consequences for many sectors in the region, with rural farmers, ranchers, mining operations, and urban areas being most heavily hit (Southwest Regional Assessment Group 2000).

Groundwater is the principal source of water for public, industrial, and agricultural uses in New Mexico. Irrigation, the largest user of water, relies on groundwater and surface water supplies. Much of streamflow in New Mexico results from spring and summer rainfall and snowmelt in the mountains. A warmer climate could mean less winter snowfall, more winter rain, and a faster, earlier spring snowmelt. This could result in higher winter and spring flows and the inability to store flood waters for use later in the summer (USEPA 1998).

Without large increases in rainfall, higher temperatures and increased evaporation could lower lake levels and streamflows in the summer (USEPA 1998). Less water would be available to distribute to the central and southern parts of the state, where adequate supplies for irrigation and municipal uses is a concern. In the densely populated middle Rio Grande Valley, which includes Albuquerque, the availability of adequate water to meet the needs of its growing population is a major issue (USEPA 1998).

During years of meager snowfall, many areas must supplement surface water supplies with groundwater; however, less spring and summer recharge could lower groundwater levels. This could amplify problems in the eastern and southeastern parts of the state, where groundwater levels are declining because of large irrigation withdrawals, as well as in west-central New Mexico, where groundwater development has increased to support municipal, domestic, industrial, and agricultural uses (USEPA 1998). Lower flows and higher temperatures could also impair water quality by concentrating pollutants and reducing the capacity of streams to assimilate wastes (USEPA 1998).

The limited surface waters of New Mexico are almost completely allocated through legal compacts and water rights agreements. Changes in water availability could complicate the complex water rights and allocation issues in New Mexico (USEPA 1998).

More rain could ease water competition, but it also could increase flooding. Earlier, more rapid snowmelts could contribute to winter and spring flooding, and more intense summer storms could increase the likelihood of flash floods. Increased rains also could increase erosion and pollution from runoff from mining areas, and exacerbate levels of pesticides and fertilizers from runoff from agricultural lands. Stream sedimentation is a major water quality problem in New Mexico, as is contaminated runoff from grazing lands, mining areas, urban areas, and irrigated fields (USEPA 1998).

Crops

More than one-half of the farmed acres in New Mexico are irrigated (USEPA 1998). The major crops in the state are sorghum, wheat, and hay. Projected climate change could reduce wheat yields by 10-30% and sorghum yields by 7-9% as temperatures rise beyond the tolerance levels of the crop. Hay and pasture yields could fall by 4% or rise by 9%, depending on how climate changes and the extent of irrigation (USEPA 1998). Farmed acres could fall by 20-25% as a result of climate change (USEPA 1998).

Agricultural systems are most sensitive to extreme climatic events such as floods, wind storms, and droughts, and to seasonal variability such as periods of frost, cold temperatures, and changing rainfall patterns. Climate change could alter the frequency and magnitude of extreme events and could change seasonal patterns in both favorable and unfavorable ways, depending on regional conditions (Adams et al. 1999). Increases in rainfall intensity pose a threat to agriculture and the environment because heavy rainfall is primarily responsible for soil erosion, leaching of agricultural chemicals, and runoff that carries livestock waste and nutrients into water bodies (Adams et al. 1999).

Farmers have a number of adaptation options open to them, such as changing planting and harvest dates, rotating crops, selecting crops and crop varieties for cultivation, consuming water for irrigation, using fertilizers, and choosing tillage practices. These adaptation strategies can lessen potential yield losses from climate change and improve yields in regions where climate change has beneficial effects (Adams et al. 1999).

Climate change can also have a number of negative indirect effects on agro-environmental systems effects that have been largely ignored in climate change assessments (Adams et al. 1999). These indirect effects include changes in the incidence and distribution of pests and pathogens, increased rates of soil erosion and degradation, and harmful effects of increased ground-level ozone levels on crops (Adams et al. 1999).

The National Assessment Synthesis Team (2000) reports that increased atmospheric CO_2 concentration can have positive and negative effects on crops. Greater concentrations of CO_2 generally result in higher photosynthesis rates and may also reduce water losses from plants, so crop yields generally rise if soil nutrients are not limiting. Most commercial crops in the US, including wheat, rice, barley, oats, potatoes, and most vegetable crops, tend to respond favorably to increased CO_2, with a doubling of atmospheric CO_2 concentration leading to yield increases in the range of 15-20%. Other crops including corn, sorghum, sugar cane, and many tropical grasses, are less responsive, with a doubling of CO_2 concentration leading to yield increases of about 5%.

At the national scale, crops showing generally positive results to the combined effects of climate change and increased CO_2 concentration include cotton, corn for grain and silage, soybeans, sorghum, barley, sugar beets and citrus fruits. Pastures also show positive results. For other crops, including wheat, rice, oats, hay, sugar cane, potatoes, and tomatoes, yields are projected to increase under some conditions and decrease under others (National Assessment Synthesis Team 2000).

Pests/Diseases/Weeds

Understandably, most studies have not fully accounted for changes in climate variability, water availability, crop pests, changes in air pollution such as ozone, and adaptation by farmers to changing climate. Including these factors could change modeling results substantially. Analyses that assume changes in average climate and effective adaptation by farmers suggest that aggregate U.S. food production would not be harmed, although there may be significant regional changes (USEPA 1998).

NATURAL SYSTEMS

Climate change and global warming are expected to impact the distribution and biological characteristics of plants and animals, and affect individuals, species, populations, and ecosystems through altered:

- spatial distribution, population numbers, geographic range, and migration of individual species;
- growth and physiology of individuals within a population;
- timing match (i.e., mismatches between climate patterns and a species' life history events);
- diversity of prey, predators, and competitors within communities;
- species composition and distribution within ecosystems;
- migration and movement corridors;
- exotic and invasive species introductions and distribution;
- parasite and disease risks; and
- ecosystem functioning (e.g., nutrient cycling) and structure (McCarty 2001, Johannes 2004, Parmesan and Galbraith 2004).

Climate changes that are expected during this century will occur within the context of increasing human populations and demand for land and water (Izaurralde et al. 2005). Habitat destruction, overharvesting, contamination, and the introduction of exotic organisms may amplify the effects of climate change on natural systems (Parmesan and Galbraith 2004).

On the global scale, effects of global warming can already be seen in changing life patterns of animals and plants, including consistent trends of poleward shifts in geographic ranges, upward shifts in elevational ranges, and shifts of seasonal life history stages to earlier in spring (Parmesan and Yohe 2003, Parmesan and Galbraith 2004)

Ecosystem Impacts

Aquatic Ecosystems

Covich et al. (2003) report that global warming is expected to reduce montane snowpacks, increase stream temperatures, advance seasonal hydrographs, reduce soil infiltration, and increase evaporation. More rapid runoff and higher peak flows would increase bank erosion and sediment transport, and silt up spawning gravels. Earlier snowmelt and higher temperatures are expected to result in lower summer streamflow (Poff et al. 2002). Lower dissolved oxygen and warmer waters will stress many species of fish and invertebrates and increase mortality, particularly in late summer.

Spring peak flows during snowmelt are forecast to be lower and earlier. Other effects include:

- reduced surface water availability, especially during summer months;
- less water available to sustain aquatic systems;
- decreases in dissolved oxygen;
- reductions in streamflow in late summer (Poff et al. 2002);

- less instream habitat for invertebrates and fish;
- significant changes in species composition and productivity;
- warming of groundwater and spring-fed streams; and
- adverse effects on eggs and larvae of fish.

Changes are expected in biotic diversity in springs and playas in the southern Great Plains (i.e., eastern New Mexico). As a result of increased evaporation with increasing air temperature, declines are anticipated in lake levels, water renewal rates, stream flows, the extent of and water levels in wetlands, soil moisture, and groundwater levels (Schindler 1997).

Fish in streams of the southern Great Plains, including eastern New Mexico, may be particularly vulnerable to local or complete extinction due to global warming (Matthews and Zimmerman 1990). If warming of 3-4°C occurs, a substantial number of species endemic to this region could face extinction unless they adapt behaviorally or genetically for thermal increases. Overall, the outlook for native fishes of the Great Plains and southwest is bleak if predicted temperature increases occur.

Effects of expected global warming on fish include:

- increased extinction rates for endemic fish species and isolated local populations in Great Plains streams;
- shifts in the distributions of cold-water fish species northward and to higher elevations (Covich et al. 2003);
- increases in warm-water fish species;
- coldwater fishes to be replaced by warmwater species such as suckers (Covich et al. 2003);
- climate warming favoring non-native species such as brown trout, or rainbow trout at the expense of native species such as cutthroat or bull trout in some habitats within the Rocky Mountain region;
- fragmentation of remaining coldwater fish populations into isolated, high-elevation enclaves;
- loss of geographic range in the Rocky Mountains of suitable habitat for trout of 17 to 72% (Keleher and Rahel 1996);
- direct adverse effects on trout reproduction (Hauer et al. 1997); and
- reduced recruitment of all fish species (Northcote 1992).

Other changes affecting fish include permanent streams becoming intermittent and shorter flow duration in temporary streams (Stanley and Valett 1991), greatly reduced area of wetted channel in ephemeral streams (Covich et al. 1997, cited in Meyer et al. 1999), population declines, loss of habitat, changes in the community, negative effects from changes in water quality, movement within catchments, and crowding of fish in reduced microhabitats.

Effects of global warming on lakes and reservoirs include:

- insufficient oxygen in deeper, cool water in late summer to support large game fish.;
- reduced potential recreational uses of reservoirs (Covich et al. 1997);
- altered lake stratification by mid to late summer (Covich et al. 2003);

- reduced dissolved oxygen concentration;
- lowered level of the thermocline;
- reduction in coldwater habitat (Poff et al. 2002);
- loss of habitat for coldwater fish species in lakes (van Dam et al. 2002);
- extinction of endemic fish species already close to their lethal thermal limits;
- reduced storage of surface flows in reservoirs through the summer and fall;
- increased evaporative losses;
- reduce fish populations through reduction in habitat and habitat quality, increased predation, increased competitive interactions, stress due to competition and lack of adequate cover, decreased fitness and increased susceptibility to disease;
- increased potential for production of nuisance algae;
- declines in water quality; and
- increasing salinity.

Effects of expected climate change on aquatic invertebrates include reduced total densities of macroinvertebrates in stream and river ecosystems, reduced size at maturity and faster development; and altered fauna of unique springs.

Expected effects of global warming on wetlands include drying trends, changes in structure and functioning, reduced extent of semi-permanent and seasonal wetlands; and gradual replacement of original wetland species species that are typical of drier, transition or upland sites (IPCC 2001b).

Expected changes to riparian systems include altered composition of riparian vegetation (Meyer and Pulliam 1991), unsuitable conditions for cottonwood regeneration and declines in cottonwoods, establishment of non-native or competitive species (e.g., saltcedar, Russian olive, Siberian elm), and loss of riparian species diversity (e.g., Merritt & Cooper 2000, cited in Poff 2002).

<u>Terrestrial Ecosystems</u>

Changes in terrestrial ecosystems will likely include changes in population density, shifts in range distributions either poleward or upward in elevation, and changes in the timing of life history events such as migration or initiation of breeding. Anticipated effects of climate change on phenology (timing of critical life history events) include earlier breeding or first singing of birds, earlier arrival of migrant birds, earlier appearance of butterflies, earlier choruses and spawning in amphibians and earlier shooting and flowering of plants. Changes in timing of bird migration and plant growth may not be synchronized, resulting in a mismatch in the timing of migratory bird offspring food availability and the timing of chick hatching.

Animal and plant populations have already shown marked responses to increases in global temperature. From a meta-analysis of a large number of species or groups of species (Parmesan and Yohe 2003), range shifts averaging 6.1 km (3.8 mi)per decade over the last 50 years toward the poles and advancement of spring events averaging 2.3 days per decade were found. A similar analysis found that the average shifts in spring phenology (breeding or blooming) in temperate species was 5.1 days earlier in a decade (Root et al. 2003).

Effects of climate change on plants include:

- displacement of biome boundaries;
- migration of the climatic boundaries of biomes northward;
- native plant migration and adaptation;
- new combinations of plant species (Walker and Steffen 1997);
- reduced local biodiversity;
- increased susceptibility of plant communities to natural and anthropogenic disturbances and eventual reductions in species diversity (Davis 1989, Huntley 1991; Overpeck et al., 1991);
- stranding of trees in unsuitable habitat by rapid climate change (Pitelka et al. 1997);
- changes in ecosystem composition and function (e.g., Sykes and Prentice 1996, Solomon and Kirilenko 1997, Kirilenko and Solomon 1998);
- invasion of alien plant species into natural ecosystems; and
- establishment and growth of new vegetation assemblages (Walker and Steffen 1997).

Habitat fragmentation is likely to impede plant migration in the future (Etterson and Shaw 2001). The complex topography and intense gradients of precipitation and temperature with elevation in the Southwest's mountain ranges have implications for ecosystem response to climatic variation and changes (SWRAG 2000). To some extent the existence of these gradients provides corridors for migration and the expansion or shrinkage of species' ranges into appropriate microclimates. However, some species typical of these "islands" of cooler habitat might be eliminated during droughts or hot periods, and recolonization across the region's desert basins might be difficult or impossible (McDonald and Brown 1992, DeBano et al. 1994).

Climate change is likely to be especially damaging for ecological communities and species that have suffered the greatest losses from human development and habitat destruction and fragmentation, such as wetlands, riparian forests, and native prairie (Malcolm and Pitelka 2000). Topographically complex regions, such as the southern Rocky Mountains and Madrean Archipelago (bootheel region) in New Mexico, are among the most vulnerable to climate change, because of inherent limits to migration due to complex topography (Diffenbaugh 2005).

New Mexico Ecoregions

<u>Southern Rocky Mountains</u> (Sangre de Cristo, Jemez, and San Juan Mountains)
Projections of declining snow cover during this century anticipate many changes in alpine ecosystems (Inkley et al. 2004). Alpine snow cover will likely recede 100–400 m (330–1,310 ft) upslope in some alpine regions during the next century (IPCC 1996).

In the Southern Rocky Mountains, under increasing temperatures (+1.5 to +3.0 C), increased winter precipitation, and decreased growing-season precipitation, the net effect would be a significant decrease in soil-available water, or an increase in soil drought (Reiners 2003), significant increases in evapotranspiration, significant decreases in productivity, losses of area in forested ecosystems, and local losses of native species. High-elevation subalpine ecosystems are likely to be lost. Areas occupied by whitebark pine will be lost due to restriction of the species to higher elevations.

Southern High Plains (eastern New Mexico shortgrass prairies)
Decreased precipitation might eliminate many of the smaller water bodies and the aquatic communities dependent on them. Many isolated spring systems that harbor endemic fishes would be at risk (Minckley and Deacon 1991).

Northern Chihuahuan Desert (southern New Mexico lowlands)
Arid and semiarid lands may be among the first regions in which ecosystem dynamics become altered by global environmental change. In total, the changes would represent (1) reduction in soil fertility, Carbon/Nitrogen ratios, and microbial action; (2) enhanced physical changes, all resulting in soils less conducive to plant production; and (3) reduced resistance to erosive loss.

Brown et al. (1997) demonstrated that a substantial ecosystem reorganization at the northwestern extent of the Chihuahuan Desert (i.e., southeastern Arizona, applicable to the bootheel of extreme southwestern New Mexico) appeared to be caused by a shift in regional climate since the late 1970s. Increased precipitation, especially during winter months, appears to have been directly or indirectly responsible for changes in woody shrub density, local extinction of previously common animals, and concomitant increases in numbers of previously rare species.

Encroachment of shrubs into grasslands is likely to continue and move northward. Increasing CO_2 concentrations appear to tip the competitive balance in favor of shrubs over grasses (Polley et al. 1996). This woody encroachment reduces the economic potential of the landscape as rangeland, and increases the likelihood of soil loss during dust storms and extreme rain events, which are expected to increase in frequency as a result of global warming. As shrubs expand northward, changing habitats will result in changes in the distribution of animal species associated with shrublands and grasslands.

Great Basin (northwestern New Mexico lowlands)
Sonoran Desert species could move north into the Great Basin, as predicted by Neilson (1998), including in particular an increase in warm-season, perennial grasses, which would replace the present Great Basin shrubs and perennial herbaceous species (Wagner 1998).

Madrean Archipelago (mountains of New Mexico bootheel)
The term "Madrean Archipelago" refers to the mountains and highlands of northwestern Mexico, southeastern Arizona, and extreme southwestern New Mexico. Climatic and other effects of a doubling of atmospheric carbon dioxide on forest communities of the Madrean Archipelago might include a 200-1,500 km (124-932 mi) shift to the northwest of some tree species (Fisher et al. 1995). At many locations more than a 2-3°C (4-5°F) rise in temperature would cause the upper boundary of the forest to shift upward beyond the top of the mountain it occupied, resulting in shrinkage in area of the forest or disappearance altogether (Fisher et al. 1995). There may be loss from the Madrean region of forest species that are commercially valuable as those species migrate northward to adapt to changing climatic conditions. The forest species that occupy the lower latitudes (18-30 degrees) may replace those species lost as the dominant commercial species in this region.

Increased woody plant establishment and growth at the expense of grasses may cause woodland boundaries to shift downslope. A shift from grassland to woodland would reduce herbaceous biomass, and subsequently reduce fire frequency because of decreased accumulation of fine fuel.

Terrestrial Vertebrates

Amphibians

Many native species, particularly fishes and amphibians, are currently in rapid decline throughout the Rocky Mountain Region (Gresswell et al. 1995, Nehlsen et al., 1991) as a consequence of habitat degradation and food-web change (Hauer et al. 1997). Climate warming and resulting eutrophication of lakes will exacerbate problems of biodiversity and ecosystem integrity already associated with destabilized food-web structure and enhancement of non-native species populations.

Amphibian populations and distributions are likely to change significantly as air and water temperatures warm (Elmberg 1991). Climate change could potentially disrupt amphibian breeding if global warming caused amphibians to breed earlier in the spring than in previous years. Species inhabiting high-altitude areas would be at particular risk (Hamilton 1995, Pounds et al. 1999). Other changes to amphibians may include reductions in larval-period length. Larvae in warmer habitats often metamorphose at smaller sizes (Werner 1986, Smith 1987). Smaller adult body size may lead to reduced mating success for males (Berven 1981) or reduced fecundity for females (Berven 1982).

Reptiles

Because of their limited dispersal abilities, reptiles with small ranges are especially vulnerable to rapid habitat changes and may be severely restricted or suffer extinctions as a result of a rapid rate of climate change (Schneider and Root 1998, cited in Gibbons et al. 2000). Additional effects of warming on some reptiles, based on empirical evidence with freshwater turtles, include enhanced juvenile growth rates, earlier ages at maturity, and shifts in functional sex ratios (Frazer et al. 1993).

Global warming may have the greatest impact on turtles that have temperature-dependent sex determination (Janzen 1994), whereby the sex ratio of the hatchlings is determined by nest temperatures during incubation. Unless shifts occur in the pivotal temperatures at which sex is determined, or female nest-site choices (i.e., shade versus sun) evolve to keep pace with rising temperatures, altered sex ratios could affect population demographics and persistence (Gibbons et al. 2000).

Birds

There is already compelling evidence that animals and plants have been affected by recent climate change (e.g., Walther et al. 2002, Parmesan & Yohe 2003, Root et al. 2003). These effects include earlier breeding; changes in timing of migration; changes in breeding performance (egg size, nesting success); changes in population sizes; changes in population distributions; and changes in selection differentials between components of a population (Crick 2004). If seasonality changes cause closely interacting species to become out of phase, essential ecological processes such as pollination, seed dispersal, and insect control (by birds) can be disrupted (Price 2002).

Some spring migrant birds in the U.S. now have earlier arrival dates (Ball 1983, Price and Root 2001) and breeding times (Brown et al. 1999, Dunn and Winkler 1999). Climate change may cause a mismatch in the timing of breeding between birds and their prey. This decoupling could lead to eggs hatching when food supplies may be low in abundance (Visser et al. 1998).

Important avian guilds (groups of functionally similar species) are in rapid decline and consequent reductions in ecosystem processes are likely (Sekercioglu et al. 2004). Greater-than-average extinction rates are expected for frugivores (fruit-eaters), herbivores, nectarivores (nectar-eaters), piscivores (fish-eaters), and scavengers.

Montane habitats in the Colorado Rockies provide examples of phenological miscuing: higher spring temperatures have led to the earlier arrival of American Robins (*Turdus migratorius*) and the earlier emergence of Yellow-bellied Marmots (*Marmota flaviventris*) from hibernation (Inouye et al. 2000). However, despite higher temperatures, the date of snowmelt has not changed because of the greater volumes of snow present due to increases in winter precipitation with the higher temperatures. Thus the interval between arrival or emergence and the first date of bare ground has actually lengthened, which may cause problems for migratory and hibernating species (i.e., these species arrive/emerge to find snow cover instead of bare ground, growing vegetation, and insect prey) (Crick 2004).

In the upland piñon-juniper habitats of central New Mexico, Bewick's wrens have been increasing (Taylor 2003). Warming climate may be a factor in the population increase and expansion in distribution.

Mammals

Change in the ranges and abundances of mammals are expected. Mammalian responses will likely consist of adjusting phenotypes and minor adjustments in geographic ranges.

Both summer and winter temperatures increased at the Sevilleta Long Term Ecological Research Station by 2.5–3°C for the years 1989 through 1996 (Smith et al. 1998). White-throated woodrat (*Neotoma albigula*) adult mean body mass decreased as temperature increased. Merriam's kangaroo rat (*Dipodomys merriami*) adult mean body mass showed no trend across years and no relationship to climate variables (Koontz et al. 2001). Temperature increases like these may influence rodent communities by altering species' ranges and/or abundances (Tracy and George 1992). With a shift in species distributions, whole ecosystems may change via the invasion or disappearance of species.

Biodiversity and Endangered Species

There is a growing consensus within the scientific community that climate change will compound existing threats to declining species and lead to an acceleration of the rate at which biodiversity is lost (Parmesan and Galbraith 2004). The species that are most vulnerable to extinction from whatever cause are those with restricted ranges, fragmented distribution within their range, low populations, reducing range, decreasing habitat within the range, and/or which are suffering population declines (Price et al. 2000, cited in Hare 2003). Species with quite restrictive habitat requirements are most vulnerable to extinction (Pimm et al. 1995). Where climate change is projected to reduce habitats of such species there are likely to be the greatest extinction risks.

Climate warming is likely to be the greatest threat to global biodiversity in many if not most regions (Thomas et al. 2004). A large body of research suggests that extinction risk in nature tends to be ordered by factors such as population size, body size, trophic position, phylogenetic history, or sensitivity to an environmental stress (Gross and Cardinale 2005). Population size and trend in population size were the best predictors of extinction risk (O'Grady et al. 2004).

Extinction risk in warming environments depends on the species position in the food web. Warmed communities disproportionately lose top predators and herbivores, and become increasingly dominated by autotrophs (e.g., plants, algae) and bacteriovores.

The destruction of riparian areas, primarily through overwhelming pressures for water resources and overgrazing, is the single most important factor threatening and endangering many species of fish and wildlife in New Mexico, according to USEPA (1998). Climate change could exacerbate these existing threats. Reductions in riparian areas could ultimately alter avian species number and community composition, with the loss of many species that rely on riparian vegetation for nesting and food resources, such as the endangered southwestern willow flycatcher.

Mountaintop island habitats are equally vulnerable to changing conditions. Whereas other ecosystems may have room for species to migrate in response to warming temperatures, those in mountain areas could have little room to move upslope.

Rio Grande silvery minnow: Recent wet winters resulted in overbank flooding opportunities at the proper time regarding water temperature for successful reproduction. If a higher winter precipitation pattern continues in the future, the opportunity will exist to store runoff in reservoirs for release at proper times of the spring to benefit silvery minnow spawning.

Warmer winters would likely cause both peak flows and optimal water temperature for reproduction to occur earlier in the year. Thus, optimal flows and optimal water temperatures may occur at the same time and allow the silvery minnow to spawn earlier in the year if other requirements for successful reproduction are also met. However, it is not certain that the shifts in seasonal timing of optimal flows and optimal temperatures would be such that both these conditions occurred at the same time.

If winter precipitation is less in the future, surface flow will likely be reduced as a result of less snowmelt runoff, increased evapotranspiration due to warmer temperatures, recharge of soil moisture (bank storage) lost to increased drying in the warmer temperatures, and recharge of water tables and shallow aquifers drawn down by evapotranspiration, pumping, and reduced basin recharge. Less surface flow would mean more intermittence and fewer summer low-flow refugia for the silvery minnow, which would result in reduced recruitment of young silvery minnows to the population.

Southwest willow flycatcher: Reduced surface flows and lowered water tables will result in declining riparian health and reduced suitability of habitat for the flycatcher. Less surface water in the riparian zone will reduce the amount of available habitat for the flycatcher. Reduced flows and lowered water tables will also result in the conversion of portions of the floodplain to grasses and transition or upland species of plants, reducing the amount of potential habitat for the flycatcher. Less habitat and lower quality habitat will result in reduced reproduction and survival of flycatchers.

Catastrophic change in forests: drought, fire and insect outbreaks

New Mexico's forests are important as watersheds, and for wildlife habitat, wood products, and recreation. Forests are also a potential wildfire threat to mountain communities.

Projected climate changes are likely to produce dramatic and significant changes to New Mexico forests, through the effects of warming and drought (punctuated by unusually wet periods) on tree water stress, insect outbreaks and fire.

Wildfire

Hotter, drier weather could increase the frequency and intensity of wildfires (USEPA 1998). A warmer climate will mean a longer fire season, and more episodes of extreme heat when fire danger is high (Wotton and Flannigan 1993). Relations between fire and precipitation are complex. In lower elevation grasslands and woodlands, an unusually wet winter and spring increases fire hazard, while at high elevations fire hazard is diminished (Crimmins and Comrie 2004). However, large fire years are associated with drought in the current year and unusually wet conditions in the preceding 1-5 years (Swetnam and Betancourt 1990). On a regional scale and over the past three centuries, the area burned by wildfire in the Southwest has been unusually high during periods of large-scale, persistent drought (Westerling and Swetnam 2003). McKenzie et al. (2004) found that total annual area burned in New Mexico was very sensitive to increasing annual and seasonal temperature; extrapolating the relationship to the warmer climate predicted by climate models for the next century yielded a potential 5-fold increase in area burned.

Contrary to popular belief, forest dieback caused by drought stress or insect outbreaks (see below) may increase fire hazard only for a brief period until the needles fall, after which the amount and continuity of fine fuels in the crown is reduced and the hazard of crown fires is less (Allen 2004).

Insect Outbreaks

The die-off of piñon trees in New Mexico in 2002-2003 was part of a regional scale episode of "massive forest dieback"; in Southwestern forests, 3 ½ million acres of piñon pine and 2 million acres of ponderosa pine were affected (Allen 2004). Piñon die-off in 2002-2003 was much greater in magnitude and extent than the last previous episode of high mortality in the 1950s drought, killing piñons of all age classes across the whole range of the species (Breshears et al. 2005). The key difference, Breshears et al. (2005) suggest, is that the 2002-3 drought was significantly warmer, which would create greater water stress in the trees.

Bark beetle outbreaks interacted with the effects of drought in causing the recent piñon and ponderosa pine die-offs. Trees defend against beetle attack by producing large amounts of sap, but drought reduces sap flow and allows beetles to overcome the tree's defense. Once beetle populations build up, they can successfully attack less severely stressed trees by "mass attack" (Allen 2004). Not all insect outbreaks are associated with drought. For example, large-scale outbreaks of western spruce budworm, which eats foliage rather than bark, have been associated with wet periods, perhaps because its population is controlled by quality and quantity of its food supply (Swetnam and Betancourt 1998).

Warmer temperatures can also be conducive to bark beetle outbreaks through direct effects on the beetles and their larvae, by reducing winter mortality and by allowing a longer breeding season. Temperatures have warmed dramatically in southwestern mountains in recent decades. For example, at McNary in the White Mountains of Arizona, the number of frost-free days per year has increased from 102 to 147 since 1940, even though average temperature has only increased by 1°C (1.8°F) (Lynch 2005). Logan and Powell (in press) describe the multiple large outbreaks of bark beetles currently underway throughout the mountain West as "unprecedented", and conclude that a warming climate is the only common factor across all of these events

Wildfire suppression over the last century has greatly reduced the area burned in New Mexico, resulting in hazardous accumulations of fuel and the growth of understory brush and small trees ("ladder fuels") that are conducive to catastrophic crown fires (Swetnam and Betancourt 1998). A shift toward greater cool-season precipitation since 1976 probably contributed to higher tree densities (Allen 2004). These increases in biomass and tree density have made New Mexico forests especially vulnerable to both catastrophic fire and dieback from drought and insect attacks. Increasing CO_2 levels may increase the rate of biomass accumulation even further in the 21^{st} century (Norby et al. 2005, DeLucia et al. 2005).

Forest management is increasingly directed towards restoration of historical conditions or trajectories, such as restoring ponderosa pine forests to their presettlement park-like structure, which was maintained by frequent ground fires but rarely experienced crown fires (Dahms and Geils 1997). Under the rapidly changing climate of the 21^{st} century, historical conditions will become increasingly less feasible as a management goal.

Effects on Ecosystem Goods and Services

The loss or reduced capacity of ecosystem services may be one of the major sources of surprise from climate change and variability (Inkley et al. 2004). As the human population continues to grow in the 21^{st} century so, too, will its need for the goods and services that terrestrial ecosystems provide.

Most of the goods and services provided by wildlife (e.g., pollination, natural pest control, seed dispersal, nutrient cycling) are derived from their roles within systems. Other valuable services are provided by species contributing to ecosystem stability or to ecosystem health and productivity. The recreational value (e.g., sport hunting, wildlife viewing) of species is large in market and non-market terms. Species loss also could impact the cultural and religious practices of indigenous peoples around the world. Losses of species can lead to changes in the structure and function of affected ecosystems and loss of revenue and aesthetics (IPCC 2001b). Vegetation protects soil against erosion, and forest dieback or catastrophic wildfires can greatly increase watershed sediment yield (Allen and Breshears 1998, Miller et al. 2003), potentially reducing water storage capacity in reservoirs.

One critically important service is the role ecosystems play in controlling the emergence and spread of infectious diseases by maintaining equilibria among predators and prey, and among hosts, vectors and parasites in plants, animals and humans (Chivian 2001). The hantavirus pulmonary syndrome outbreak in the southwestern United States provides an example of how a pattern of year-to-year variability in precipitation can impact an ecosystem and lead to emergence of an infectious disease potentially lethal to humans (see Environmental Quality and Health section of this report).

OUTDOOR RECREATION AND RELATED TOURISM

Opportunities for outdoor recreation are valued by New Mexicans as an important part of their quality of life, and are very important in attracting tourists whose visits support the tourism industry and the state's economy (New Mexico Tourism Department 2005). Some New Mexico communities are heavily dependent on outdoor recreation related tourism for their local economy.

Potential impacts of climate change on outdoor recreation and tourism include:

Skiing and other snow sports: As noted elsewhere in this report, warming will be especially pronounced in winter and spring, and at high elevations, resulting in a winter precipitation falling more as rain and less as snow. Mountain snowpacks and the duration of the snowfields will be substantially reduced. Ski and snow sport areas at lower elevations and southerly locations may be forced to close, and others may have difficulty remaining economically viable with a severely limited season of operation and unpredictable snow conditions from year to year.

Water recreation (boating, sailing, white-water rafting and kayaking, swimming): Warmer temperatures will exacerbate cyclical droughts to further reduce water levels in New Mexico's lakes and rivers, which draw hundreds of thousands of visitors each year for various forms of water recreation. If New Mexico experiences another protracted drought, lower water levels in reservoirs and rivers will significantly reduce these recreational activities. Because of earlier runoff, peak white-water rafting and kayaking conditions will tend to occur during the school year, reducing its attractiveness to tourists whose vacations are tied to school schedules.

Camping, fishing and hunting: Increasing frequency and duration of forest closures because of high wildfire hazard will restrict access to these activities in mountain areas. Warmer water temperatures are projected to reduce habitat for trout by 50-100% in New Mexico (USEPA 1999). Angling for warm-water fish (bass, striped bass) in lakes may be adversely impacted by lower water levels and warmer water temperatures in reservoirs. Habitat changes (see Natural Systems chapter of this report) may adversely impact hunting opportunities for ducks, and possibly for deer, elk, pronghorn, and other game.

Outdoor sports requiring strenuous activity (e.g., soccer, football, track, running): These may need to be restricted during episodes of extreme heat or increased air pollution.

Scenic vistas: Scenic vistas of New Mexico's natural beauty draw thousands of visitors annually. Increased levels of air pollution (see Environmental Quality and Health section of this report) would compromise such vistas and could adversely affect tourism as well as the quality of life for New Mexicans.

ENVIRONMENTAL QUALITY AND HEALTH

Air Pollution

Ozone (Smog)
Climate change could increase peak concentrations of ground-level ozone in New Mexico. Ground-level ozone, the main ingredient of smog, is an air pollutant that can aggravate asthma and chronic lung diseases, and may cause permanent lung damage. New Mexico currently has three areas with elevated ozone levels that nearly exceed the federal health standards: Bernalillo County, Rio Rancho, Sunland Park (adjacent to El Paso-Juarez), and San Juan County.

Ozone is formed when volatile organic compounds (VOCs) and nitrogen oxides (NOx) react in the presence of sunlight. VOCs and NOx are emitted by motor vehicles, power plants, refineries and other industrial sources, and other VOCs are emitted by vegetation.

Ozone concentrations tend to be highest on hot, sunny days. High temperatures increase ozone levels in several ways: 1) increased evaporation of VOCs, 2) increased NOx production from power plants as they increase output to meet demands for more air conditioning; and 3) increased rates of the chemical reactions which produce ozone. Modeling studies have been used to quantify the effect of temperature on ozone formation in other regions of the U.S. (Grambsch 2002). The magnitude of the temperature effect varies, but the results suggest that the effect of likely temperature increases in New Mexico could be a 5-20% increase in ozone concentrations, which would likely result in exceedance of the federal air quality standards in some areas of the state.

During air stagnation episodes, pollutants accumulate in the lower atmosphere near their source, causing unusually high pollution levels to persist for several days. High-resolution regional climate modeling has been used to project the effects of global warming on air stagnation episodes in the U.S. (Leung and Gustafson 2005). Results indicate that the number of stagnation days in New Mexico during the fall is likely to double. This would augment the effects of higher temperature and result in even higher concentrations of ozone.

Actual 21st century ozone levels will depend greatly on changes in emissions of ozone precursors, which are largely produced by fuel combustion. Emissions would tend to increase with population growth, but this trend could be reversed if there are increases in vehicle fuel economy and a switch to renewable energy sources for electricity production.

Particulate Matter (Smoke and Dust)
Particulate matter refers to very small particles and droplets suspended in the air. Health effects of particulate matter range from irritation of the eyes and respiratory tract to more serious problems such as aggravation of asthma, bronchitis, reduced lung function, increased cardiovascular disease morbidity and mortality, and premature death.

Some of New Mexico's worst air quality episodes have been caused by smoke from large, catastrophic wildfires. In recent years, thick smoke from wildfires has far exceeded federal health standards, and health concerns have led to evacuations of some heavily impacted communities. Large wildfires in neighboring states have caused significant deterioration of air quality and reduced visibility over large parts of New Mexico, sometimes for several consecutive days.

Global warming will likely increase the risk of large wildfires (McKenzie et al. 2004, and see under Forests in this report). High temperatures during droughts will reduce fuel moisture and increase the likelihood of catastrophic fire. If increased atmospheric levels of CO_2 do have a "fertilization effect" which increases forest vegetation growth when moisture is available (Norby et al. 2005), this will result in higher fuel loads which can burn when drought returns. Episodes of thick smoke caused by wildfires will likely increase as a result of climate change.

The need to reduce fuel accumulations and restore forest ecosystems to a more natural state has led land management agencies in New Mexico to step up their prescribed burning activity. Prescribed burning is likely to increase even more as climate change increases wildfire hazards. Although smoke from prescribed burning is managed to minimize impacts, some adverse impact on air quality and visibility will result from more prescribed burning.

Dust storms are a frequent occurrence in the drier parts of New Mexico. For example, some areas in Doña Ana County commonly experience 6 to 15 or more days per year when the levels of particulate matter exceed federal air quality standards because of dust storms. In addition to causing health problems in people breathing the dust, these storms are a safety hazard. In recent years, severe dust storms have caused serious driving hazards on highways, resulting in fatal accidents and closures of the interstate highways.

Dust storms tend to be more frequent, more severe, and more widespread during droughts, especially long-term droughts. Drought increases the susceptibility of soil to blowing by reducing vegetation cover, by the lack of surface crusts formed by rain, and because dry soil blows easily. New Mexico has large areas of surface soils which are inherently susceptible to blowing but are currently stabilized by desert or grassland vegetative cover (SWRAG, 2000). Severe drought during the 21^{st} century will likely result in more frequent and more widespread dust storms, which will significantly reduce air quality.

Heat-Related Illnesses and Death

In New Mexico, episodes of extreme heat are projected to increase several-fold in the mid to late 21^{st} century as a result of global warming; daily maximum temperatures which are now exceeded on only the hottest 18 days of the year are projected to be exceeded on 60 to 70 days per year (Diffenbaugh et al. 2005). Nighttime low temperatures during heat waves are also projected to increase significantly (Meehl and Tebaldi 2004).

Mortality rates can increase significantly during heat waves, especially in urban areas (Patz et al. 2000). Prolonged heat is associated with heat cramps, heat exhaustion and heat stroke, and increases the likelihood of heart attacks and stroke in people with cardiovascular disease. The most vulnerable populations are infants, children, the elderly and the infirm (Physicians for

Social Responsibility 2000). Heat-related illness occurrence and mortality depend not only on daily maximum temperature, but can be further increased by unusually high nighttime minimum temperatures, high humidity, increased duration of the heat wave, and if the heat wave occurs early in the summer before people have acclimated to hotter weather (Balbus and Wilson 2004).

Even though residents of the desert southwest are better acclimated to high temperatures than people living in cooler regions, episodes of extreme heat can still cause mortality and illness, as evidenced by the heat-related deaths occurring in Phoenix during the heat wave of summer 2005 (CBS News 2005). Adaptation to higher extreme temperatures can require changes of behavior and lifestyle, such as curtailing strenuous outdoor activities during the heat wave. In New Mexico, the adverse effects of future heat waves may be greatest not in the desert areas, but in higher-elevation and northerly areas where air conditioning is lacking in most homes and many schools and other public buildings.

Infectious Diseases

Infectious diseases that have animal hosts or reservoirs are potentially sensitive to climate change. Future risks of these diseases are very difficult to predict, because of the many factors affecting these risks, and the complexity of disease transmission dynamics (Balbus and Wilson 2004).

<u>Mosquito-borne diseases</u>
Diseases transmitted to humans by mosquitoes include dengue fever, malaria, and arboviruses such as western equine encephalitis and West Nile virus. Warmer temperatures can increase the epidemic potential of these diseases by shortening the incubation period of the disease-causing organism in the mosquito, and by increasing the feeding frequency of the mosquito (Martens et al. 1995, Patz et al. 1998). Warmer temperatures may also increase the breeding season of mosquitoes, increasing the likelihood of them transmitting disease.

Dengue fever is one of the most serious mosquito-borne viral diseases of humans and is a leading cause of childhood deaths and hospitalizations in many countries of the tropics and subtropics (Hopp and Foley 2003). Dengue is carried from person to person by the mosquito, so the disease spreads faster the more people are infected. There is currently no effective vaccine against dengue. The eggs and larvae of the mosquitoes that carry dengue fever (*Aedes aegypti* and *Aedes albopictus*) do not survive freezing winter temperatures, so their distribution in the southwestern United States is currently limited to southern Arizona and southern Texas. Dengue fever is prevalent in northern Mexico, but only a few locally-acquired cases have been reported in the United States.

One model of virus and mosquito responses to temperature indicates that global warming is likely to greatly increase epidemic potential in the southwest U.S. (Patz et al. 1998). In New Mexico, global warming is projected to increase winter minimum temperatures substantially (Diffenbaugh et al. 2005), which could bring areas of southern New Mexico within the climate range of dengue fever vectors.

The sharp contrast between high dengue incidence in northeast Mexico and low incidence just across the border in Texas indicates incidence and transmission of the disease are greatly affected by factors other than climate, such as well developed public health infrastructure, use of air conditioning, and window screens (National Assessment Synthesis Team 2000).

Rodent-borne diseases

Plague is a bacterial disease usually contracted from the bite of an infected flea carried by a prairie dog or other rodent. Outbreaks of plague in New Mexico have been linked to increased winter and spring precipitation, which increases vegetation growth and rodent abundance (Parmenter et al. 1999).

Hantavirus is another disease with a reservoir in infected rodent populations, but is transmitted to humans by inhalation of air containing particles contaminated with dried feces and urine of an infected mouse. Six years of drought in the Four Corners area ended in the late winter and spring of 1993 with unusually heavy snow and rainfall, associated with an El Niño event. The drought had reduced the populations of owls, snakes and foxes, the natural predators of the native deer mouse, while the increased precipitation led to a heavy crop of pine nuts and grasshoppers, food for the mice (Wenzel 1994). As a result, there was a 10-fold increase over baseline levels in the deer mouse population. Rodent populations can increase quickly when food is abundant, but predator populations are slower to respond.

During this period a severe respiratory syndrome developed rapidly in 17 previously healthy people, most of them Native Americans; 13 of them died (Duchin et al. 1994). It was discovered that the deer mice were carrying a new strain of hantavirus that they shed in their saliva and excreta. With the greater numbers of mice, there was a greater chance for viral transmission among mice and for people to come in contact with mouse excreta and thus to become infected (Kolivras and Comrie 2004).

For hantavirus and plague, it appears that the pattern of year-to-year variability in precipitation (relatively dry years followed by an unusually wet year) is important in creating conditions conducive to disease outbreaks (Glass et al. 2000, 2002). This precipitation pattern may be becoming more frequent in New Mexico. In central New Mexico, year-to-year variability in precipitation was greater in the 20th century than any period in the last 1,370 years (Grissino-Mayer et al. 2002), and the contribution of extreme precipitation events to annual totals has increased in the Southwest during the late 20th century (Mock 1996). Global climate models project a greater likelihood of drought in mid-latitude continental interiors, more intense precipitation events, and possibly an increase in El Niño-like conditions (IPCC 2001a); in combination, these trends could increase the frequency of the precipitation pattern (drought followed by unusually wet year) conducive to hantavirus outbreaks.

Coccidioidomycosis (Valley Fever)

Valley fever is a fungal disease endemic to the San Joaquin Valley of California and drier parts of the southwestern U.S., including southern New Mexico. Most people infected do not have any symptoms, and others have mild influenza-like symptoms. However, in about 1% of infected individuals, the disease spreads beyond the lungs to other parts of the body and causes serious, sometimes fatal, conditions such as meningitis and damage to internal organs (Kolivras and Comrie 2004).

The fungus lives in the soil and produces spores in the surface soil layers. The disease is contracted by inhalation of spores that have become airborne in a dust storm or by mechanical disturbance of the soil.

Effects of climate on valley fever incidence are complex: soil moisture is conducive to fungus growth and spore production, extreme heat may suppress spore production in soil surface layers, and drought and high wind events produce dust storms that suspend and disperse the spores. In Tucson, valley fever incidence is associated with high levels of suspended dust, and with precipitation occurring in the foresummer (April-June), the hottest and usually driest season, one or two years earlier (Comrie 2005).

Although further study is needed for a more complete understanding of valley fever responses to climate, it is reasonable to expect that global warming is likely to increase the distribution and incidence of the disease in New Mexico. The hot, arid climate conducive to growth of the fungus will likely spread northward and to higher elevations, and dispersal of airborne spores would be enhanced by more widespread and severe dust storms.

<u>Future Disease Threats</u>

With continued investment in research, the climate-sensitive infectious diseases that have already been identified as potential threats will be better understood in the future. If our public health systems are strengthened and maintained, it may be possible to anticipate potential disease outbreaks before they become serious, and take appropriate actions, such as enhanced surveillance, vaccinations, improved treatments, better vector control, and changing human behavior and the human-built environment to reduce exposure.

However, a comparison of disease threats fifty years ago with those of concern today shows that we cannot safely assume that all significant future threats of climate-sensitive infectious disease have already been identified. West Nile virus and the Sin Nombre strain of hantavirus were unknown or not identified as potential problems in New Mexico fifty years ago, and we can expect that new threats would continue to emerge even in the absence of climate change. The emergence of new infectious disease threats, and the resurgence and redistribution of existing threats is likely to increase under conditions of a rapidly changing climate (Epstein 1997). Rapid changes in climate will tend to disrupt natural ecosystems, favoring growth of some species over others, allowing some species to extend their range and restricting the range of others, causing local extinctions or population explosions, and disrupting predator-prey relationships and food webs — all in ways that are difficult to predict. Organisms that are vectors, hosts, or reservoirs for infectious diseases could become super-abundant if climate change disrupts their natural controls.

Sharp contrasts across national borders in the incidence of environmentally sensitive diseases show clearly that well equipped and prepared public health systems are crucial to keeping these diseases under control. Under conditions of changing climate, it will be important to maintain and enhance the capacity of our public health systems not only to better understand and control those potential threats which have already been identified, but also to provide early detection and response to new and unanticipated threats (Burke et al. 2001).

Infectious diseases arising around the globe can affect New Mexico and the United States, as evidenced by the spread of AIDS and recent concerns about a possible influenza pandemic caused by mutation of the current avian influenza ("bird flu") infecting wild birds and poultry in many parts of Asia and Europe. Infectious disease epidemics are an outcome of social and economic disruption (Epstein 1997), which is a likely consequence of global warming and human intrusion into new areas and other ecosystems in many developing countries. Enhancing and maintaining public health infrastructure in other countries, and the social and economic systems that support them, will be important in protecting the health of New Mexicans from effects of climate change.

Other Potential Environmental Quality and Health Issues

Following is a brief summary of some additional environmental quality and health issues which have been raised in previous climate change impact assessments, and which may be of concern to New Mexico.

- Extreme storm events (flash floods, tornadoes): Includes direct effects, such as injury and/or death, as well as indirect effects on health from damage to infrastructure (housing, and power, water and sewer systems) (Patz et al. 2001).

- Water-borne diseases (*E. coli, Cryptosporidium, Giardia*): May increase if flooding results in damage to sewer or septic systems, or runoff of animal waste into surface waters (Patz et al. 2001) and shallow ground water.

- Water quality: Drought may increase salinity and concentrations of many natural and man-made contaminants in surface waters (Patz et al. 2001).

- Tick-borne infectious diseases (e.g., Rocky Mountain spotted fever): These are potentially climate-sensitive, but responses to possible climate change are not well understood.

- Food quality and quantity: Global agricultural productivity may increase in some regions and decrease in others. Significant decreases would threaten nutritional status if costs and/or availability of food were affected (Balbus and Wilson 2004). Even if total caloric intake is not affected, reduced availability of certain foods (fresh vegetables, fish) could reduce the nutritional value of diets. Some studies suggest that while increased levels of atmospheric carbon dioxide may increase crop productivity, nutritional quality may be detrimentally affected (Jablonski et al. 2002, Loladze 2002).

- Pollen-induced disease (allergic reactions, asthma, sinusitis): These diseases may increase with a longer vegetation growing season, especially if precipitation increases, either in the average or in extreme years (Patz et al. 2001). Also, some plants grown at higher atmospheric CO_2 concentrations produce much greater amounts of pollen (Epstein and Mills 2005).

- Psychological effects: Adverse mental health consequences may result if climate change causes social and economic disruption, and as a result of perceived ecological disruption, frequent severe storms, and disease outbreaks. These effects are poorly understood and have rarely been considered (Balbus and Wilson 2004).

- Conflict and war: Disruption of agricultural production, water resources, human diseases, and inundation of coastal zones may exacerbate tensions and conflict in areas such as the Middle East, southern Africa, and southern Asia, raising the likelihood of international conflict and war in which the United States may become involved (Balbus and Wilson 2004).

ENVIRONMENTAL JUSTICE AND NATIVE PEOPLES

> "Whereas, the State of New Mexico is committed to affording all of its residents, including communities of color and low-income communities, fair treatment and meaningful involvement in the development, implementation, and enforcement of environmental laws, regulations, and policies regardless of race, color, ethnicity, religion, income or educational level;" (from Environmental Justice Executive Order 2005-056, State of New Mexico Office of the Governor)

The potential impacts of climate change will disproportionally affect communities of color and low-income communities, thereby raising issues of environmental justice. These communities have limited resources available to adapt and cope with additional impacts.

Health

Health impacts would be greater for low-income individuals and people of color because they are less likely to have health insurance and easy access to health care information and providers, especially in rural areas.

People with existing respiratory and cardiovascular disease are among the most susceptible to the effects of air pollution. Any climate-change related increases in air pollution (see Environmental Quality and Health section regarding smoke, dust, and ozone) would therefore disproportionally impact communities where air pollutant levels are already high enough to cause health problems, such as in heavily industrialized zones.

During episodes of extreme heat, mortality has tended to be highest among low-income inner city residents, who often lack air conditioning (Kalkstein and Valimont 1987). During the July 2005 heat wave in Phoenix, Arizona, 14 of the 18 deaths were homeless persons (CBS News 2005). The elderly and those taking certain medications are also more vulnerable to extreme heat (Longstreth 1999). Construction workers, farm workers, and others doing strenuous manual labor outdoors would also be more vulnerable.

Climate change may increase outbreaks of agricultural pests and diseases, and promote weed growth. A likely response would be increased pesticide and herbicide use, which could create additional health hazards for farmworkers and rural communities.

Economic Impacts

Low-income families may be impacted economically by higher food and energy costs. Costs may rise due to disruption of agricultural systems nationally or internationally. Drought, high temperatures, and pest outbreaks may reduce the amount of food supplied by home gardens, forcing households who have relied on home gardens to purchase more of their food. Drought and the seasonal shift in snowmelt runoff to earlier in the spring may seriously impact agricultural production in Native American and Hispanic communities in northern New Mexico that are dependent on acequia systems. Costs for water from municipal systems are also likely to rise.

Wildfires and floods have disproportionate impacts on low-income households, because they are less likely to be insured, either because they are renters or because they own housing which does not require homeowner's insurance. Low-income housing is more likely to be older structures that will require costs for retrofitting to add air conditioning and reduce water use.

Native American Cultural Values

Traditional Native American subsistence systems could potentially be disrupted by climate change. For example, much of the grazing land on the Navajo Nation is on sand dunes and sand sheets that are currently stabilized by vegetation. Severe drought may cause remobilization of these sand dunes, with serious impacts on living conditions, grazing and farming (SWARG 2000).

Impacts of climate change on natural ecosystems would be of special concern to New Mexico's Native American communities (NAST 2000, Maynard 2002). Plants and animals integral to the cultural life and religious beliefs and practices of these communities may become extinct or shift their range so that they no longer occur within the native homeland. For peoples whose spiritual and cultural identity is tied to ecological systems, severely altering the natural balance of their homeland would be as disruptive to identity as outright displacement to a new region.

CONTRIBUTORS

The following state agency personnel contributed to the development of this report:

Jason Allen, NM Department of Agriculture

Tim Darden, NM Department of Agriculture

Randy Floyd, NM Department of Game and Fish

Dr. Maggi Gallaher, NM Department of Health

Doug Jones, NM Department of Transportation

Kim Kostelnik, NM Energy, Minerals and Natural Resources Department

Kathy Kretz, NM Department of Transportation

Richard Lucero, NM Regulation and Licensing Department

Brad Musick, NM Environment Department (editor)

Rudy Romero, NM Regulation and Licensing Department

Barbara Toth, NM Department of Health

Mary Uhl, NM Environment Department

Lany Weaver, NM Environment Department

REFERENCES CITED

Adams, R.M., B.H. Hurd, and J. Reilly (1999), Agriculture & Global Climate Change: A Review of Impacts to U.S. Agricultural Resources, Prepared for the Pew Center on Global Climate Change (URL: http://www.pewclimate.org/global-warming-in-depth/all_reports/agriculture/env_agriculture_exec.cfm).

Allen, C. (2004), Massive forest dieback, in Proceedings, Mountain Climate Sciences Symposium, Anticipating Challenges to Western Mountain Ecosystems and Resources (URL: http://www.x-cd.com/mcss04/program.html).

Allen, C.D., and D.D. Breshears (1998), Drought-induced shift of a forest-woodland ecotone: rapid landscape response to climate variation, Proceedings of the National Academy of Sciences 95:14839-14842.

Alley, R.B., J. Marotzke, W. Nordhaus, J. Overpeck et al. (2002), Abrupt Climate Change: Inevitable Surprises, National Academy Press, Washington, D.C. (URL: www.nap.edu/openbook/0309074347/html/R1.html).

Balbus, J.M., and M.L. Wilson (2004), Human health and global climate change: a review of potential impacts in the United States, in C. Parmesan and H. Galbraith (eds.), Observed Impacts of Global Climate Change in the U.S., Pew Center on Global Climate Change.

Ball, T. (1983), The migration of geese as an indicator of climate change in the southern Hudson Bay region between 1715 and 1851, Climatic Change 5:85–93.

Berven, K.A. (1981), Mate choice in the wood frog, *Rana sylvatica*, Evolution 35:707–722.

Berven, K.A. (1982), The genetic basis of altitudinal variation in the wood frog (Rana sylvatica). II. An experimental analysis of larval development, Oecologia 52:360–369.

Breshears, D.D., N.S. Cobb, P.M. Rich, K.P. Price et al. (2005), Regional vegetation die-off in response to global-change-type drought, Proceedings of the National Academy of Sciences 102:15144-15148.

Brown, J.H., T.J. Valone, and C.G. Curtin (1997), Reorganization of an arid ecosystem in response to recent climate change, Proceedings of the National Academy of Sciences 94:9729–9733.

Brown, J.L., S.-H. Li, and N. Bhagabati (1999), Long-term trend toward earlier breeding in an American bird: a response to global warming?, Proceedings of the National Academy of Sciences 96:5565–5569.

Burke, D., A. Carmichael, D. Focks, D.J. Grimes et al. (2001), Under the Weather: Climate, Ecosystems, and Infectious Disease, National Academy Press.

Cayan, D.R., S.A. Kammerdiener, M.D. Dettinger, J.M. Caprio, and D.H. Peterson (2001), Changes in the onset of spring in the western United States, Bulletin of the American Meteorological Society 82:399-415.

CBS News (2005), Phoenix heat kills at least 18 (July 21, 2005), www.cbsnews.com/stories/2005/07/21/national/main710772.shtml (accessed Nov. 29, 2005).

Chivian, E. (2001), Environment and health: 7. Species loss and ecosystem disruption —the implications for human health, Canadian Medical Association Journal 164:66-69.

Christensen, N.S., A.W. Wood, N. Voisin, D.P. Lettenmaier, and R.N. Palmer (2004), The effects of climate change on the hydrology and water resources of the Colorado River basin, Climatic Change 62:337-363.

Cicerone, R.J (2005), Current state of climate science: recent studies from the National Academies, Statement before the Committee on Energy and Natural Resources, U.S. Senate, July 21, 2005 (URL: ww7.nationalacademies.org/ocga/testimony/Climate_Change_Science_and_Economics.asp#TopOfPage, accessed Dec. 6, 2005).

Comrie, A.C. (2005), Climate factors influencing coccidiodomycosis seasonality and outbreaks, Environmental Health Perspectives 113:688-692.

Congressional Budget Office (2005), Uncertainty in Analyzing Climate Change: Policy Implications. The Congress of the United States, Congressional Budget Office.

Covich, A.P. and Members of the Aquatic Ecosystems Workshop Group (2003), Chapter 8: Natural Ecosystems II. Aquatic Systems, in Wagner, F.H. (ed.), Preparing for a Changing Climate. The Potential Consequences of Climate Variability and Change. Rocky Mountain/Great Basin Regional Climate-Change Assessment. A Report of the Rocky Mountain/Great Basin Regional Assessment Team for the U.S. Global Change Research Program.

Covich, A.P., S.C. Fritz, P.J. Lamb, R.D. Marzolf, W.J. Matthews, K.A. Poiani, E.E. Prepas, M.B. Richman, and T.C. Winter (1997), Potential effects of climate change on aquatic ecosystems of the Great Plains of North America, Hydrological Processes 11, 993–1021.

Crick, H.Q.P. (2004), The impact of climate change on birds, Ibis 146 (Suppl.1), 48–56.

Crimmins, M.A., and A.C. Comrie (2004), Interactions between antecedent climate and wildfire variability across south-eastern Arizona, International Journal of Wildland Fire 13:455-466.

Dahms, C.W., and B.W. Geils (eds.) (1997), An Assessment of Forest Ecosystem Health in the Southwest, General Technical Report RM-GTR-295. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Southwestern Region, Fort Collins, CO. (URL: www.rmrs.nau.edu/publications/rm_gtr_295/)

Davis, M.B. (1989), Lags in vegetation response to greenhouse warming. Climatic Change 15:75–82.

DeBano, L.E., P.F. Folliott, A. Ortega-Rubio, G.J. Gottfried, R.H. Hamre, C.B. Edminster (technical coordinators) (1994), Biodiversity and management of the Madrean archipelago: the sky islands of Southwestern United States and northwestern Mexico. Gen. Tech. Rep. RM-GTR-264, Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Forest and Range Experiment Station.

DeLucia E., D. Moore, and R. Norby (2005), Contrasting responses of forest ecosystems to rising atmospheric CO2: Implications for the global C cycle, Global Biogeochemical Cycles 19(3):GB3006.

Dettinger, M.D. (2005), Changes in streamflow timing in the western United States in recent decades, U.S. Geological Survey Fact Sheet 2005-3018.

Diffenbaugh, N.S. (2005), Atmosphere-land cover feedbacks alter the response of surface temperature to CO_2 forcing in the western United States. Climate Dynamics 24: 237–251.

Diffenbaugh, N.S., J.S. Pal, R.J. Trapp, and F. Giorgi (2005), Fine-scale processes regulate the response of extreme events to global climate change, Proceedings of the National Academy of Sciences 102: 15774-15778, doi: 10.1073/pnas.0506042102.

Duchin, J.S., F.T. Koster, C.J. Peters, G.I. Simpson et al. (1994), Hantavirus pulmonary syndrome: a clinical description of 17 patients with a newly recognized disease, New England Journal of Medicine 330:949-955.

Dunn, P.O., and D.W. Winkler (1999), Climate change has affected the breeding date of tree swallows throughout North America, Proceedings of the Royal Society of London Series B 266:2487–2490.

Elmberg, J. (1991), Ovarian cyclicity and fecundity in boreal common frogs *Rana temporaria* L. along a climatic gradient, Functional Ecology 5:340–350.

Epstein, P.R. (1997), Climate, ecology, and human health, Consequences, Vol. 3, No. 2, U.S. Global Change Research Information Office, www.gcrio.org/CONSEQUENCES/vol3no2/climhealth.html (accessed Oct. 5, 2005).

Epstein, P.R., and E. Mills (eds.) (2005), Climate Change Futures: Health, Ecological and Economic Dimensions, Center for Health and the Global Environment, Harvard Medical School.

Etterson, J.R., and R.G. Shaw (2001), Constraint to adaptive evolution in response to global warming, Science 294:151-154.

Fisher, J.T., P.A. Glass, and J.T. Harrington (1995), Temperate pines of northern Mexico: their use, abuse, and regeneration, pp. 165–173 in DeBano, L.F., P.F. Ffolliott, A. Ortega-Rubio, G.J. Gottfried, R.H. Hamre, and C.B. Edminster (technical coordinators), Biodiversity and Management of the Madrean Archipelago: The Sky Islands of Southwestern United States and Northern Mexico, USDA Forest Service General Technical Report RM-GTR 264.

Frazer, N.B., J.L. Greene, and J.W. Gibbons (1993), Temporal variation in growth rate and age at maturity of male painted turtles, *Chrysemys picta*, American Midlands Naturalist 130:314–324.

Gibbons, J.W., D.E. Scott, T.J. Ryan , K.A., Buhlmann, T.D. Tuberville, B.S. Metts, J.L. Greene, T. Mills, Y. Leiden, S. Poppy, and C.T. Winne (2000), The global decline of reptiles, déjà vu amphibians, BioScience 50:653-666.

Glass, G.E., J.E. Cheek, J.A. Patz, T.M. Shields, T.J. Doyle, D.A. Thoroughman, D.K. Hunt, R.E. Enscore, K.L. Gage, C. Irland, C.J. Peters, and R. Bryan (2000), Using remotely sensed data to identify areas at risk for hantavirus pulmonary syndrome, Emerging Infectious Diseases 6:238-247.

Glass, G.E., T.L. Yates, J.B. Fine, T.M. Shields, J.B. Kendall, A.G. Hope, C.A. Parmenter, C.J. Peters, T.G. Ksiazek, C-S. Li, J.A. Patz, and J.N. Mills (2002), Satellite imagery characterizes local animal reservoir populations of Sin Nombre virus in the southwestern United States, Proceedings of the National Academy of Sciences 99:16817-16822.

Grambsch, A. (2002), Climate change and air quality, pp. 225-235 in The Potential Impacts of Climate Change on Transportation, U.S. Department of Transportation.

Gresswell, R.E., W.J. Liss, and G.L. Larson (1995), Life-history organization of Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*) in Yellowstone Lake, Canadian Journal of Fisheries and Aquatic Sciences 51:298-309.

Grimm, N.B., A. Chaco, C.N. Dahm, S.W. Hostetler, O.T. Lind, P.L. Starkweather. and W.W. Wurtsbaugh (1997), Sensitivity of aquatic ecosystems to climatic and anthropogenic changes: the Basin and Range, American Southwest and Mexico, Hydrological Processes 11:1023-1041.

Grissino-Mayer, H.D., C.H. Baisan, K.A. Morino, and T.W. Swetnam (2002), Multi-century trends in past climate for the middle Rio Grande basin, AD 622-1992, Report 2002/6, Laboratory of Tree-Ring Science, University of Tennessee.

Gross, K., and B.J. Cardinale (2005), The functional consequences of random versus ordered species extinctions, Ecology Letters 8:409-418.

Gutzler, D.S. (2005), Climate change: what's in store for New Mexico, presentation at New Mexico Climate Change Advisory Group meeting, October 19, 2005 (URL: www.nmclimatechange.us/ewebeditpro/items/O117F7187).
Hamilton, L.S. (1995), Mountain cloud forest conservation and research: a synopsis, Mountain Research and Development 15:259–266.
Hamlet, A.F., P.W. Mote, M.P. Clark, and D.P. Lettenmaier (2005), Effects of temperature and precipitation variability on snowpack trends in the western U.S., Journal of Climate (in press).
Hare, W. (2003), Assessment of Knowledge on Impacts of Climate Change –Contribution to the Specification of Article 2 of the UNFCCC: Impacts on Ecosystems, Food Production, Water and Socio-economic Systems. Potsdam, Berlin. Available online at http://www.wbgu.de/wbgu_sn2003_ex01.pdf.
Hauer, F.R., J.S. Baron, D.H. Campbell, K.D. Fausch, S.W. Hostetler, G.H. Leavesley, P.R. Leavitt, D.M. McKnight, and J.A. Stanford (1997), Assessment of climate change and freshwater ecosystems of the Rocky Mountains, USA and Canada, Hydrological Processes 11:903-924.
Hopp, M.J., and J.A. Foley (2003), Worldwide fluctuations in dengue fever cases related to climate variability, Climate Research 25:85-94.
Huntley, B. (1991) How plants respond to climate change: migration rates, individualism and the consequences for plant communities. Annals of Botany, 67 (Suppl. 1), 15–22.
Inkley, D. B., M.G. Anderson, A.R. Blaustein, V.R. Burkett, B. Felzer, B. Griffith, J. Price, and T.L. Root (2004), Global climate change and wildlife in North America, Wildlife Society Technical Review 04-2, The Wildlife Society, Bethesda, Maryland, USA. 26 pp.
Inouye, D.W., B. Barr, K.B. Armitage, and B.D. Inouye (2000), Climate change is affecting altitudinal migrants and hibernating species, Proceedings of the National Academy of Sciences 97:1630–1633.
Intergovernmental Panel on Climate Change (IPCC) (1996), Climate Change 1995, Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Cambridge University Press, New York, USA.
Intergovernmental Panel on Climate Change (IPCC) (2001a), Climate Change 2001: The Scientific Basis, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
Intergovernmental Panel on Climate Change (IPCC) (2001b), Ecosystems and Their Goods and Services. Chapter 5. Climate Change 2001: Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the Intergovernmental Panel on Climate Change Third Assessment Report . J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds.). Cambridge University Press, Cambridge, UK.
Intergovernmental Panel on Climate Change (IPCC) (2004), Describing Scientific Uncertainties in Climate Change to Support Analysis of Risk and of Options. IPCC Workshop 11–13 May, 2004, National University of Ireland, Maynooth, Co. Kildare, Ireland. IPCC Workshop Report. M. Manning, M. Petit, D. Easterling, J. Murphy, A. Patwardhan, H-H. Rogner, R. Swart, and G. Yohe, Eds. IPCC Working Group I, Technical Support Unit, Boulder, Colorado.
Izaurralde, R.C., A.M. Thomson, N.J. Rosenberg, and R.A. Brown (2005) Climate Change Impacts for the Conterminous USA: An Integrated Assessment, Part 6: Distribution and Productivity of Unmanaged Ecosystems, Climatic Change 69:107–126.
Jablonski, L.M., X. Wang, and P.S. Curtis (2002), Plant reproduction under elevated CO_2 conditions: a meta-analysis of reports on 79 crop and wild species, New Phytologist 156:9-26.
Janzen, F.J. (1994), Climate change and temperature dependent sex determination in reptiles, Proceedings of the National Academy of Sciences 91:7487–7490.
Johannes, M.R.S. (2004) Species at Risk from Climate Change: Adapting to Climate Variation and Change in Canada, pp. 1-8 in T.D. Hooper (ed.), Proceedings of the Species at Risk 2004 Pathways to Recovery Conference, 1 March 2–6, 2004, Victoria, B.C., Species at Risk 2004 Pathways to Recovery Conference Organizing Committee, Victoria, B.C.
Kalkstein, L.S., and K.M. Valimont (1987), Climate effects on human health, pp. 122-152 in Potential Effects of Future Climate Changes on Forests and Vegetation, Agriculture, Water Resources, and Human Health, EPA Science Advisory Committee Monograph 25389 (URL: www.ciesin.org/docs/001-338/001-338.html).
Keleher, C.J. and F.J. Rahel (1996), Thermal limits to salmonid distributions in the Rocky Mountain region and potential habitat loss due to global warming: a geographic information system (GIS) approach, Transactions of the American Fisheries Society 125:1-13.
Kirilenko, A.P. and Solomon, A.M. (1998), Modeling dynamic vegetation response to rapid climate change using bioclimatic classification, Climatic Change 38:15–49.

Kolivras, K.N., and A.C. Comrie (2004), Climate and infectious disease in the southwestern United States, Progress in Physical Geography 28:387-398.

Koontz, T.L., U.L. Shepherd, and D. Marshall (2001), The effects of climate change on Merriam's kangaroo rat, *Dipodomys merriami*, Journal of Arid Environments 49:581–591.

Leung, L.R., and W.I. Gustafson, Jr. (2005), Potential regional climate change and implications to U.S. air quality, Geophysical Research Letters 31, L16711, doi:10.1029/2005GL022911.

Logan, J.A., and J.A. Powell (in press), Ecological consequences of climate change altered forest insect disturbance regimes, in F.H. Wagner (ed.), Climate Change in Western North America: Evidence and Environmental Effects, Allen Press.

Loladze, I. (2002), Rising atmospheric CO_2 and human nutrition: toward globally imbalanced plant stoichiometry?, Trends in Ecology and Evolution 17:457-461.

Longstreth, J. (1999), Public health consequences of global climate change in the United States—some regions may suffer disproportionately, Environmental Health Perspectives 107(Suppl. 1):169-179.

Lynch, A. (2005), Global warming and insect outbreaks in Southwestern forests, in Proceedings, 8th Biennial Conference, Integrating Science and Management on the Colorado Plateau, US Geological Survey (URL: www.usgs.nau.edu/conf2005), cited in M. Lenart (2005), Is global warming creeping into southwest forests?, pp. 2-5 in CLIMAS Southwest Climate Outlook, February 2005, University of Arizona.

Malcolm, J.R. and L.F. Pitelka (2000), Ecosystems & Global Climate Change: A Review of Potential Impacts on U.S. Terrestrial Ecosystems and Biodiversity, Prepared for the Pew Center on Global Climate Change.

Martens, W.J.M., L.W. Niessen, J. Rotmans, T.H. Jetten, and A.J. McMichael (1995), Potential impacts of global climate change on malaria risk, Environmental Health Perspectives 103:458-464.

Matthews, W.J., and E.G. Zimmerman (1990), Potential effects of global warming on native fishes of the southern Great Plains and the Southwest, Fisheries 15:26-32.

Maynard, N.G. (ed.) (2002), Native Peoples-Native Homelands Climate Change Workshop, Final Report: Circles of Wisdom, U.S. Global Change Research Program, National Aeronautics and Space Administration Publication NP-2002-3-443-GSFC.

McCarty, J.P. (2001), Ecological consequences of recent climate change, Conservation Biology 15:320-331.

McDonald, K.A. and J.H. Brown (1992), Using montane mammals to model extinctions due to global change, Conservation Biology 6:409–415.

McKenzie, D., Z. Gedalof, D.L. Peterson, and P. Mote (2004), Climatic change, wildfire, and conservation, Conservation Biology 18:890-902.

Meehl, G.A., and C. Tebaldi (2004), More intense, more frequent, and longer lasting heat waves in the 21st century, Science 305: 994-997.

Meehl, G.A., J.M. Arblaster, and C. Tebaldi (2005), Understanding future patterns of increased precipitation intensity in climate model simulations, Geophysical Research Letters 32:L18719.

Merritt, D.M. and D.J. Cooper (2000), Riparian vegetation and channel change in response to river regulation: a comparative study of regulated and unregulated streams in the Green River basin, USA, Regulated Rivers Research and Management 16, 543-564.

Meyer, J.L. and W.M. Pulliam (1991), Modifications of terrestrial-aquatic interactions by a changing climate, pp. 177-191 In P. Firth and S.G. Fisher (eds.) (1991), Climate Change and Freshwater Ecosystems. New York: Springer-Verlag.

Meyer, J.L., M.J. Sale, P.J. Mulholland, and N.L. Poff (1999), Impacts of climate change on aquatic ecosystem functioning and health, Journal of the American Water Resources Association 35:1373-1386.

Miller, J.D., J.W. Nyhan, and S.R. Yool (2003), Modeling potential erosion due to the Cerro Grande Fire with a GIS-based implementation of the Revised Universal Soil Loss Equation, International Journal of Wildland Fire 12:85-100.

Mills, B. and J. Andrey (2002), Climate Change and Transportation: Potential Interactions and Impacts, pp. 77-88 in The Potential Impacts of Climate Change on Transportation, [US] DOT Center for Climate Change and Environmental Forecasting (http://climate.volpe.dot.gov/workshop1002/mills.doc).

Milly, P.C.D., K.A. Dunne, and A.V. Vecchia (2005), Global pattern of trends in streamflow and water availability in a changing climate, Nature 438:347-350.

Minckley, W.L., and J.E. Deacon (eds.) (1991), Battle Against Extinction: Native Fish Management in the American West, University of Arizona Press, Tucson.

Mock, C.J. (1996), Climatic controls and spatial variations of precipitation in the western United States, Journal of Climate 9:1111-1125.

Nash, L.L. and P.H. Gleick (1991), Sensitivity of streamflow in the Colorado basin to climate changes, Journal of Hydrology 125:221-241.

Nash, L.L. and P.H. Gleick (1993), The Colorado River Basin and climatic change/The sensitivity of streamflow and water supply to variations in temperature and precipitation, U.S. Environmental Protection Agency Publication EPA 230-R-93-009.
National Assessment Synthesis Team (NAST) (2000), Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change, US Global Change Research Program (URL: www.usgcrp.gov/usgcrp/Library/nationalassessment/overview.htm)
National Climatic Data Center (2005), Climate of 2004: Annual Review, National Oceanic and Atmospheric Administration (URL: http://www.ncdc.noaa.gov/oa/climate/research/2004/ann/global.html).
National Oceanic and Atmospheric Administration (NOAA) (2005), NOAA reports warmer 2005 for the United States, near-record warmth globally; hurricanes, floods, snow and wildfires all notable, NOAA News Online (Story 2548) (URL: www.noaanews.noaa.gov/stories/2005/s2548.htm).
National Snow and Ice Data Center (NSIDC) (2005), Sea ice decline intensifies, Press release dated September 28, 2005 (URL: nsidc.org/news/press/20050928_trendscontinue.html, accessed Dec. 6, 2005).
Nehlsen, W., J.E. Williams, and J.A. Lichatowich (1991), Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington, Fisheries (Bethesda) 16:421.
Neilson, R.P. (1998), Potential effects of global warming on natural vegetation at global, national, and regional levels, pp. 55-63 in F.H. Wagner and J. Baron (eds.). Proceedings of the Rocky Mountain/Great Basin Climate Change Workshop. Feb. 16-18, 1998, Salt Lake City, UT, Utah State Univ., Logan, UT.
New Mexico Tourism Department (2005), TravelScope: Quarterly Demographic, Geographic and Trip Information on Visitors to New Mexico [data from Travel Industry Association of New Mexico] (URL: www.newmexico.org/go/loc/research/page/dept-travelscope.html)
Norby, R.J., E.H. DeLucia, B. Gielen, C. Calfapietra et al. (2005). Forest response to elevated CO_2 is conserved across a broad range of productivity. Proceedings of the National Academy of Sciences 102:18052-18056.
Northcote, T.G. (1992), Prediction and assessment of potential effects of global environmental change on freshwater sport fish habitat in British Columbia, Geo Journal 28(1):39-49.
O'Grady, J.J., D.H. Reed, B.W. Brook, and R. Frankham (2004), What are the best correlates of predicted extinction risk?, Biological Conservation 118:513–520.
Oreskes, N. (2004), The scientific consensus on climate change, Science 306:1686.
Overpeck, J. (2005), Climate change: What's ahead for the southwest?, presentation at New Mexico Climate Change Advisory Group meeting, July 27, 2005 (URL: www.nmclimatechange.us/ewebeditpro/items/O117F6670).
Overpeck, J.T., M. Strum, J.A. Francis, D.K. Perovich, M.C. Serreze et al. (2005), Arctic system on trajectory to new, seasonally ice-free state, EOS 86:309, 312-313.
Overpeck, J.T., P.J. Bartlein, and T. Webb III (1991), Potential magnitude of future vegetation change in eastern North America: comparisons with the past, Science 254: 692–695.
Parmenter, R.R., E.P. Yadev, C.A. Parmenter, P. Ettestad, and K.L. Gage (1999), Incidence of plague associated with increased winter-spring precipitation in New Mexico, American Journal of Tropical Medicine and Hygiene 61:814-821.
Parmesan, C. and H. Galbraith (2004), Observed impacts of global climate change in the U.S., Pew Center on Global Climate Change (URL: www.pewclimate.org/global-warming-in-depth/all_reports/observedimpacts/index.cfm).
Parmesan, C., and G. Yohe (2003), A globally coherent fingerprint of climate change impacts across natural systems, Nature 421:37-42.
Patz, J.A., M.A. McGeehin, S.M. Bernard, K.L. Ebi, P.R. Epstein, A. Grambsch, D.J. Gubler, P. Reiter, I. Romieu, J.B. Rose, J.M. Samet, and J. Trtanj (2000), The potential health impacts of climate variability and change for the United States: Executive summary of the report of the health sector of the U.S. National Assessment, Environmental Health Perspectives 108:367-376.
Patz, J.A., M.A. McGeehin, S.M. Bernard, K.L. Ebi, P.R. Epstein, A. Grambsch, D.J. Gubler, P. Reiter, I. Romieu, J.B. Rose, J.M. Samet, J. Trtanj, and T.E. Cecich (2001), Potential consequences of climate variability and change for human health in the United States, Ch. 15, pp. 437-458 in National Assessment Synthesis Team, Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change, Report for the US Global Change Research Program, Cambridge University Press, Cambridge, UK.
Patz, J.A., W.J.M. Martens, D.A. Focks, and T.H. Jetten (1998), Dengue fever epidemic potential as projected by general circulation models of global climate change, Environmental Health Perspectives 106:147-153.
Peteet, D. (2000), Sensitivity and rapidity of vegetational response to abrupt climate change, Proceedings of the National Academy of Sciences 97:1359-1361.

Peters, D.P.C., R.A. Pielke Sr., B.T. Bestelmeyer, C.D. Allen, S. Munson-McGee, and K.M. Havstad (2004), Cross-scale interactions, nonlinearities, and forecasting catastrophic events, Proceedings of the National Academy of Sciences 101:15130-15135.

Physicians for Social Responsibility (2000), Death by Degrees: The Health Threats of Climate Change in New Mexico, Physicians for Social Responsibility.

Pimm, S.L., G.J. Russell, and T.M. Brooks (1995), The future of biodiversity, Science 269:347.

Pisano, P., L. Goodwin, and A. Stern (2002), Surface transportation safety and operations: the impacts of weather within the context of climate change, in The Potential Impacts of Climate Change on Transportation workshop, October 1-2, 2002, [US] DOT Center for Climate Change and Environmental Forecasting (http://climate.volpe.dot.gov/workshop1002/pisano.doc).

Pitelka, L.F. and Plant Migration Workshop Group (1997), Plant migration and climate change, American Scientist 85:464-473.

Poff, N.L., M. Brinson, and J.B. Day (2002) Aquatic Ecosystems and Global Climate Change. Potential Impacts on Inland Freshwater and Coastal Wetland Ecosystems in the United States, Pew Center on Global Climate Change (URL: www.pewclimate.org/global-warming-in-depth/all_reports/aquatic_ecosystems/index.cfm)

Polley, H.W., H.B. Johnson, H.S. Mayeux, and C.R. Tischler (1996), Are some the recent changes in grassland communities a response to rising CO_2 concentrations?, pp. 177-195 in C. Korner and F.A. Bazzaz (eds.), Carbon Dioxide, Populations, and Communities, Academic Press, San Diego, California.

Pounds, J.A., M.P.L. Fogden, and J.H. Campbell (1999), Biological responses to climate change on a tropical mountain, Nature 398:611–615.

Price, J. (2002), Climate change, birds and ecosystems —Why should we care?, pp. 465–469 in D.J. Rapport, W.L. Lasley, D.E. Rolston, N.O. Nielsen, C.O. Qualset, and A.B. Damania (eds.), Managing For Healthy Ecosystems. Lewis Publishers, Boca Raton, Florida, USA.

Price, J.T., and T.L. Root (2001), Climate change and neotropical migrants, Transactions of the North American Wildlife and Natural Resources Conference 66:371–379.

Price, J.T., T.L. Root, K.R. Hall, et al. (2000), Climate change, wildlife and ecosystems, Supplemental information prepared for the Intergovernmental Panel on Climate Change Working Group II.

Reiners, W.A. (2003), Natural ecosystems I. the Rocky Mountains, Chapter 7 (pp. 145-184) in Wagner, F.H. (ed.), Preparing for a Changing Climate. The Potential Consequences of Climate Variability and Change. Rocky Mountain/Great Basin Regional Climate-Change Assessment. A Report of the Rocky Mountain/Great Basin Regional Assessment Team for the U.S. Global Change Research Program.

Richardson, B. (2005), Climate Change and Greenhouse Gas Reduction Executive Order 05-033 (issued June 9, 2005) (URL: www.governor.state.nm.us/orders/2005/EO_2005_033.pdf).

Root, T.L., J.T. Price, K.R. Hall, S.H. Schneider, C. Rosenzweig, and J.A. Pounds (2003), Fingerprints of global warming on wild animals and plants, Nature 421:57–60.

Rossetti, M.A. (2002), Potential impacts of climate change on railroads, pp. 209-221 in The Potential Impacts of Climate Change on Transportation, [US] DOT Center for Climate Change and Environmental Forecasting (http://climate.volpe.dot.gov/workshop1002/rossetti.doc).

Schindler, D.W. (1997), Widespread effects of climatic warming on freshwater ecosystems in North America, Hydrological Processes 11:1043-1067.

Schneider, S.H. and K. Kuntz-Duriseti (2002), Uncertainty and climate change policy, Ch. 2, pp. 53-87 in S.H. Schneider, A. Rosencranz, and J.O. Niles (eds.), Climate Change Policy: A Survey, Island Press, Washington, D.C.

Schneider, S.H. and T.L. Root (1998) Climate change, pp. 89–116 in Mac, M.J., Opler, P.A., Haecker, C.E.P., and Doran, P.D. (eds.), Status and Trends of the Nation's Biological Resources, Vol. 1. Reston (VA), US Department of Interior, US Geological Survey.

Sekercioglu, C.H., G.C. Daily, and P.R. Ehrlich (2004), Ecosystem consequences of bird declines, Proceedings of the National Academy of Sciences 101:18042–18047.

Sheppard, P.R., A.C. Comrie, G.D. Packin, K. Angersbach, and M.K. Hughes (1999), The Climate of the Southwest, CLIMAS Report Series CL 1-99, Institute for the Study of Planet Earth, University of Arizona.

Smith, D. C. (1987), Adult recruitment in chorus frogs: effects of size and date at metamorphosis, Ecology 68:344–350.

Smith, F.A., H. Browning, and U.L. Shepherd (1998), The influence of climate change on the body mass of woodrats *Neotoma* in an arid region of New Mexico, USA, Ecography 21:140-148.

Smith, J.B. (2004), A Synthesis of Potential Climate Change Impacts on the U.S., Pew Center on Global Climate Change (URL: www.pewclimate.org/global-warming-in-depth/all_reports/synthesisimpacts/index.cfm).

Smith, J.B., and D. Tirpak (eds.) (1989), The Potential Effects of Global Climate Change on the United States, Report to Congress, US Environmental Protection Agency Publication EPA-230-05-89-050.

Smith, S.J., A.M. Thomson, N. Rosenberg, R.S. Izaurralde, R.A. Brown, and T.M.L. Wigley (2005), Climate change impacts for the conterminous USA: an integrated assessment, Climatic Change 69:7-25.
Solomon, A.M. and Kirilenko, A.P. (1997), Climate change and terrestrial biomes: what if trees do not migrate?, Global Ecology and Biogeography 6:139–148.
Southwest Regional Assessment Group (SWRAG) (2000), Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change, U.S. Global Change Research Program (URL: www.ispe.arizona.edu/research/swassess/report.html).
Stainforth, D.A., T. Aina, C. Christensen, M. Collins, N. Faull et al. (2005), Uncertainty in predictions of the climate response to rising levels of greenhouse gases, Nature 433:403-406.
Stanley, E.H., and H.M. Valett (1991), Interactions between drying and the hyporheic zone of a desert stream, pp. 211–233 in P. Firth and S.G. Fisher (eds.), Global Climate Change and Freshwater Ecosystems, Springer-Verlag, New York.
Stewart, I.T., D.R. Cayan, and M.D. Dettinger (2005), Changes toward earlier streamflow timing across western North America, Journal of Climate 18:1136-1155.
Stohlgren, T.J. (2003), Climatologists' workshop on scenarios, pp. 38-58 in F.H. Wagner (ed.), Rocky Mountain/Great Basin Regional Climate-Change Assessment, Report for the U.S. Global Change Research Program.
Swetnam, T.W., and J.L. Betancourt (1990), Fire-Southern Oscillation relations in the southwestern United States, Science 262:885-889.
Swetnam, T.W., and J.L. Betancourt (1998), Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest, Journal of Climate 11:3128-3147.
Sykes, M.T., and I.C. Prentice (1996), Climate change, tree species distributions and forest dynamics: a case study in the mixed conifer/northern hardwoods zone of northern Europe, Climatic Change, 34, 161–177.
Taylor, R.V. (2003), Factors influencing expansion of the breeding distribution of Bewick's wren into riparian forests of the Rio Grande in central New Mexico, The Southwestern Naturalist 48:373–382.
Thomas, C.D., A. Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont., Y.C. Collingham, B.F.N. Erasmus, M. Ferreira de Siquelra, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A.S. van Jaarsveld, G.F. Midgley, L. Miles, M.A. Ortega-Huerta, A.T. Peterson, O.L. Phillips, and S.E. Williams (2004), Extinction risk from climate change, Nature 427:145-148.
Tracy, C.R., and T.L. George (1992), On the determinants of extinction. American Naturalist 139:102–122.
United States Environmental Protection Agency (USEPA) (1998), Climate Change and New Mexico, Environmental Protection Agency Publication EPA-236-F-98-007p, (URL: yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/SHSU5BVJHF/$File/nm_impct.pdf).
United States Environmental Protection Agency (USEPA) (1999), Climate Change and Cold Water Fish, Environmental Protection Agency Publication EPA-236-F-99-002.
United States Environmental Protection Agency (USEPA) (2000), Global Warming - Impacts: Rangelands (URL: yosemite.epa.gov/OAR/globalwarming.nsf/content/ImpactsRangelands.html).
van Dam, R., H. Gitay, and M. Finlayson (2002), Climate Change and Wetlands: Impacts, Adaptation and Mitigation, Scientific and Technical Review Panel, Expert Working Group on Climate Change and Wetlands, Wetlands: water, life, and culture, 8th Meeting of the Conference of the Contracting Parties to the Convention on Wetlands (Ramsar, Iran, 1971), Valencia, Spain, 18-26 November 2002, Ramsar COP8 – DOC. 11, Information Paper.
Visser, M.E., A.J. van Noordwijk, J.M. Tinbergen and C.M. Lessells (1998), Warmer springs lead to mistimed reproduction in great tits (*Parus major*), Proceedings of the Royal Society of London B265:1867–1870.
Wagner, F.H. (1998), Ecological effects of projected changes on Great Basin ecosystems, pp. 81-87 in Wagner, F.H. and J. Baron (conveners), Proceedings of the Rocky Mountain/Great Basin Regional Climate-Change Workshop, February 16-18, 1998, Little America Hotel, Salt Lake City, Utah, U.S. National Assessment of The Consequences of Climate Change.
Walker, B., and W. Steffen (1997), An overview of the implications of global change for natural and managed terrestrial ecosystems Conservation Ecology [online]1(2):2 (URL: www.consecol.org/vol/iss2/art2/).
Walther, G.-R., E. Post, P. Convey, A. Menzel, C. Parmesan, T.J.C. Beebee, J.-M. Fromentin, O. Hoegh-Guldberg, and F. Bairlein (2002), Ecological responses to recent climate change, Nature 416:389–395.
Watson, R.T., M.C. Zinyowera, and R.H. Moss (eds.) (1997), The Regional Impacts of Climate Change: An Assessment of Vulnerability, A Special Report of Working Group II of the Intergovernmental Panel on Climate Change, Summary for Policymakers, Cambridge University Press. http://yosemite.epa.gov/OAR/globalwarming.nsf/UniqueKeyLookup/SHSU5BPJWH/$File/chaptsum.pdf
Wenzel, R.P. (1994), A new hantavirus infection in North America, New England Journal of Medicine 330:1004-5.

Werner, E.E. (1986), Amphibian metamorphosis: growth rate, predation risk, and the optimal size at transformation, American Naturalist 128:319–341.
Westerling, A.L., and T.W. Swetnam (2003), Interannual to decadal drought and wildfire in the western United States, EOS 84:545-560.
Wotton, B.M., and M.D. Flannigan (1993), Length of the fire season in a changing climate, Forestry Chronicle 69:187-192.