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Hotter and Drier

The West's Changed Climate

Principal Authors

Stephen Saunders
Charles Montgomery
Tom Easley
The Rocky Mountain Climate Organization

Contributing Author

Theo Spencer
Natural Resources Defense Council

the ROCKY MOUNTAIN CLIMATE Organization

NRDC
THE EARTH'S BEST DEFENSE

About RMCO
The Rocky Mountain Climate Organization is a coalition of 17 local governments, Colorado's largest water provider, 17 businesses, and 11 nonprofit organizations. Our mission is spreading the word about what climate disruption can do to the Rocky Mountain region and what we can do about it. Learn more at www.rockymountainclimate.org.

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NRDC Director of Communications: Phil Gutis
NRDC Marketing and Operations Director: Alexandra Kennaugh
NRDC Publications Manager: Lisa Goffredi
NRDC Publications Editor: Anthony Clark
Production: Tanja Bos, tanja@bospoint.com

Cover photo: White "bathtub rings" show the pre-drought water level of Lake Powell in Arizona. © Mike Reyfman

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Executive Summary

Human activities are already changing the climate of the American West. This report by the Rocky Mountain Climate Organization (RMCO) and the Natural Resources Defense Council (NRDC), drawn from 50 scientific studies, 125 other government and scientific sources, and our own new analyses, documents that the West is being affected more by a changed climate than any other part of the United States outside of Alaska. When compared to the 20th century average, the West has experienced an increase in average temperature during the last five years that is 70 percent greater than the world as a whole. Responding quickly at all levels of government by embracing the solutions that are available is critical to minimizing further disruption of this region's climate and economy.

The West Is Getting Hotter

The planetary warming that scientists predict will result from human emissions of heat-trapping gases is already underway. In February 2007, the Intergovernmental Panel on Climate Change (IPCC) declared, "Warming of the climate system is unequivocal," and it is "very likely" that most of the warming since the middle of the 20th century is the result of human pollutants.

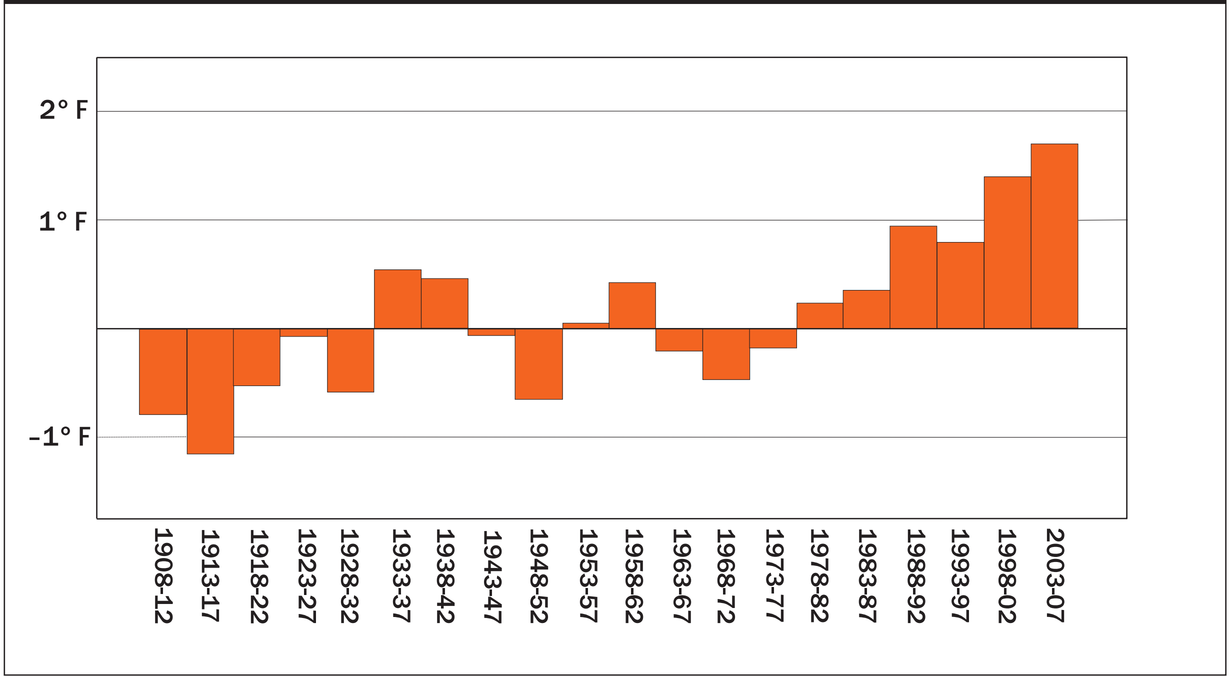
The American West has heated up even more than the world as a whole. For the last five years (2003 through 2007), the global climate has averaged 1.0 degree Fahrenheit warmer than its 20th century average. For this report, RMCO found that during the 2003 through 2007 period, the 11 western states averaged 1.7 degrees Fahrenheit warmer than the region's 20th century average. That is 0.7 degrees, or 70 percent, more warming than for the world as a whole. And scientists have confirmed that most of the recent warming in the West has been caused by human emissions of heat-trapping gases.

Understanding the Conclusions of the IPCC

The Intergovernmental Panel on Climate Change (IPCC) recently released *Climate Change 2007*, an assessment of the current scientific understanding of climate change and its effects, prepared by hundreds of scientists and approved by the governments of countries in the United Nations. Key terms used by the IPCC (and often quoted in this report) were defined as follows:

- "Very likely" means greater than a 90 percent probability of occurring.
- "Likely" means about an 80 percent probability of occurring.
- "Very high confidence" means at least 9 out of 10 chances of being correct.
- "High confidence" means about 8 out of 10 chances of being correct.
- "Medium confidence" means 5 out of 10 chances of being correct.

A Warmer West: Five-year Average Temperatures in 11 Western States Compared to 20th Century Average



Data from the National Oceanic and Atmospheric Administration's climate division series. Analysis by the Rocky Mountain Climate Organization.

More Rapid Warming in the West

2003 to 2007 5-Year Average Temperatures Compared to 20th Century Averages

Planet	+1.0°F
Western United States	+1.7°F
Colorado River Basin	+2.2°F
Arizona	+2.2°F
California	+1.1°F
Colorado	+1.9°F
Idaho	+1.8°F
Montana	+2.1°F
Nevada	+1.7°F
New Mexico	+1.3°F
Oregon	+1.4°F
Utah	+2.1°F
Washington	+1.4°F
Wyoming	+2.0°F

The West has also experienced more frequent and severe **heat waves**, with the number of extremely hot days increasing by up to four days per decade since 1950. These heat waves, particularly those with excessive nighttime heat, can be deadly.

The West Is Getting Drier

In the arid and semi-arid West, global warming is already having serious consequences for the region's scarce water supplies, particularly the snow that makes up most of the region's precipitation and, when melted, provides 70 percent of its water. Already, **decreases in snowpack, less snowfall, earlier snow melt**, **more winter rain events, increased peak winter flows**, and **reduced summer flows** have been documented. Scientists have recently attributed more than half of these changes in the West between 1950 and 1999 to the effects of heat-trapping pollutants.

As global warming continues, the IPCC also predicts **more intense and longer droughts**, and characterized the severe drought that began in the western United States in 1999 and continues today as a "notable extreme climate event."

The Colorado River Basin: Hotter and Drier

The Colorado River is the major source of water for the driest part of the country. Upwards of 30 million Americans across seven states now depend on it for agricultural, municipal, industrial, and hydroelectric needs—and the basin is among the fastest growing areas in the country.

The Colorado River Basin, which stretches from Wyoming to Mexico and includes parts of Arizona, California, Colorado, Nevada, New Mexico, and Utah, is the epicenter of the hotter and drier climate changes underway in the West. Since the late 1970s, the basin has warmed more than any other region in the contiguous United States. A new analysis done for this report documents that in years 2003 through 2007, the Colorado River basin was 2.2 degrees Fahrenheit warmer than its 20th century average. Our analysis also documents how the river basin's snowpacks are now melting faster than before, as recent spring snowpacks have shrunk quicker than they used to.

These changes have contributed to reductions in what matters most in this basin: the volume of water in the Colorado River. The years 2000 through 2004 were the first five consecutive years of below-average flow since the start of modern records. The Colorado River's two main reservoirs, Lake Powell and Lake Mead, are now only 45 and 50 percent full, respectively. It could take 15 to 20 consecutive years of what used to be normal inflow to refill them to capacity.

Several studies have concluded that these changes are likely the result of human emissions of heat-trapping gases. Even if the recent drought is "just" an illustration of what scientists are predicting for the Colorado River basin in the future, there still is reason for great concern in the region.

Global Warming Is Disrupting Ecosystems

The IPCC also concluded that "recent warming is already strongly affecting" ecosystems and wildlife. One study found that warmer spring and summer temperatures are responsible for **increases in wildfire** in the West. The researchers found that spring and summer temperatures in the West in the 17 years after 1987 were 1.5 degrees Fahrenheit warmer than in the previous 17 years, leading to:

- a 78-day increase in the length of the fire season.
- a fourfold increase in the number of fires.
- a fivefold increase in the time needed to put out the average wildfire.
- 6.7 times as much area being burned.

The IPCC concluded that recent warming trends have led to **proliferation of mountain pine beetles** in the West. Because they kill their host trees to reproduce, mountain pine beetles are agents of great disturbance in western forests. Their populations normally are held in check by extreme cold, but now western mountains are warmer and so more beetles can survive winters; they can survive at higher latitudes and higher elevations where it used to be too cold; and they even can complete their life cycles in just one year rather than two. Largely for these reasons, beetle outbreaks are now widespread across the West. The U.S. Forest Service (USFS) and state foresters recently predicted that in Colorado and southern Wyoming mountain pine beetles will likely kill the majority of the mature lodgepole pine forests within the next three to five years.

Also newly linked to global warming is a rapid mortality of aspen trees that scientists call "**sudden aspen decline**." New research by the USFS has, for the first time, linked the sudden aspen decline in Colorado to the hotter and drier conditions that represent an altered climate in the interior West.

Another effect of global warming is **increased melting of glaciers** across the West. U.S. Geological Survey researchers projected in 2003 that all glaciers in Glacier National Park could be completely melted by 2030, but

Realities of Global Warming in the 11 Western States

Deadly Heat Waves: In **California**, a heat wave in July 2006 led to an initial official count of at least 143 deaths—a total being reviewed by the state government following a press analysis that the real death toll may have been 466.

Diminishing Reserves: The volume of water in Lake Powell—a man-made Colorado River reservoir in **Arizona**—dropped by two-thirds between 2000 and 2005. This draining of the reservoir was more rapid and severe than thought possible. It is currently less than half full.

No Snow: On the date the snowpack at Snoqualmie Pass in **Washington** normally reaches its peak of 92 inches, in 2005 there was no measurable snow at all.

Charred Habitat: Destructive wildfires in northern **Nevada** in 2006 charred pronghorn antelope habitat and forced the relocation of half the regional herd.

Grizzly Bears at Risk: Warmer temperatures in **Wyoming** have allowed mountain pine beetles to invade high-elevations in the Yellowstone area, where they may eliminate whitebark pines, whose nuts are the most important food source for the area's grizzlies.

Ruinous Wildfire: Colorado suffered the largest wildfire in its history in 2002. Nine firefighters died, nearly 1,000 structures were destroyed, 915,000 acres burned, and $1.7 billion were lost in tourism revenue.

Disastrous Drought: Drought hit **Utah** so hard in 2002 that every county in the state qualified for disaster relief. 2,600 Utahans lost their agricultural jobs and the dryland harvest shrank 30 percent.

Livestock Loss: New Mexico lost $279 million in income from livestock production due to the 2002 drought. In **Montana,** drought forced ranchers to cull 150,000 cattle from their herds in three years, bringing the state's cattle population to a 40-year low in 2004.

Lost Revenue: Idaho was forced to cancel sage grouse hunting season after wildfires destroyed much of the bird's habitat in 2007.

Dead Zone: An area of ocean waters with too little oxygen to support sea life off the **Oregon** coast, caused by changed weather patterns, has grown in four years to cover an area the size of Rhode Island.

they actually are melting so fast they are likely to be gone by 2022. In Washington's North Cascades Mountains, 47 glaciers monitored since 1984 have lost, on average, 20 to 40 percent of their volume, with five having melted entirely away. In North Cascades National Park in Washington, the total area covered by glaciers has fallen by 13 percent since 1971.

The warming of the West is also **disrupting the natural timing of seasons** and leading to **loss of wildlife**. Lilacs and honeysuckle bushes are blooming earlier in the spring, marmots are emerging from hibernation earlier, jays are nesting earlier, ptarmigan are hatching earlier, and butterflies are emerging earlier. Species of wildlife are adapting to an altered climate by changing where they live—and in some cases are being eliminated from areas where they used to live. In Yosemite National Park, 14 of 50 studied animal species can no longer be found in lower-elevation portions of the range they occupied early in the 20th century.

Warmer Temperatures Affect Business, Recreation, and Tourism

In the first few years of the 21st century, western farmers and ranchers have suffered significantly from the combination of **above-normal heat and drought**. Across the country, four of the five top years for crop loss claims due to drought have been since 2000.

Warming temperatures and other manifestations of a changing climate are already **diminishing fishing and hunting** opportunities in the West. Sea-run salmon stocks are in steep decline throughout much of North America. In Montana, in eight out of the last 10 years, drought and higher temperatures have led to the shutdown of fishing in nationally acclaimed angling rivers. Hotter and drier conditions have also led to fewer opportunities for hunting in some places and times.

In the West, ski areas at lower elevations have recently suffered from **less snow**, with the Northwest and the Southwest taking turns having very bad years.

Conclusion and Recommendations

This report shows that the West is being affected by a changed climate more than any other part of the United States outside Alaska. Comparing average temperatures in the last five years to 20^{th} century averages, the West has experienced 70 percent more warming than the world as a whole. The economic damages of this disrupted Western climate are being felt in the tourism, agriculture, hunting, fishing and skiing industries, to name just a few. The good news is this is a problem residents of the West can help solve.

This challenge can be met through improvements in building, vehicle and industrial efficiency; increased investment in renewable energy and low carbon fuel; and deployment of technologies to capture and store carbon emissions. Enacting mandatory federal greenhouse gas limits will stimulate investment in cleaner energy technologies.

Additionally, policies that will help overcome the significant barriers to investment in energy efficiency must be adopted. Relying on the market alone to drive investment is not enough. Federal and state policies are also needed to promote building and transportation efficiency by reforming perverse regulatory incentives and allowing investment in energy efficiency to compete on a level playing field with expenditures on electric and gas supply.

There are several ways of achieving these goals. One is regional. To date, seven western states (Arizona, California, Montana, New Mexico, Oregon, Utah, and Washington) have entered into a regional agreement to limit global warming pollution. Governors of these states, and others that join the Western Regional Climate Initiative (WCI), have agreed to a goal of reducing their aggregate greenhouse gas emissions 15 percent below 2005 levels by 2020. Current and future members of the WCI should ensure that a suite of comprehensive policies achieves these targets either on or ahead of schedule. Additionally, the WCI states should agree to the firm target of reducing emissions of global warming pollution at least 80 percent below current levels by mid-century.

State action, however, cannot do the job alone. We also need leadership at the federal level, where the U.S. Senate is working on a major bill that would get the United States started on addressing global warming. We urge western state Senators to support and strengthen S. 2191, the Lieberman-Warner bill ("America's Climate Security Act") on global warming.

The sooner and the more decisively we act to usher in the next generations of buildings, vehicles, fuels and energy, the greater our chances will be of avoiding the most dangerous effects of human-caused global warming and preserving the West we know and love.

CHAPTER 1

The West Is Getting Hotter

The planetary warming that scientists have predicted as a result of human emissions of heat-trapping gases is already underway, and it is greater in the American West than across most of the globe. In February 2007, the world's scientists and governments united in declaring, "Warming of the climate system is unequivocal." This declaration, embodied in the Fourth Assessment Report by the Intergovernmental Panel on Climate Change, was accompanied by a parallel conclusion that it is "very likely" that most of the warming since the middle of the 20th century is the result of human pollutants.[1]

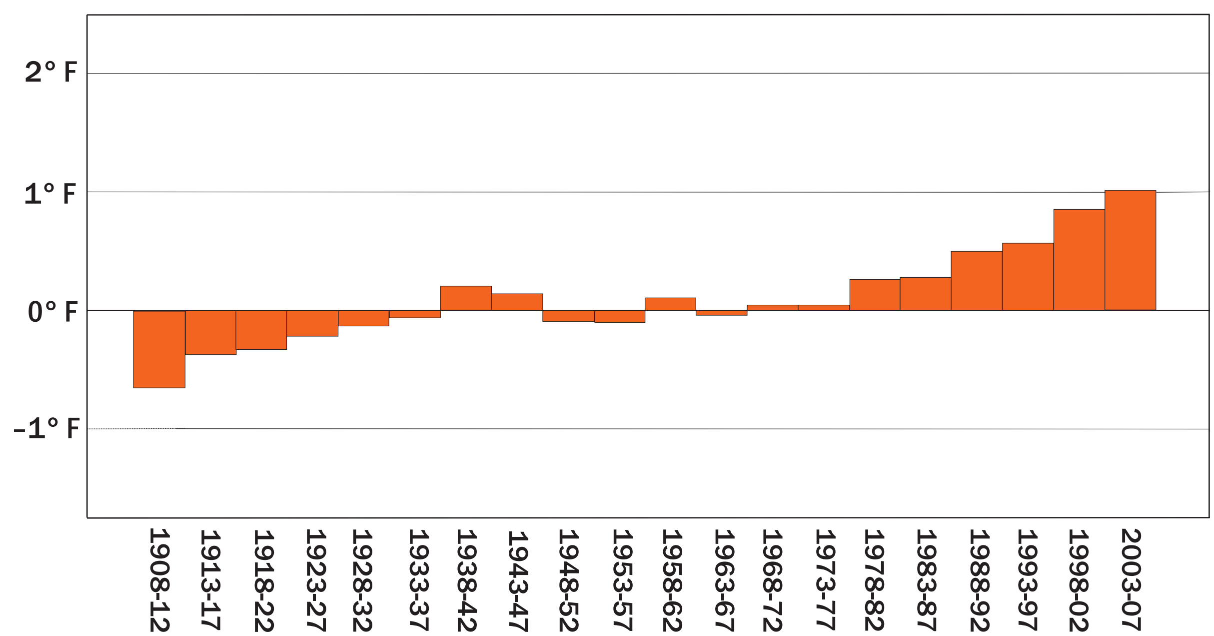
The Reality of Global Warming

The IPCC reported that the average surface temperature of the world has increased by more than 1 degree Fahrenheit in the past 100 years.[2] The warming has not been equal everywhere, with more warming over land areas than over oceans and more over land in the Northern Hemisphere than over land in the Southern Hemisphere.[3] These differences are related to each other, as the Northern Hemisphere's land masses are larger than the Southern Hemisphere's and so are cooled less by the oceans' lower temperatures and the prevailing winds coming from the oceans. For Northern Hemisphere land, the IPCC reports that four different datasets show a warming trend of about 1.3 degrees Fahrenheit to 1.6 degrees Fahrenheit between 1901 and 2005.[4] The warming has not been a steady progression during this time: there were the ups and downs expected from natural variation until about 1915; an increase from then until about 1940; a slight cooling until about 1950; and rapid, steady warming thereafter.[5]

> *"The West is warming dramatically. Things are just going to get hotter. You can bet the farm on it."*
>
> —Dr. Jonathan Overpeck, University of Arizona (2006)[6]

Figure 1 shows the trend in global warming from 1908 through 2007, using the dataset of the U.S. government's National Oceanic and Atmospheric Administration (NOAA), one of the four datasets relied upon by the IPCC. As in other comparable figures in this report, temperatures are shown as five-year averages (to show trends better than single-year temperatures do) compared to the historical average for the 20th century. This analysis shows that the five most recent years (2003 to 2007)

Figure 1. Global Temperature Change, 1908 - 2007



Global temperatures averaged over five years, compared to the average global temperature for 1901 - 2000. The average temperature for 2003 - 2007 was 1° F warmer than the historical average. Data from the National Oceanic and Atmospheric Administration. Analysis by the Rocky Mountain Climate Organization.

were 1.0 degree Fahrenheit warmer than the 20th century average. Another way to look at this is that, according to this dataset, Earth during the period 1908 to 1912 was about 0.6 degrees Fahrenheit cooler than the 20th century average, and during the period 2003 to 2007 was 1 degree Fahrenheit warmer, for a total warming over this 100-year period of 1.6 degrees Fahrenheit.

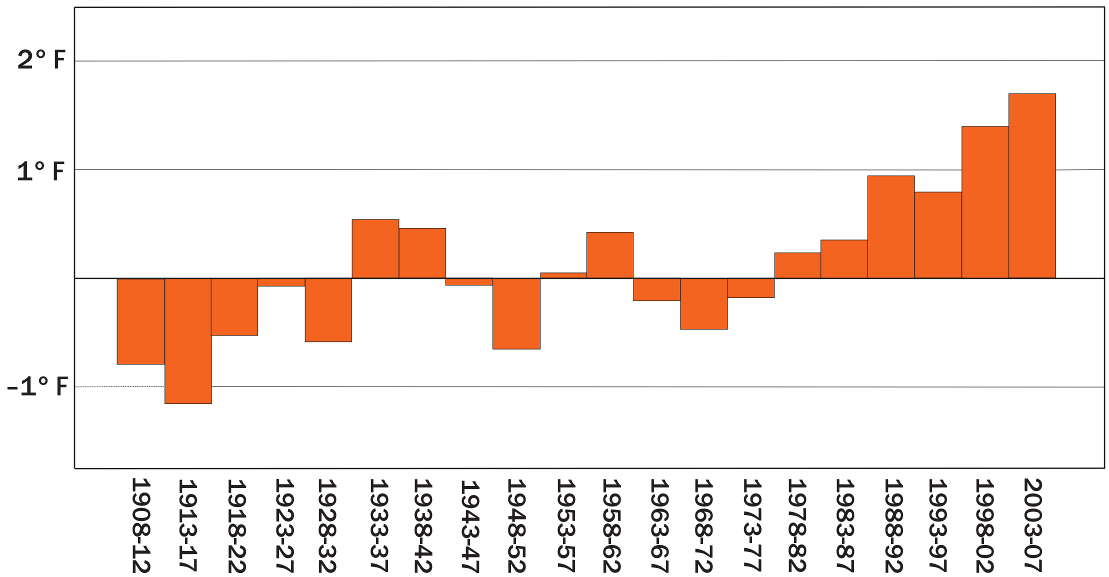
The West Is Warming Faster

For this report, the Rocky Mountain Climate Organization similarly analyzed the trend in measured temperature changes for the 11 western states for the past 100 years, from 1908 through 2007, again using NOAA data (state-by-state results are presented in Appendix 1). As shown in Figure 2, compared with the 20th century average, the West in the five latest years was 1.7 degrees Fahenheit warmer—0.7 degrees, or 70 percent, more than the overall planet's warming. The 100-year trend shows that the West was 0.8 degrees Fahrenheit cooler than the 20th century average in the initial five years (1908 to 1912) and ended it 1.7 degrees Fahrenheit warmer in the most recent five years (2003 through 2007). In other words, over the 100-year period the West has become 2.5 degrees Fahrenheit hotter—representing 0.9 degrees Fahrenheit more warming than the globe as a whole over the 100-year period.

Scientific analyses confirm that the recent warming in the West is in large part a regional manifestation of the same global warming that is being driven by human activities, and not just a matter of natural climate variability:

- According to the IPCC, "For the century-long period 1906 to 2005, warming is statistically significant over most of the world's surface"—including the American West.[7]

Figure 2. Temperature Change in the West, 1908 - 2007



Temperatures in the 11 western states averaged over five years, compared to the average regional temperature for 1901 - 2000. The average temperature for 2003 - 2007 was 1.7° F warmer than the historical average. Data from the National Oceanic and Atmospheric Administration's climate division series. Analysis by the Rocky Mountain Climate Organization.

- NOAA scientists studied the causes of the record high temperatures in the contiguous United States in 2006, and discovered that the warming could not be assigned to El Niño conditions in the Pacific Ocean (sometimes identified as a possible cause of high temperatures in the United States). Instead, they found that climate models enabled them to attribute more than half of the year's record warmth to the effects of increased greenhouse gas concentrations, which they found to now exceed the range of natural fluctuations. In summary, they concluded that "the record warmth was primarily due to human influences."[8]

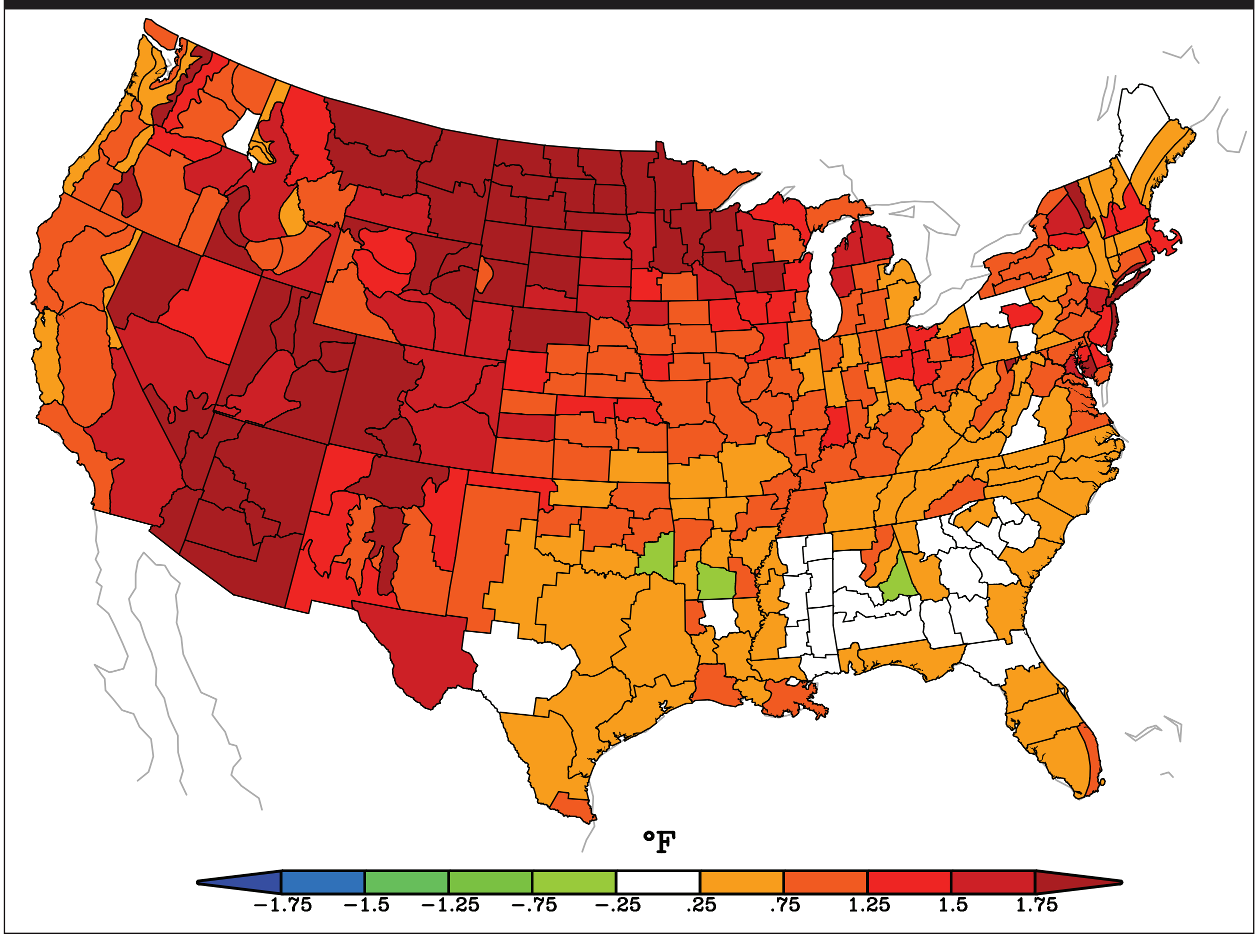
- Researchers at the University of Washington have analyzed the warming in the western United States and that of the globe as a whole and concluded that they are "robustly coupled." [9]

The real confirmation, though, came in a study by researchers at the Scripps Institution of Oceanography and elsewhere, released in January 2008. They demonstrated statistically that most (up to 60 percent) of the observed changes in three key climate factors in the West, including increases in winter temperatures, in the second half of the 20th century are due to human causes. They did so both by demonstrating that the observed changes are more than 99 percent likely to be outside what could be expected through natural climate variation, and that the changes are consistent with (although stronger than) the modeled projections of how human activities should affect climate. The observed changes could be clearly attributed to human activities beginning in the mid-1980s, they reported.[10] One striking point about this work is that the researchers found such strong evidence that people were already changing the West's climate in the last century, without even considering the greater changes that are already underway in the early years of this century. (This study is explained in more detail in the next chapter.)

The warming in the West has occurred at a faster rate than across Northern Hemisphere land and the overall planet. Western warming is also markedly greater than that of the eastern states, as shown by comparisons in Figure 3 of temperatures in the first seven years of this century with average 20th century temperatures across the contiguous United States. One explanation offered by the IPCC is that changes in atmospheric circulation patterns appear to have made the East cloudier and wetter, keeping it cooler.[12]

> *"Almost all of the models we've seen in recent years show the area becoming warmer and more arid due to climate change, but the question was always whether we could believe them… Now someone has done the statistical analysis to connect the dots so they can say with real confidence that this is happening because of greenhouse gases."*
>
> —Dr. Jonathan Overpeck, University of Arizona (2008)[11]

Figure 3. The Interior West: Epicenter of Warming in the Contiguous U.S. (2000 - 2007 Average Temperatures Compared to 20th Century Averages)



Average temperatures in 2000 - 2007 compared to averages for 1901 - 2000. Source: Dr. Martin Hoerling, National Oceanic and Atmospheric Administration.

Western temperatures have increased more at high elevations than at lower ones, meaning that the West's warming has been concentrated where snow falls and is naturally stored in mountain snowpacks.[13] The warming therefore particularly affects western snow resources, which supply most of the region's fresh water, of vital importance in this water-short region. (See Chapter 2.)

The warming of the West is predicted to continue. The 21 climate models used by the IPCC to project the consequences of a moderate-emissions future project increases of 3.8 to 10.6 degrees Fahrenheit in warming for western North America over the course of the 21st century, with an average projection of 6.1 degrees. These projections are in comparison to a baseline of 1980 to 1999 temperatures, and so include the warming that has already occurred early in the 21st century.[14] If future emissions were to be lower or higher than in this future scenario, temperature increases also likely would be lower or higher. Climate models generally project that future warming will be greater in the interior West than near the coast.[15]

> *"The western part of the United States is always warming much more than the rest."*
>
> —Dr. Claudia Tebaldi, National Center for Atmospheric Research (2007)[16]

An Epicenter for Heat Waves

In addition to rising average temperatures, global warming is predicted to increase the hottest periods that we call heat waves. The IPCC identifies the western United States as one area (along with three others) where it is "very likely" that heat waves will become more frequent, more intense, and longer lasting.[17] The IPCC further states with "high confidence" that "[s]evere heatwaves, characterized by stagnant, warm air masses and consecutive nights with high minimum temperatures, will intensify in magnitude and duration over the portions of the U.S. and Canada where they already occur."[18] Such temperatures are likely to have deadly effects. Excessive heat is responsible for the deaths of about 1,500 Americans a year, making it the most lethal of all weather events—even before figuring in a hotter climate.[19]

The IPCC's identification of the western United States as an epicenter of heat waves is based on the findings of several studies. A study by the National Center for Atmospheric Research (NCAR), using nine climate models to project future regional increases in heat waves, projected that they would increase more in the interior West than elsewhere in the contiguous United States and as much as anywhere in the world.[20] An earlier NCAR study projected that in the United States the greatest increase in the severity of future heat waves would be in the interior West.[21] Similarly, a third study done at Purdue University projected that the greatest increases in both heat wave frequency and duration would be in the interior West, where high temperatures previously reached only in the 18 hottest days of the year would be reached as often as in 102 days per year in the Southwest, 73 days per year in high-elevation California and central Utah, and 55 days per year in central Idaho.[22]

Yet another study from the California Climate Change Center, a state government agency, projects there will be by the end of this century a doubling or tripling of the number of days in that state getting as hot as each locality's hottest 36 days of the year. In Los Angeles, for example, temperatures are projected to reach 88 degrees Fahrenheit in 70 to 145 days per year, rather than the 36 days per year that has been the norm. By the end of the century, excessive heat is projected to kill anywhere from twice as many to 9.5 times as many Californians. [23]

> *"[C]limate change is a reality, and heat storms may be a symptom of it. After two successive summers with prolonged periods of stifling heat, we must consider ourselves warned about the shape of things to come."*
>
> —H. David Nahai, president, Los Angeles Board of Water and Power Commissioners (2007)[24]

The projected increases in heat waves are already happening, around the world and in the western United States. The IPCC concluded that globally, since 1950, the number of days with extreme temperatures has increased, with a greater increase in nighttime extremes than in daytime extremes. The European heat wave in the summer of 2003 provides a recent example of how deadly extreme heat can be. The heat wave brought continent-wide summer temperatures averaging 4.1 degrees Fahrenheit warmer than average and the hottest there during at least the last five centuries.[25] About 35,000 people died as a result of the heat wave, according to the IPCC, which concluded that the excess deaths in 2003 are likely the result of human influences on the climate system.[26]

The western United States has experienced a trend since 1950 of up to four more days per decade with extreme high temperatures. The eastern United States, by contrast, has experienced a decrease in extreme highs. The entire West also has had an increase in warm nights, along with the rest of the contiguous United States. The extreme Southwest has had the greatest increase in warmer nights, with a trend of four to eight more nights with extreme temperatures per decade.[27]

The western heat waves of July 2006, for example, brought unprecedented high nighttime temperatures—and the deadliest heat waves are those with excessively hot nights that offer no relief from the heat.[28] Scientists for the California state government found that the nighttime temperatures of this heat wave greatly exceeded that of any other California heat wave recorded in 59 years of reliable measurements.[29] In Sacramento, for example, three straight nights were each hotter than the previous record of 78 degrees Fahrenheit for the hottest nighttime temperature set in 1909. Even in major heat waves in Sacramento, nighttime temperatures typically fall into the mid-60 degrees Fahrenheit.[30] The consequences were deadly. In California alone, the heat wave led to an initial official count of at least 143 deaths from the heat—a total being reviewed by the state government following an Associated Press analysis suggesting that the real death toll may have been 466. [31]

In the summer of 2007, the West experienced another round of major heat waves. Montana, Idaho, and Wyoming experienced their hottest Julys ever that year. [32] Arizona had its hottest August, and Phoenix set a record of 31 days reaching at least 110 degrees Fahrenheit, breaking the old record of 28 days. [33]

In sum, the West, even more than other parts of the contiguous United States or the globe as a whole, is already hotter because of human emissions of heat-trapping gases. Particularly consequential is that the West's temperatures have risen more at higher elevations than at lower ones. This means that the region's warming is most pronounced precisely where it has the greatest effects on the snow resources that provide most of the region's water. Those effects are the subject of Chapter 2.

CHAPTER 2

The West Is Getting Drier

In the arid and semi-arid West, global warming will have serious consequences for the region's scarce water supplies, particularly the snow that makes up most of the region's precipitation and, when melted, provides 70 percent of its water. The Intergovernmental Panel on Climate Change projected with "high confidence" that water supplies stored in mountain snowpacks will decline around the world, reducing water availability in regions supplied by meltwater.[1] The IPCC identified the American West as vulnerable, warning, "Projected warming in the western mountains by the mid-21st century is very likely to cause large decreases in snowpack, earlier snow melt, more winter rain events, increased peak winter flows and flooding, and reduced summer flows."[2] These changes would shift available water supplies from summer—when they are most needed by people, agriculture, and ecosystems—to earlier in the year. The IPCC also warned that the results would include "a projected increase in the chance of summer drying in the mid-latitudes," which includes the American West, "with associated increased risk of drought."[3] All in all, the IPCC concluded that in North America, including the fast-growing western United States, "Reduced water supplies coupled with increases in demand are likely to exacerbate competition for over-allocated water resources."[4]

These effects could be mitigated, at least partially, if overall levels of precipitation were to increase.[5] On a global basis, as the water cycle heats up, evaporation is projected to increase, leading to more atmospheric moisture and so more precipitation. But increases in precipitation are believed to be more likely in wet areas, not dry areas. Current climate models disagree about whether overall precipitation levels in the West are likely to increase or decrease—except for the Southwest, where the IPCC concluded that precipitation is "likely" to decline.[6]

The IPCC found that these predicted changes are underway around the world, with "very high confidence" that snow resources are affected, and with "high confidence" that water resources are affected.[7] In particular:

> There is abundant evidence for an earlier occurrence of spring peak river flows and an increase in winter base flow in basins with important seasonal snow cover in North America and northern Eurasia, in agreement with local and regional climate warming in these areas. The early spring shift in runoff leads to a shift in peak river runoff away from summer and autumn, which are normally the seasons with the highest water demand, resulting in consequences for water availability. [8]

Human-Caused Changes in the West

As explained in Chapter 1 (see page 3), researchers at the Scripps Institution of Oceanography and elsewhere recently demonstrated statistically that most (up to 60 percent) of the changes in the West's hydrology measured in the second half of the 20th century are due to human causes. The scientists did this by examining three values that are key to the West's snow/water cycle: average minimum temperatures in January, February, and March; April 1 snowpack levels; and the timing of peak river flows. They did a sophisticated "detection and attribution" analysis that demonstrated that the measured increases in temperatures, decreases in snowpack, and earlier peak flows from 1950 to 1999 are more than 99 percent likely to be outside what could be expected through natural climate variation. They also demonstrated that the measured changes were consistent with (although stronger than) the modeled projections of how heat-trapping gases should affect these values. The effects of emissions on the West's hydrology were clear by the mid-1980s, they reported. As noted in Chapter 1, one striking aspect of this study is that the researchers were able to identify that greenhouse gases were already changing the West's climate in the last decade and a half of the 20th century, even without considering the much greater increases in temperature, decreases in snowpack, and acceleration of peak river flows that have been present in the early years of the 21st century.[9]

> *"We've known for decades that the hydrology of the West is changing, but for much of that time people said it was because of Mother Nature and that she would return to the old patterns in the future. But we have found very clearly that global warming has done it, that it is the mechanism that explains the change and that things will be getting worse."*
>
> —Tim Barnett, Scripps Institution of Oceanography (2008)[10]

The Scripps Institution study is unique in so clearly linking changes in the West's snow and water resources to human causes, but is consistent with a wide variety of other studies that have pointed out that these changes are already underway. A summary of how global warming is affecting the hydrology of the West follows.

Smaller Snowpacks

Three previous studies show springtime western snowpacks now average smaller than they used to. The first, an analysis by researchers at the University of Washington of the records of 824 government snowpack measurement sites across the West with records from 1950 to 1997, showed that snowpack levels have declined at most of those sites over that period, with the greatest decreases where winters are mild and warming of a few degrees can more often push temperatures above freezing. After considering possible contributing factors, the researchers concluded that the pattern of the declines points to the warming already underway in the West as the cause.[11] This observed trend was cited by the IPCC as one of seven indicators that climate change is underway in North America.[12] Also, as the IPCC has reported, the extent of area covered by snow in spring and summer has decreased in the West.[13]

In the second study, the Rocky Mountain Climate Organization analyzed the snowpack measurement sites with records from 1961 through 2005 in each of the West's four largest river basins: the Columbia River basin (163 sites), the Missouri River basin (109 sites), the Colorado River basin (59 sites), and the Rio Grande basin (19 sites). RMCO compared snowpack levels for each site to its average for 1961 to 1990, rather than the 1971 to 2000 baseline used by the Natural Resources Conservation Service, to evaluate how recent years compare to an earlier baseline period that includes less warming. Of the 16 years from 1990 on, the Columbia basin had below average snowpacks in 13 years, the Missouri basin in 14 years, the Colorado basin in 11 years, and the Rio Grande basin in 10 years.

A third study had consistent results. Researchers at the University of Colorado-Boulder studied snowpack measurement sites in the West with records spanning from 1950 to 1999 for March 1 data (469 sites), April 1 data (501 sites), and May 1 data (239 sites) and found that significant declines occurred at about half the sites, primarily those below 8,200 feet, with little difference at higher sites. As did the researchers in the first study, the authors of this study concluded that the greater decline at lower elevations appears to show that the declines are driven by warming temperatures, since (1) at lower elevations winters generally are milder and so the relatively modest increase in temperatures that has occurred would more often push temperatures above freezing; and (2) any changes in precipitation would be nearly uniform at different elevations.[14]

> *"Much of the mountain West has experienced declines in spring snowpack, especially since mid-century, and despite increases in winter precipitation in many places . . . [T]hese results emphasize that the West's snow resources are already declining as Earth's climate warms."*
>
> —Dr. Philip Mote and others (2005)[15]

Of course, as with all such changes in climate, the declines in western snowpack are measured as changes in averages for a period of sufficient length, compared to previous times. Even with snowpacks now averaging less than they used to, some winters may have above-average snowpacks (as currently is the case with this winter across some of the West). The effect of global warming is like loading dice; it makes it more likely that a certain outcome will happen, but does not end the chance that another outcome can happen from time to time.

Less Snowfall

One of the reasons that snowpacks have diminished is that, with warming, more winter precipitation is falling as rain rather than as snow. A study by three U.S. Geological Survey (USGS) scientists showed that less winter precipitation is falling as snow and more as rain at 74 percent of 200 western mountain sites. As with snowpack studies, the greatest changes have been at lower-elevation sites.[16]

Earlier Snowmelt

Western snowpacks are also melting earlier in the year. A study by Scripps Institution of Oceanography and USGS scientists concluded that for a majority of 279 snowmelt-dominated western rivers and streams, the timing of peak flows advanced over the period 1948 to 2000, with the peak flow coming 10 to 30 days earlier in many cases.[17] The study by University of Colorado-Boulder researchers mentioned previously concluded that, in most places in the West, peak spring flows occur an average of at least 10 to 15 days earlier, related to earlier warm-up in spring. The changes in snowmelt timing vary with elevation: In basins less than 8,200 feet in elevation, shifts in peak flows 10 to 20 days earlier in spring are common, while in higher basins little change is evident. The Pacific Northwest, with both lower-elevation water basins and an above-average advancement of warm spring weather, is the region where the most significant changes in the timing of peak flows has occurred.[18] A third study by scientists from the USGS and the University of Colorado-Boulder confirmed that since the mid-1980s snowmelt has occurred earlier in lower-elevation, warmer river basins in the West, and identified as the primary cause a regional rise in April-June temperatures.[19]

In the springs of 2004 and 2006, the earlier snowmelt in the West was particularly extreme. At the beginning of March 2004, much of the region had above-average snowpacks, raising hopes of relief from drought. The month that followed, though, was the third-driest March in the West's history, with record-setting heat. Across more than half of the West, the month averaged more than 5 degrees Fahrenheit above normal. Under these conditions, an unprecedented snowmelt occurred, with a loss of snowpack that "far outstripped any in the past 70 years," according to federal climate scientists, with peak streamflows occurring 20 to 30 days earlier than normal. "March 2004 may be a harbinger of even more extreme changes to come," the scientists warned.[20]

The spring of 2006 was essentially a replay of 2004. "Once again lack of precipitation and warm temperatures combined to turn reasonable expectations of near average runoff into disappointment," wrote four federal scientists. Across most of the West, winter snowpacks were in better shape than in other recent years. Then the cold of winter turned into the heat of summer so quickly that "spring was almost missing." Snow melted and even evaporated, and the pulse of springtime river flows came as much as three weeks earlier than normal. Across the West, snowpack levels went from above average on April 1 to less than 75 percent of normal by May 1.[21]

Reduced Streamflow

Changes in climate lead to less streamflow in at least two ways. First, earlier snowmelt shifts the timing of flows of snowmelt-fed rivers, increasing flows early in the year and diminishing them in the summers, when water needs are greatest. This change in hydrology, which as noted above is already occurring, can have significant effects on water users and ecosystems, even if total annual streamflow volumes are unchanged.

Second, the higher temperatures already occurring can increase evaporation enough to reduce overall streamflow volumes, even if precipitation levels remain the same. An early study of the Colorado River, for example, projected that a 7.2 degrees Fahrenheit increase in temperature—by itself, without any changes in precipitation—would increase evaporative losses enough to reduce snowmelt runoff by 9 to 21 percent.[22] As yet, there are only very limited direct measurements of evaporation, and conclusions are not yet possible about whether or how warming has led to changes in actual evaporation rates.[23]

> *"The western mountain states are by far more vulnerable to the kinds of change we've been talking about [water resource impacts] compared to the rest of the country, with the New England states coming in a relatively distant second."*
>
> —Dr. Michael Dettinger, U.S. Geological Survey (2007)[24]

The IPCC has reported that average annual streamflow in the central Rocky Mountains over the last century has decreased by about 2 percent per decade, and that since 1950 stream discharge in both the Colorado and Columbia river basins has decreased. (For more on the Colorado River basin, see chapter 3.) By contrast, in the eastern United States average annual streamflow has increased 25 percent in the last 60 years.[25]

Less Precipitation in the Southwest

Another possible effect of climate change on overall streamflow levels in the West and elsewhere would be a reduction in average amounts of precipitation. With respect to future precipitation trends in North America, the IPCC has stated that annual mean precipitation is "very likely" to increase in Canada and the northeastern United States, and "likely" to decrease in the southwestern United States.[26] For other areas of North America, including the rest of the West, the IPCC has not reached any comparable conclusions with respect to likely future precipitation levels, as model projections vary.

According to the IPCC, changes in measured precipitation levels from 1901 to 2005 show a pattern consistent with the projections for a changed climate, with increases in annual precipitation over most of North America. The primary exception is over the southwestern United States, where precipitation has declined 1 to 2 percent per decade, as drought has prevailed there in recent years.[27]

More Drought

The IPCC concluded that more intense and longer droughts have been observed over wider areas of the world since the 1970s. The regions where droughts have occurred were found to be driven largely by changes in ocean temperatures, although "[i]n the western USA, diminishing snow pack and subsequent reductions in soil moisture also appear to be factors."[28]

Beginning in 1999, much of the West has experienced severe drought conditions, which the IPCC featured as a "notable extreme climate event," characterizing it and other such events this way: "The odds may have shifted to make some of them more likely than in an unchanging climate, but attribution of the change in odds typically requires extensive model experiments . . . It may be possible, however, to say that the occurrence of [these] recent events is consistent with physically based expectations arising from climate change." The IPCC described the recent, continuing western drought this way:

Drought conditions were recorded by several hydrologic measures, including precipitation, streamflow, lake and reservoir levels and soil moisture. The period 2000 through 2004 was the first instance of five consecutive years of below-average flow in the Colorado River since the beginning of modern records in 1922 . . . At its peak (August 2002), this drought affected 87 percent of the West (Rocky Mountains westward), making it the second most extensive and one of the longest droughts in the last 105 years.[29]

Economic and Human Losses Stemming from the Drought of 2002

- In Colorado, agricultural losses from the drought were estimated at $1.1 billion. [30] In New Mexico, the net income from livestock production fell approximately $279 million between 2001 and 2002. [31] In Arizona, losses in the cattle industry and the ripple effects cost the state's economy an estimated $2.8 billion from 2002 through 2005. [32] In Utah, 2,600 agricultural jobs were lost. [33]

- In 2002, both Arizona and Colorado had the largest individual wildfires in their histories. In Colorado, nine firefighters died, nearly 1,000 structures were destroyed, and 915,000 acres burned.[34] In 2002, the Rodeo-Chediski fire, the largest in Arizona history, burned across 468,638 acres, destroyed 467 homes, caused at least $28 million in damage, and cost $43 million to extinguish. [35]

- In Colorado, the drought and fires combined to cause an estimated $1.7 billion in lost tourism income. [36]

> *"[G]lobal warming is a fact and water managers need to plan accordingly."*
>
> —American Water Works Association (1997)[37]

Water Management in the Face of Global Warming

As detailed earlier in this report, global warming is already having an impact on the West's scarce water resources. That impact is likely only to grow larger as populations expand, precipitation patterns change, and temperatures rise. Water managers—elected or appointed officials who control water resource decisions at the local, state, regional, and national level—can play a crucial role in helping the West deal with global warming. In a 2007 report *In Hot Water: Water Management Strategies to Weather the Effects of Global Warming*, NRDC laid out a roadmap for water managers. The report recommended that water officials:

- *Realize the past is not prologue.* Water managers should not rely only on past water levels and patterns in planning how to meet present and future needs. Future projections should include the potential impacts of global warming, such as reduced snowpack, earlier stream flows, greater evaporation, and increased stress on natural habitats.

- *Look beyond their boundaries.* Water, time, and money can be saved when managers work with their neighboring districts to plan for coming water needs and capital expenditures. This is particularly true of districts within large watersheds.

- *Put conservation first.* Increased investments in water efficiency represent a sound and basic "no regrets" water management approach to global warming impacts. Cost-effective water conservation investments can generate significant benefits for water supplies and aquatic ecosystems as well as reduced energy and greenhouse gas emissions.

- *Collaborate with energy utilities.* Water conservation generates substantial water and energy savings, and thus reductions in greenhouse gas emissions. Water agencies should work with local energy utilities to develop joint programs, such as rebate offers, to encourage customers to conserve water and energy. In California, 20 percent of total energy consumption comes from water-related uses.

- *Factor in flood management.* To reduce future damage, floodplains should be managed with awareness that they will be inundated more frequently. Managers should investigate opportunities such as floodplain restoration, groundwater recharge, flood-compatible agriculture and the re-operation of existing facilities.

- *Protect and restore aquatic ecosystems.* Degraded aquatic ecosystems result in the loss of species and create endangered species conflicts. Healthy aquatic ecosystems will be more resistant to climate impacts, help reduce conflicts, and provide other benefits to water quality, recreation, and flood protection.

- *Support policies including mandatory caps on global warming emissions.* For example, the Lieberman-Warner Climate Security Act, which was reported out of the Senate Environment and Public Works Committee in December 2007, would establish a national cap on global warming pollution that declines over time. It would reduce overall U.S. emissions 18 to 25 percent by 2020 and 62 to 66 percent by 2050.[38]

- *Educate customers and decision makers, and increase public awareness.* Water managers have a unique role of authority and credibility in the West. They should use this to help change attitudes and policy.

CHAPTER 3

The Colorado River Basin: Hotter and Drier

The Colorado River basin is the regional epicenter of the changes underway as much of the West gets hotter and drier. To begin with, the basin is second only to Alaska as an area in the United States where the evidence is strongest that climate disruption is already underway. Since the late 1970s, the basin has warmed more than any other region in the contiguous United States.[1] Also, the basin is not yet out of a multi-year drought that began in October 1999.[2] This drought is consistent with scientific projections that this basin, even more than most continental interiors, is likely to become both hotter and drier as the climate continues being altered.

The consequences of global warming also matter here—a lot. The Colorado does not have the water volume of the nation's other great rivers, but it is the major source of water in the driest part of the country. Water is in such need in this vast, arid region that the river is not only tapped for use throughout its basin, but also diverted by pipelines under mountains and canals across deserts for use hundreds of miles outside the basin. Upwards of 30 million Americans across seven states depend on this water for agricultural, municipal, industrial, and hydroelectric needs. The cities that rely on the Colorado River, including Denver, Albuquerque, Las Vegas, Phoenix, Los Angeles, and San Diego, are among the fastest growing population centers in the country, with even faster growth projected for the future. These populations are sustained in large part because Colorado River water is used to supplement local water supplies. [3]

In recent years, though, we have learned that because of natural climate variability—not even considering the effects of a changed climate—the Colorado River is not as reliable a source of water as once thought. Several recent reconstructions of likely river flows over the past five centuries based on tree growth rings and other evidence show that our beliefs about what river flows are "average" have been distorted by above normal flows early in the 20th century. The Colorado River, we now know, has for centuries been subject to widely varying flows and recurring mega-droughts. [4]

> *"You can't call it a drought anymore, because it's going over to a drier climate. No one says the Sahara is in drought."*
>
> —Dr. Richard Seager, Columbia University (2007)[5]

On top of this, scientists warn us that a disrupted climate will hit this rapidly growing region hard. A 2006 report by the National Academy of Sciences on Colorado River basin water management reviewed projections in scientific studies for the effects of climate disruption in the basin. The Academy reported that the average projection of 11 different climate models is for a temperature increase of more than 9 degrees Fahrenheit in the basin by the end of the century if emissions of heat-trapping gases continue to go up on a business-as-usual course.[6] The Academy identified several "likely effects" of this additional heat on the water resources of the Colorado River, including "more winter precipitation will fall as rain rather than snow; shorter seasons of snow accumulation at a given elevation; less snowpack accumulation compared to the present; earlier melting of snowpack … lowered water availability during the important late-summer growing seasons" and other impacts.[7]

During the past 30 years, numerous scientific studies have attempted to quantify these effects, and all have painted bleak pictures. Four of the most recent studies have projected that:

- River flows could be reduced by 8 to 11 percent by the end of the century, enough to trigger water curtailments under the Colorado River Compact every fourth year.[8]
- By the end of the century, Dust Bowl conditions will be the new climate norm of the Southwest.[9]
- As soon as 2030, the average flow of the river could be reduced to only half of the level on which the Colorado River Compact is based.[10]
- If current levels of use continue, as soon as 15 years from now there is a 50 percent chance that water levels in the river's two main reservoirs, Lake Powell and Lake Mead, will fall below the outlets, so that the reservoirs will have effectively gone dry.[11]

White "bathtub rings" show the pre-drought water level of Lake Powell.

> *"All of the recent studies suggest that Colorado River flows will decline as the earth warms. Flow declines could either be modest, or quite substantial."*
>
> —Bradley Udall, Western Water Assessment (2007)[12]

Higher Temperatures

The warming that is expected to drive these changes is already underway. In 2007, the National Academy of Sciences concluded:

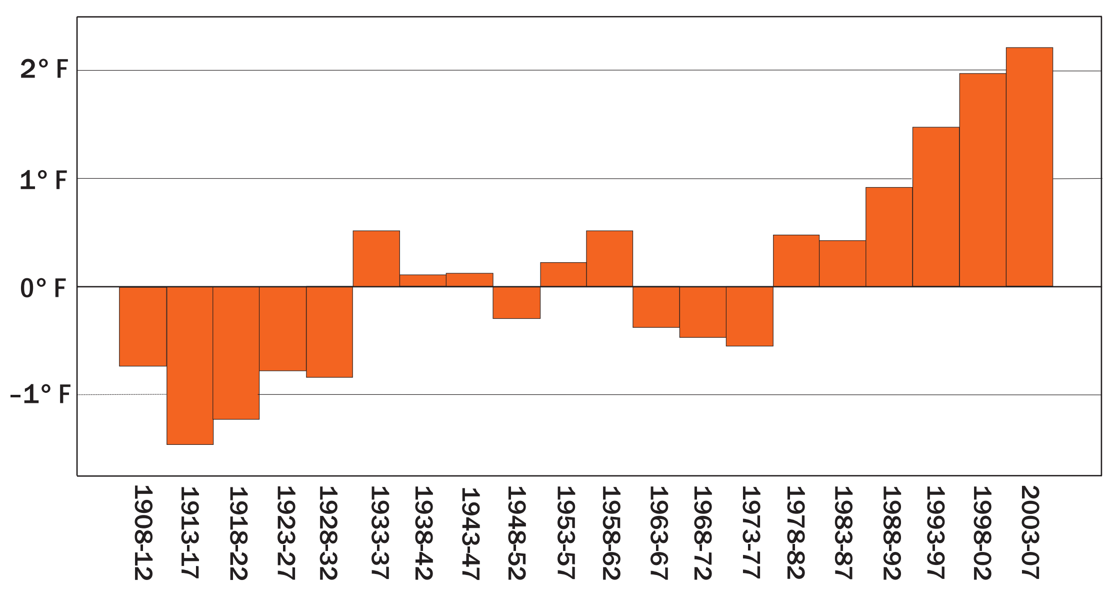
> "[T]he Colorado River basin has warmed more than any region of the [contiguous] United States —a fact that should be of great interest throughout the region. . . . This warming is well grounded in measured climatic data, corroborated by independent data sets, and widely recognized by climate scientists throughout the West."[13]

To demonstrate how temperatures in the Colorado River basin have increased in the past 100 years, the Rocky Mountain Climate Organization for this report analyzed government temperature data for the National Oceanic and Atmospheric Administration's climate divisions that most closely coincide with the basin. That analysis, represented in Figure 4, shows that the five most recent years in the Colorado River basin averaged 2.2 degrees Fahrenheit hotter than the 20th century average, and 2.9 degrees Fahrenheit hotter than the five years at the beginning of this time series 100 years ago.

Less Snow

More heat, of course, can translate into less snow. The Colorado River is fed mostly by cold-season precipitation in the mountains of Wyoming, Utah, and Colorado. Much of the basin's precipitation falls in the winter, and more of that season's precipitation than of warm-season precipitation actually makes it to the river. (In warm seasons, rainfall is largely soaked up by actively

Figure 4. Temperature Change in the Colorado River Basin, 1908 - 2007



Temperatures in the Colorado River Basin averaged over five years, compared to the average basin temperature for 1901 - 2000. The average temperature for 2003 - 2007 was 2.2^0 F warmer than the historical average. Data from the National Oceanic and Atmospheric Administration's climate division series. Analysis by the Rocky Mountain Climate Organization.

growing plants or evaporates before it reaches streams and aquifers.) On the other hand, when winters are cold enough, as they have been historically, winter precipitation falls as snow and is stored naturally in mountain snowpacks until it melts in the spring or summer. This natural system of storage and release of the winter precipitation conveniently delivers water from the higher elevations where it falls to the lower elevations where people and crops need it. And the water flows to them, not in the winter when they have less need for it, but later in the year, when their need is greater. [14]

This natural system already appears to be changing. As the Colorado River basin has warmed in recent years, winter snowpacks in the upper basin have diminished. In the 10 most recent years, 1998 through 2007, the April 1 snowpacks for sites in the upper Colorado River basin were below average for eight years. And this official tally is in comparison to the average snowpack levels for 1971 to 2000, the baseline period used by the U.S. Department of Agriculture's Natural Resources Conservation Service, which gathers and reports snowpack data.[15] This practice of using the most recent three complete decades as a baseline masks the extent to which recent years may vary from earlier times. A comparison of recent years, which may be influenced by the first manifestation of global warming, to a more natural baseline requires analysis of data from only those snowpack measurement sites in operation long enough to have a pre-warming baseline. As described in Chapter 2, the Rocky Mountain Climate Organization did such an analysis in 2005 of the 59 sites in the upper Colorado River basin with records going back to 1961, and found that from 1990 on those sites were below the 1961 to 1990 average for 11 of those 16 years.

The Colorado basin, while getting less snow, has seen less of a change than some other parts of the West. In RMCO's 2005 analysis, similar snowpack sites in the Missouri and Columbia river basins showed more of a reduction. Missouri River snowpacks were below average for 14 of the 16 most recent years, and Columbia River snowpacks for 13 of those 16 years. This difference is consistent with the effects of global warming. The mountains of the Colorado River basin tend to be higher—and colder in winter—than other western mountains. At the lower elevations of other mountain ranges, winter temperatures are milder, so that warming of a few degrees is more often enough to push temperatures above freezing, changing precipitation to rain rather than snow and changing snowpacks to snowmelt. Still, in recent years the Colorado River has had reduced snowpacks, too, and any reduction in this snow-dependent, water-short area has a proportionately severe impact.

Some of the recent reductions in Colorado River snow levels have been quite severe:

- In 2002, the three watersheds in Colorado that are part of the Colorado River basin had April 1 snowpack levels of 57, 63, and 34 percent of the averages for that date. A month later they had fallen to 19, 27, and 6 percent of the averages for May 1.[16]
- In 2006, many locations in the mountains of southern Colorado, New Mexico, and Arizona reported record or near-record low snowpack. In Arizona, for example, more than 90 percent of reporting stations were snow free on January 1, the most snow-free locations in at least the past 40 years. [17]

Earlier, Quicker Snowmelt

Snow in the Colorado River basin is also melting earlier in the spring. Figure 5 shows the results of a new analysis by the Rocky Mountain Climate Organization of government data for automated (SNOTEL) upper-basin snowpack measurement sites collected between 1985 and 2007 for March 1, March 15, April 1, April 15, May 1, and May 15 as compared to the 1971 to 2000 averages for each of those dates. The snowpacks from 1985 onward began the springs already below normal and then melted faster than normal. On March 1 they averaged 94 percent of normal for that date; on March 15, 93 percent of normal for that date; on April 1, 87 percent; on April 15, 84 percent; on May 1, 84 percent; and finally, on May 15, 78 percent. Again, if the baseline for the average were derived only from earlier years, instead of including the recent, warming-influenced years as the Natural Resources Conservation Service does, the trend of earlier snowmelt would be even more obvious.

Two recent examples further illustrate early snowmelt. In 2004, the warmest March in the Southwest in at least 110 years dropped the basin-wide snowpack from

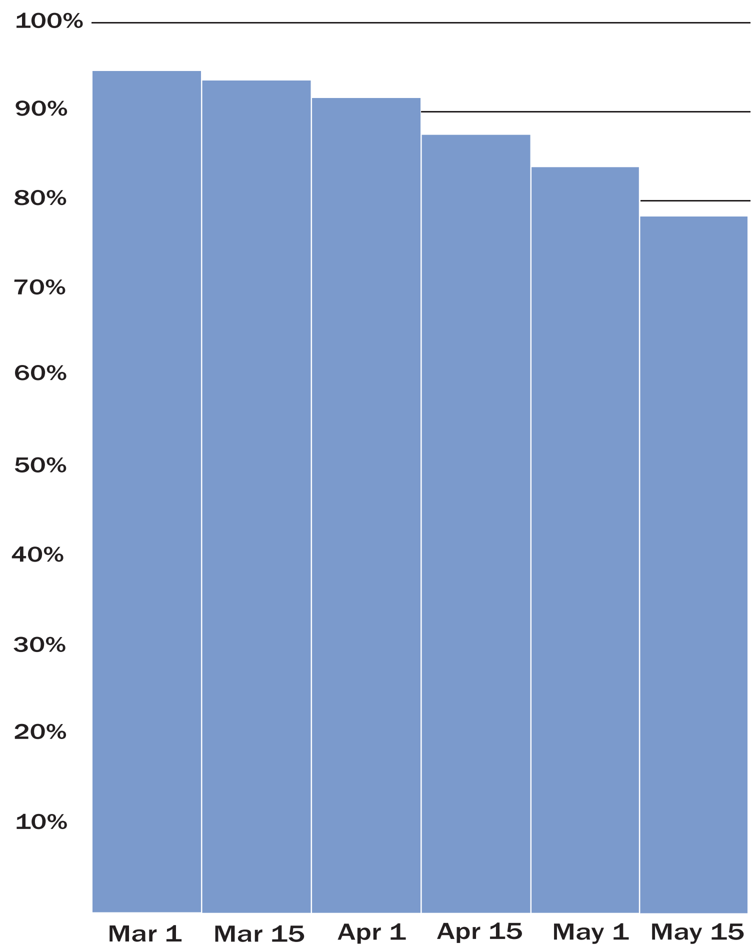
97 to 66 percent of average.[18] In 2006, the snowpack was 2 percent above average on April 1, but by May 15 it had plummeted to only 54 percent of average because of below normal precipitation and above normal temperatures.[19]

Scientists from the National Snow and Ice Data Center at the University of Colorado-Boulder and other institutions recently identified an additional climate-related mechanism besides warmer temperatures that may bring about earlier snowmelt in the Colorado River basin. They reported that desert dust blown from basin lowlands deposits on snowfields, absorbs sunlight, and speeds up spring snowmelt by 18 to 35 days, compared to dust-free conditions. In a year when drought led to more dust deposition (2006), the acceleration of snowmelt was up to 40 percent greater than in a more normal year (2005). The researchers concluded that the increased drought forecast in the Southwest with global warming may lead to earlier snowmelt more often in the future.[20]

Reduced River Volume

The high temperatures, below-average snowpacks, and early snowmelt of recent years have led to reductions in what matters most in this basin: the volume of water in

Figure 5. Quicker Colorado River Basin Snowmelt: Springtime Snowpacks 1985-2007 Compared to 1971-2000 Norms for Date



Aggregated data for upper Colorado River basin SNOTEL snowpack-measurement sites. Data from Natural Resource Conservation Service, U.S. Department of Agriculture, aggregated by U.S. Bureau of Reclamation.

the Colorado River. The years 2000 through 2004 were the first five consecutive years of below-average flow since the start of modern records in 1922. [21]

Natural Inflow to Lake Powell Compared to Average Inflow[22]

Year	Percentage of Average
2000	62%
2001	59%
2002	25%
2003	51%
2004	49%
2005	105%
2006	73%
2007	68%

Whether taken as the first signs of a changing climate or just as an indication of what the future may increasingly be like, the recent years of low river flows warrant our attention.

> *"You don't need to know all the numbers of the future exactly. You just need to know that we're drying. And so the argument over whether it's 15 percent drier or 20 percent drier? It's irrelevant. Because in the long run, that decrease, accumulated over time, is going to dry out the system."*
>
> —Dr. Roger Pulwarty, National Oceanic and Atmospheric Administration (2007)[23]

Just as importantly, in a clear sign of a changing climate, the recent, continuing drought in the Colorado River basin has been accompanied by unprecedented heat—at least 1.5 degrees Fahrenheit hotter than values recorded during the very intense drought of the 1950s.[24] Extra heat makes drought worse by increasing the water needs of everything from people and crops to ecosystems and wildlife.[25]

Recent conditions have led to huge drops in the Colorado River's two main reservoirs, Lake Powell and Lake Mead. In the summer of 1999, Lake Powell was at 97 percent of capacity. By early April 2005, it had fallen to 33 percent, its lowest level since it began to be filled in 1969. This was a larger and quicker drop than had been believed to be possible. The one recent year of above average runoff, 2005, refilled the reservoir somewhat, but as of February 4, 2008, it remained only 45 percent full.[26] Downstream, since the drought began in 1999, Lake Mead also has fallen every year except in 2005, and is now only 50 percent full.[27] Estimates are that it would take 15 to 20 consecutive years of what used to be normal inflow to refill the reservoirs to capacity.[28]

The most extreme year of the recent drought was 2002. By June of that year, nearly every area of the basin had attained the status of "extreme drought" under the Palmer Drought Severity Index (PDSI); by August, the Southwest had reached its most severe PDSI value in 102 years.[29] Colorado had the driest year in the state's 108-year record.[30] In Utah, January through August was the driest such period ever recorded. [31] Arizona precipitation from June 2001 to May 2002 was the lowest recorded since 1895.[32] Although at its worst in the Four Corner states of the Colorado River's upper basin, the drought affected most of the West.

Is this recent drought a manifestation of a climate already changing or a harbinger of changes likely to come? Four studies have used climate models to show that the effects of human emissions of heat-trapping gases should already have shown up in drying of the Colorado River basin. In three studies, the model outputs show that human-induced climate change should already be leading to reductions of Colorado River flows in recent years, although those flows are still within the range of natural variations.[33] As the authors of one study wrote, "This [modeled] change is remarkably consistent with observations and suggests an emerging warming effect on streamflow."[34] Another study, by a researcher at Columbia University and others, used 19 climate models to project changes in precipitation and evaporation in the American Southwest, centered on the Colorado River basin, both backward to 1860 and forward through the 21st century. The results, they reported, show a consensus of the modeling for significant drying in the region throughout the 21st century "and that the transition to a more arid climate should already be underway."[35]

Alternatively, the recent drought might be "just" an illustration of what scientists are predicting is likely to happen more often in the Colorado River basin in the future. Either way, there is still reason for great concern in the region.

CHAPTER 4

Disruption of Ecosystems

The Intergovernmental Panel on Climate Change has concluded with "high confidence" that "[s]ubstantial changes" in ecosystems are "very likely" to occur if global warming reaches more than 3.6 to 5.4 degrees Fahrenheit above pre-industrial levels. According to the IPCC, many of the significant impacts of climate change may result from more intense and frequent extreme weather events, such as drought.[1]

These changes are already underway. Globally, the IPCC has concluded that "recent warming is already strongly affecting" ecosystems and wildlife.[2] The confidence with which the IPCC links observed changes in natural systems to warming ranges from "high" to "very high," depending on the ecosystems and wildlife being affected.[3] The kinds of changes documented around the world by the IPCC are underway in the American West, too, with forests, glaciers, alpine tundra, the timing of seasons, and wildlife affected.

Larger and More Frequent Wildfires

The IPCC reports, "Climate change is known to alter the likelihood of increased wildfire sizes and frequencies" and "more prevalent fire disturbances" have "recently been observed."[4] In North America, the IPCC reports with "very high confidence" that "[d]isturbances such as wildfire . . . are increasing and are likely to intensify in a warmer future with drier soils and longer growing seasons."[5]

> *"You won't find them [climate change skeptics] on the fire line in the American West anymore."*
>
> —Tom Boatner, Chief of Operations, National Interagency Fire Center (2007)[6]

The IPCC cited in support of its conclusion evidence from both Canada and the western United States. The evidence for the West comes from a 2006 study by scientists at the Scripps Institution of Oceanography and elsewhere that, in the words of the IPCC, "established a dramatic and sudden increase in large wildfire activity in the western USA in the mid-1980s closely associated with increased spring and summer temperatures and an earlier spring snow melt."[7] That study was derived from what another scientist called "the most comprehensive data set of wildfire occurrences yet compiled for the western United States, although it was largely limited to forested areas, not grasslands or other ecosystems."[8] Correlating climate and fire data, the researchers found that spring and summer temperatures in the West in the 17 years after 1987 were 1.5 degrees Fahrenheit warmer than in the 17 years before then, and that the extent to which an area's temperatures were high in a year was more related to fire activity than previous fire suppression efforts, age of timber stands, or other factors. Especially important was the timing of spring warm-up in a year. They found that, compared to the earlier 17-year period, the warmer temperatures of the most recent 17 years were linked to:

- A 78-day increase in the length of the fire season.
- A fourfold increase in the number of fires.
- A fivefold increase in the time needed to put out the average wildfire.
- 6.7 times as much area being burned.

The researchers found that the recent increases in wildfire were particularly pronounced in northern, wetter forests, where previous fire suppression efforts were relatively limited. This supported their conclusion that the recent increases in wildfire are more tied to warming trends than to the effects of past fire suppression.[9]

The greater extent of western wildfire in recent years noted in this study is consistent with other near-term trend data. For instance, the IPCC points out that in the United States an average of 5.4 million acres have burned in wildfires each year since 1980, nearly 70 percent more than the 1920 to 1980 average of 3.2 million acres per year.[10] Also, according to the federal government, since 1960 eight of the top 10 years for acreage burned have occurred since 1996.[11] However, these data should be put in a longer-term context. In the pre-industrial era, according to the U.S. government, about 10 times as much acreage burned annually in the contiguous United States as burns today.[12] Governmental efforts to suppress wildfire since about 1911 have worked well enough that the acreage burned dropped dramatically. Over time, though, prolonged absence of fire has meant that fuels have increased, particularly in lower elevation and drier forest areas. Now, when fires do occur, they may be larger and in some cases more severe than before fire suppression.[13]

A forest fire smolders in Montana in 2007, part of an unusually severe fire season in the state.

> *"We have now turned the fundamental function of the Forest Service into the fire service."*
>
> —Congressman Raúl M. Grijalva, chairman, House Subcommittee on National Parks, Forests and Public Lands (2007)[14]

In short, much of the wildland in the United States (mostly in the West) is primed for an increase in wildfire. For this report, what is significant is the extent to which recent warming and perhaps other climate changes may already be the precipitating event triggering such an increase in wildfire. The conclusion of the study cited above is that warming is already having that effect in the West. Other studies have similarly linked warmer temperatures in Alaska and Canada to recent increases in wildfires there.[15] The IPCC selected the correlation between increases in temperature and forest area burned in Canada between 1920 and 1999 as one of seven indicators of how climate has changed in North America.[16]

> *"Fire has emerged as more and more a mega-catastrophic risk like we saw with Katrina. The financial exposure is huge, well into the billions."*
>
> —Carole Walker, executive director of Rocky Mountain Insurance Information Association (2007)[17]

One consequence of the recent increases in wildfire is that federal firefighting costs have soared, from about $1 billion in 1999 to $3 billion in 2006, so draining the budgets of federal land management agencies that they are shortchanging their core missions.[18] In 2006, the USFS spent 45 percent of its budget on firefighting, compared to 13 percent in 1991.[19]

Loss of Forests

The IPCC warned that it is "very likely" that pest and disease outbreaks in forests will be increased by global warming.[20] This already is happening in North America. Here, the IPCC reports with "very high confidence" that "[d]isturbances such as . . . insect outbreaks are increasing and are likely to intensify in a warmer future with drier soils and longer growing seasons." [21]

BARK BEETLE INFESTATIONS

A prominent example is an increase in bark beetles. According to the IPCC, "Recent warming trends in the U.S. and Canada have led to . . . proliferation of some species, such as the mountain pine beetle."[22] The IPCC further noted, "Climate warming can also change the disturbance regime of forests by extending the range of some damaging insects, as observed during the last 20 years for bark beetles in the USA."[23]

The mountain pine beetle is one of several species of bark beetles native to western forests, and the disturbances they create are a major force in shaping the forests. Mountain pine beetles are the most aggressive insect affecting pines in western North America, favoring mature and stressed trees. They are unusual in that they must kill their hosts to be able to reproduce. By midsummer of the year following a successful infestation, the infested tree is dying or dead, its needles have turned from green to a tell-tale red, and the next generation of beetles flies to new host trees, often in numbers sufficient to infest many more live trees. Beetle populations are usually at low levels in western forests, but when conditions are right they can rapidly soar in large outbreaks. Today's western forests are vulnerable to such outbreaks in part because widespread fires in the late 19th century and human fire suppression since then have increased the proportion of mature trees that beetles favor.[24]

Changing climate conditions are also increasing the vulnerability of western forests. Global warming has eroded the severe winter cold of the West's mountains, which has served as the most important natural check on beetle populations and ranges. In the heart of winter, beetle larvae are fully cold-hardened, powerfully protected by a natural antifreeze, and can survive brief periods in weather as low as almost -40 degrees Fahrenheit. Sustained cold less than that, though, can kill them when in this state, and in less cold-hardened states at other times of their life cycles they are vulnerable to even more modest cold. With global warming having already eased minimum temperatures, more beetles can survive winters, and they now can survive at higher latitudes and higher elevations, where extreme cold used to keep them from becoming widespread.[25] A warmer climate has enabled some bark beetles to complete their life cycle in one year rather than two, exponentially increasing populations.[26] Drought, too, particularly when coupled with unusual heat, can make trees more vulnerable to beetle attacks and lead to more widespread outbreaks, in part by diminishing the quantities of pine pitch that can kill or drive away infesting beetles.[27] As a result of these non-climatic and climatic factors, the West is now experiencing major outbreaks of bark beetles.

> *"I guess we're the lucky ones because in our lifetime we got to see these forests. Our children won't. For many that's a bitter pill to swallow."*
>
> —Jan Burke, U.S. Forest Service (2007)[28]

Mountain pine beetles are now mounting large-scale attacks on whitebark pines, a high-altitude species that grows where winters almost always have been too cold to allow beetle populations to reach outbreak numbers. Whitebark pines are already in substantial decline in much of their range because of a pathogen (blister rust). Not having coexisted with bark beetles, whitebark pines have not evolved the natural defenses against beetles that lower-elevation pines have—and in fact may have evolved to live in the harsh conditions atop western mountains principally because that is where they have needed to live to avoid the beetles.[29] Now, according to one expert, "Whitebark pine is a sitting duck for the beetle."[30] The ecological consequences could be great. Particularly in the Yellowstone ecosystem, local extinction of whitebark pines, which some experts consider possible, could ripple through the mountain ecosystem, and even threaten the survival of the region's grizzly bears, which depend on the fatty seeds of the whitebark pine as their single most important food source.[31]

In Colorado, mountain pine beetles similarly have spread into bristlecone and limber pines, which, like whitebark pines, live at higher elevations than the normal range of the beetles. In one area inspected by the USFS in 2007, one half of the bristlecone and limber pines were infested by beetles. "We have not seen such quick and extensive spread in these high-elevation Colorado forests before," said a USFS scientist.[32]

In the lodgepole pine forests where bark beetles have long existed, outbreaks across the West have reached "epidemic proportions," according to an organization of state and federal foresters from western states. Between the years of 2002 to 2003, the number of acres of western forest with bark beetle-caused tree mortality jumped from 4 million to 10 million acres.[33] Although newer West-wide numbers are not available since 2004, beetle epidemics have continued to accelerate across the West.[34]

In Canada, western forests are experiencing widespread mountain pine beetles infestations in areas far enough north or high enough in elevation that they have always been too cold for beetles to survive, leading to the largest infestation that country has ever seen.[35] Government researchers have concluded "that the increase in the occurrence of mountain pine beetles in these formerly climatically unsuitable areas can only be explained by changes in climate."[36]

Also in Canada, the mountain pine beetles have for the first time crossed from west to east over the Continental Divide, which used to be a limit on their range because of the cold temperatures of that backbone of the Rocky Mountains. This opens the possibility that the outbreak of mountain pine beetles in western Canada can cross the continent through the jack pine forests of central Canada and then down eastern North America into the pine forests of the southeastern United States.[37] "There is a continental-scale event waiting to happen," says one beetle expert.[38]

> *"Any one of these [bark-beetle outbreak] events would be unusual; their simultaneous occurrence is nothing short of remarkable. Significant biogeographical events are occurring at a continental scale, and a warming climate is the one commonality across all of these spectacular outbreak events."*
>
> —Dr. Jesse Logan, U.S. Forest Service (retired), and Dr. James Powell, Utah State University (2005)[39]

In the Southwest, a combination of high temperatures, drought, and the piñon ips bark beetle has led to widespread forest die-back in the piñons that comprise the dominant forests of the Four Corners area of Arizona, New Mexico, Utah, and Colorado. In just the two years of 2002 and 2003, beetles killed piñon pines across much of the Southwest, with piñon mortality reaching or exceeding 90 percent in studied portions of New Mexico's Bandelier National Monument and of Mesa Verde National Park. Researchers at the University of Arizona and elsewhere found that the piñon die-off was driven by climate factors, as sustained heat and drought left the trees particularly vulnerable to bark beetles. More trees died than during an even drier period in the 1950s, leading the researchers to conclude that the higher temperatures of the recent drought increased the forest die-off. "This recent drought episode in southwestern North America,"

The "Death" of Colorado's Mature Lodgepole Forests

In Colorado, the U.S. Forest Service (USFS) and the Colorado State Forest Service recently predicted, "At current rates of spread and intensification of tree mortality, the MPB [mountain pine beetle] will likely kill the majority of Colorado's large diameter lodgepole pine forests within the next 3 to 5 years."[40] The Wyoming state forester similarly predicted that 85 percent to 90 percent of the mature lodgepole pine in the Medicine Bow Mountains of southern Wyoming will also be killed in the same time frame.[41] These are the projected outcomes of a mountain pine beetle epidemic in Colorado that began in 1996 and has infested since then 1.5 million acres of lodgepole forests in the state. Fully one-third of that acreage was infested for the first time in 2007, as the outbreak has spread at great speed.[42]

The scale of this outbreak is consistent with others in lodgepole (and spruce-fir) forests from the region's historic record.[43] What is different about this outbreak is how warmer temperatures have particularly accelerated the epidemic in high-elevation lodgepole forests, between 9,500 and 11,000 feet high. There, beetles used to take two years to complete the life cycle, limiting their spread. With recent warming, they now are able to produce a new generation in a single year, enabling them to expand an infested area five-fold in a year. The beetles now "roll right through high-elevation forests," according to a USFS scientist.[44] More formally, the U.S. Forest Service and Colorado State Forest Service describe what they call a "catastrophic event" this way: "Although bark beetles are a natural part of lodgepole pine ecosystems, warm winters and the drought of recent years have intensified the problem—and provided an ideal environment for the beetles to multiply and spread."[45]

Is the "unprecedented combination of drought and warm winters" (in the words of the Colorado State Forester) that has triggered the beetle epidemic a manifestation of climate change?[46] As explained elsewhere in this report, scientists predict that droughts will increase in the interior West as a result of human-caused climate change, and some attribute recent drought conditions in the West to a changing climate (see page 18). More certainly, scientists have attributed the warmer temperatures of the West in recent years to global warming caused by human emissions and reported that the warming in the West has shown up most at high elevations (see page 5)—in other words, when and where that warming would have the most effect on beetle populations. In short, it is fair to say that the bark beetle infestation at least in upper elevations in Colorado would not be exploding as it is except for the ways in which emissions from human activities are already changing the climate of the West, just as some experts have concluded on a region-wide scale (see pages 2 to 4).

> *"We were surprised by the spread into high-altitude forests—it was very uncharacteristic for the mountain pine beetle to go that high up in elevation."*
>
> —Susan Gray, U.S. Forest Service (2008)[47]

The USFS says, "Although bark beetle outbreaks are natural, the current outbreak is a major threat to regional economics and public safety. The area most affected by beetles is the heart of Colorado's tourism industry."[48] The USFS, Colorado State Forest Service, and non-governmental experts agree that beetle infestations on this scale cannot be stopped.[49] However, the loss of the forests being killed by beetles will not be permanent. "Mountain pine beetles are an agent of regeneration," USFS regional forester Rick Cables points out, and post-outbreak forests will recover much as Yellowstone National Park's forests are recovering after large fires in 1988.[50] Already, new lodgepole seedlings are growing in Colorado where mature trees were killed in the early stages of the current epidemic. Other tree species may move into what have been nearly single-species forests, creating more diverse and resilient mixed forests.[51]

The dead and dying red trees show how completely mountain pine beetles are killing the lodgepole pines in this Colorado forest.

RON COUSINEAU, COLORADO STATE FOREST SERVICE

they write, "may be a harbinger of future global-change-type drought throughout much of North America and elsewhere, in which increased temperature in concert with multidecadenal drought patterns . . . can drive extensive and rapid changes in vegetation."[52]

SUDDEN ASPEN TREE DECLINE

Another development in western forests recently linked to global warming is a rapid dieback of aspen trees that scientists have labeled "sudden aspen decline." Beginning in 2004, people noticed that aspen trees in Colorado were dying in large numbers and that the dead trees were not regenerating as usual through new trees growing from the roots of the old. This aspen dieback has increased rapidly. Aerial surveys by the USFS show that the extent of affected aspens in the most heavily affected ranger district in the San Juan National Forest increased from 6.8 percent of the aspen cover in 2005 to nearly 10 percent in 2006, a 58 percent increase in a single year.[53] Wider aerial surveys show that the area affected by sudden aspen decline in Colorado increased from 144,244 acres in 2006 to 338,248 acres in 2007. In 31 aspen stands examined on the ground, an average of 32 percent of the trees were dead, and 20 percent of the rest were dying.[54] Unusually high rates of aspen die-off have also been observed recently in northern Arizona, southern Utah, and Montana.[55] The rapid die-off of aspen is of great concern in Colorado, where the greatest declines have been observed and where the tree is considered emblematic of the Rocky Mountains.

In Canada, where substantial dieback of aspen began in the late 20th century, studies have linked the decline to reduced snowpacks and drought, among other climatic factors, and continued dieback is expected with the hotter and drier conditions of an altered climate.[56] Now, new research by the USFS has, for the first time, linked the sudden aspen decline in Colorado to the hotter and drier conditions that represent an altered climate in the interior West. To begin with, USFS researchers concluded that the recent aspen mortality is different from earlier known episodes of aspen decline, in two ways. First, this dieback has spread far more rapidly and widely than have earlier episodes. Second, the immediate causes of tree death are not the usual agents of mortality in mature aspen stands but rather two types of wood borers and a canker, none of which are usually fatal to aspen, and two types of aspen bark beetles "previously unimportant in Colorado," as they have not previously been known to be present in the state in great numbers or to cause aspen mortality.[57] But the researchers found the beetles to be "abundant" in dead and dying aspens. [58] The IPCC has reported that a hotter climate can shift the boundaries of insect populations, with effects on tree health, but the researchers did not venture an opinion on whether the newly discovered abundance of aspen bark beetles is a manifestation of this.[59]

The researchers did offer as an explanation for the sudden aspen decline that the hotter, drier conditions recently present in Colorado's mountains have enabled these unexpected agents to so quickly kill so many aspen. In support of this conclusion, they point to their discovery of patterns where the aspen die-off is greatest—on southern (especially) and western slopes, which receive more warmth from the sun, and also at lower elevations. These are the locations where warming would push temperatures highest during the growing season. Where the aspen decline was greatest at higher elevations, local soils are particularly prone to drought. Putting the evidence together, the researchers conclude, "Likely inciting factors [for the sudden aspen decline] are the acute drought with high temperatures during the growing season."[60]

Loss of Glaciers

The IPCC reports that the observed melting of glaciers worldwide is larger than at any time during at least the last 5,000 years and that recent studies give "confidence that the glacier wastage in the late 20th century is essentially a response to post-1970 global warming."[61] In 2003, U.S. Geological Survey researchers projected that all glaciers in Glacier National Park could be completely melted by 2030.[62] But the glaciers actually are melting much faster than expected. In October 2007, a researcher at the U.S. Geological Survey said, "[W]e're about eight and a half years ahead of schedule … Our initial

BLASE REARDON/USGS

CARL KEY/USGS

Photographs of Grinnell Glacier in Glacier National Park taken from the same point demonstrate the retreat of the glacier.

projection has proved too conservative. They're going faster than we thought." Between 2005 and 2007, for example, Grinnell Glacier lost 9 percent of its acreage.[63]

> *"It looks like we're already past the melt-water peak . . . because we're seeing a declining flow. Of course, eventually that will go to zero."*
>
> —Dr. Daniel Fagre, U.S. Geological Survey (2007)[64]

Glaciers are also disappearing elsewhere around the West:

- In Washington's North Cascades Mountains, home of more than half of the nation's glacier-covered lands south of Alaska, 47 glaciers monitored since 1984 have lost, on average, 20 to 40 percent of their volume, with five having melted entirely away.[65]

- In North Cascades National Park in Washington, the total area covered by glaciers has fallen by 13 percent since 1971.[66]

- On Oregon's Mount Hood, the Ladd and White River Glaciers have lost one-third of their surface area since the mid-1970s.[67]

> *"We're now at the point where we can say pretty confidently that the warming in the West is due to human activities, and the fact that virtually every glacier in the West is retreating certainly underscores that."*
>
> —Dr. Philip Mote, Washington State Climatologist (2006)[68]

More than scenery and tourism are at stake as the West's glaciers melt. When glaciers disappear, watersheds lose crucial sources of late-season runoff. The National Park Service estimates that as much as 50 percent of late-summer stream flow in North Cascades National Park is fed by glaciers. In one watershed, shrinking glaciers have already reduced summer flows by 31 percent.[69] In Glacier National Park, the loss of glacial runoff, which has dried up streams and scenic waterfalls, has also jeopardized the park's aquatic life. At particular risk are Glacier's native bull trout, a threatened species, which spawn in the fall and therefore rely on strong late-season stream flow.[70]

Loss of Alpine Tundra

The IPCC has said with "high confidence" that mountain ecosystems are among the most vulnerable ecosystems to climate alteration.[71] One example of this vulnerability is a projected reduction of areas of mountaintop tundra around the world. For instance, scientists studying the effects of climate change on Rocky Mountain National Park in Colorado, home to the largest expanse of alpine tundra in the United States outside of Alaska, projected that warming of 5.6 degrees Fahrenheit could cut the park's area of tundra in half and of 9 to 11 degrees Fahrenheit could virtually eliminate it.[72]

The IPCC has reported that shifts of mountain-side plant species to higher altitudes are well documented.[73] In one case, a recent survey of mountain summits in the Swiss Alps found that a 20th-century trend of upward migration of alpine plants had accelerated since 1985.[74] The IPCC also reports instances of pronounced rises in treelines in the 20th century throughout the Northern Hemisphere.[75]

Observations within Glacier National Park point to subtle changes in vegetation at or above treeline, but not (at least yet) to any wholesale encroachment of trees into tundra. In one study, scientists recorded 31 to 65 percent declines in abundance of seven tundra plants from 1989 through 2002. In a second study, scientists using repeat photography have documented that trees just below timberline have begun to grow more upright and have filled in forest edges.[76]

By one calculation, however, the extent of western tundra has sharply declined in the 20th century. Two researchers at the National Oceanic and Atmospheric Administration reached this conclusion by studying high-altitude temperature change. Rather than examining changes in types of vegetation, which are difficult to survey on the ground and unrecorded by satellite before 1981, the researchers defined tundra by temperature, as an area where the warmest summer monthly mean temperature is between 32 and 50 degrees Fahrenheit. They found that only 27 percent of the area qualifying as tundra by this definition in 1901 to 1930 still qualified in 1986 to 2007. Moreover, all areas that could still be characterized as tundra were within one degree of the 50 degrees Fahrenheit threshold. They concluded that temperatures are now rising so steeply that all western areas that can still be considered tundra using this standard are on the verge of disappearing.[77]

Disruption of Seasonal Timing

Breeding, flowering, migration, hibernation, and other behaviors of plants and animals are often keyed by changes in temperature, and earlier warm-up in the spring can disrupt these links. The IPCC reported with "very high confidence" that recent warming is leading to such changes as earlier timing of spring events, such as leaf growth and bird migration and egg-laying. With "high confidence," the IPCC also concluded that there has been a trend toward earlier spring "greening" of vegetation in many regions.[78]

These kinds of changes are also afoot in the American West:

- Two indicators of spring onset in western states for which there are long-term records, the blooming of lilac and honeysuckle, advanced at rates of two and almost four days per decade, respectively, since the 1950s, coinciding with a 3 degrees Fahrenheit increase in spring temperatures from 1948 to 1995.[79] A similar trend in spring bud-burst dates for aspen in Edmonton since 1900 was cited by the IPCC as one of seven indicators that North America's climate is already changing.[80]

- Compared to the mid-1970s, yellow-bellied marmots near Crested Butte, Colorado, emerge from hibernation 23 days earlier, coinciding with a local 2.5 degrees Fahrenheit rise in minimum April temperatures.[81]

- In southeastern Arizona, Mexican jays in 1998 built nests and laid eggs ten days earlier than in 1971, coinciding with a trend to warmer minimum temperatures.[82]

- The first spring flights of butterflies in California's Central Valley have moved up steadily over the past 31 years, with changes for many species of as much as 24 days.[83]

- In Rocky Mountain National Park, young white-tailed ptarmigans now hatch significantly earlier than they did in 1975, presumably as a result of earlier spring thaws.[84]

These changes by plants and animals may be viewed as adaptations to warmer spring temperatures, but the warming can still present risks. For example, Colorado State University researchers working in Rocky Mountain National Park have suggested that the earlier hatching of ptarmigan chicks mentioned above may have contributed to the 50 percent decline in the ptarmigan population there during the last two decades, as the timing of spring plant growth has not shifted as ptarmigan breeding has, and chicks now are being born when there is less food available for them.[85]

Loss of Wildlife

With "medium confidence," the IPCC has warned that approximately 20 to 30 percent of plant and animal species are "likely to be at increasingly high risk of extinction" if global warming exceeds 4 to 5 degrees Fahrenheit.[86] In a hotter climate, many plant and animal species are expected to seek the habitat they need by moving toward the poles or to higher elevations. The IPCC reports with "very high confidence" that adaptive movement of plants and animals is already occurring, with poleward shifts in ranges documented on all continents.[87] In many cases where this kind of adaptation to new climate conditions will not be possible or sufficient, species may not survive.

In the West, a few scientists have begun documenting that species are adapting to an altered climate by changing where they live. For example, scientists from the University of California, Berkeley, have found in Yosemite National Park that 14 of 50 studied animal species can no longer be found in lower-elevation portions of the range they occupied early in the 20th century, with eight species having lost over half of their previous range.[88] For example, the alpine chipmunk, which once ranged as low as 7,800 feet in elevation, is now confined to areas above 9,600 feet, and has lost 92 percent of the elevation range it once occupied.[89]

In another example of range change, the Edith's checkerspot butterfly in California has moved northward and to higher elevations. Below 7,900 feet, the butterflies are no longer found in more than 40 percent of the areas they used to inhabit.[90] Also, the sachem skipper butterfly expanded its range 420 miles from California to Washington in just 35 years, believed by scientists to be a response to a 5-degrees Fahrenheit rise in January minimum temperatures in eastern Washington.[91]

In some cases, species are not able to guarantee their survival by making such changes in their range or otherwise adapting. In particular, the IPCC reports with "very high confidence" that global warming is a driver of amphibian mass extinctions in many highland localities, by creating increasingly favorable conditions for a disease fatal to amphibians.[92] In recent years, 67 percent of the harlequin frog species of Central and South America have become extinct. Scientists hypothesize that warmer nights and increased cloud cover have led to the spread of a lethal fungus into the frogs' habitat.[93]

In the American West, researchers have recently discovered a 10 percent decline per year in the population of the mountain yellow-legged frog in lakes and streams of the Sierra Nevada, including in Yosemite and Sequoia/Kings Canyon national parks. Most lakes in the parks now have only one to five frogs present, and about 85 percent are infected with the same fungal disease responsible for widespread amphibian extinctions elsewhere. Also, two scientists from the Sierra Nevada Research Center have linked shrinking Sierra Nevada snowpacks to the frogs' decline: Smaller snowpacks dry up smaller ponds, limiting the frogs to larger permanent ponds where introduced non-native trout can prey on them.[94]

Other species at great risk from climate disruption are those in isolated areas not connected to a large, intact ecosystem, and alpine species that can run out of higher elevations into which to climb. Examples of the latter are two emblematic species of western mountaintops, pikas, and ptarmigan.

Pikas, small mammals whose habitat is limited to the slopes and tops of mountains, can survive only in cold climates. In the Great Basin, they used to inhabit areas averaging 5,700 feet in elevation. Now they can be found only above 8,300 feet, if at all. A USGS ecologist and his colleagues have concluded that of 25 Great Basin pika populations recorded in the 1930s, seven no longer exist.[95] In Yosemite National Park, a century ago pikas lived as low as 7,800 feet; today, they cannot be found any lower than 8,300 feet.[96] One researcher says, "[w]e might be staring pika extinction in the Great Basin, maybe in Yosemite, too, right in the face . . . They don't have much up-slope habitat left."[97]

> *"Pikas are an iconic animal to people who like high elevations . . . What's happening to them is telling us something about the dramatic changes in climate happening in the Great Basin."*
>
> —Dr. Donald Grayson, University of Washington (2005)[98]

White-tailed ptarmigans also are in decline, at least in one prominent place, apparently because of warming. To birdwatchers, one of the most accessible and famous populations of white-tailed ptarmigan is in the alpine tundra of Rocky Mountain National Park along Trail Ridge Road. In just two decades, however, their numbers there have been cut in half, and researchers suspect earlier spring warm-ups are to blame. Chicks are being born earlier in the year, when food supplies are less certain.[99] Ptarmigan also depend on deep snow to survive alpine winters, using the natural insulation of snow caves to keep warm and using snowpack like a ladder to reach willow shrub branches for food. Researchers predict the elimination of the birds from the park if temperatures keep warming as expected.[100]

Some animals at lower elevations are also declining because of global warming. Of 80 separate populations of desert bighorn sheep in California, 30 now are extinct, with climate disruption the likely explanation. After considering various possible causes, researchers concluded that "climate was consistently correlated with extinction in a way the other factors weren't."[101]

Warming of their alpine habitat has led to a decline of white-tailed ptarmigan in Rocky Mountain National Park.

CHAPTER 5

Global Warming Harms Business, Recreation, and Tourism

The American West contributes significantly to our national agricultural, recreational, and tourism industries, all of which are dependent upon the natural resources of the West. A hotter climate poses a significant threat to residents of the West whose livelihoods are linked to what was once assumed to be a relatively stable climate.

Reduced Agricultural Productivity

The IPCC reports with "high confidence" that increases in extreme climate events such as droughts and heat waves will reduce crop yields and livestock production beyond the impacts of just increased average temperatures.[1]

In the first few years of the 21st century, western farmers and ranchers have suffered significantly from extreme climate events, primarily the frequent and widespread combination of above-normal heat and drought. Across the country, four of the five top years for crop loss claims due to drought have been since 2000, topping out at $2.7 billion in 2002.[2]

In **Utah**, ongoing drought has qualified most of the state for disaster relief during several years. In the summer of 2007, the U.S. Department of Agriculture (USDA) declared 24 of 29 Utah counties primary disaster areas due to drought, wildfire, and flash floods.[3] In 2003, the USDA declared all 29 counties primary disaster areas due to drought, insect infestations, and high winds.[4] In 2002, the amount of non-irrigated farm lands that were harvested fell by more than 30 percent, compared to 1997.[5]

In **Montana** in 2002, wheat production was down 38 percent compared to 1997, a pre-drought year.[6] In 2002 through 2004, state cattle producers lost about 50,000 head per year due to drought-related reductions and culling.[7] In 2004, the number of cattle and sheep in the state fell to the lowest count in 40 years.[8]

> *"The longer the drought goes, the more significant the impacts will be because you just run out of tricks. The only thing you can do is sell."*
>
> —Steve Pilcher, Montana Stockgrowers Association (2003)[9]

In **Colorado**, the 2002 drought hit particularly hard. All 64 Colorado counties were declared drought disaster areas. The estimated direct cost to crop producers was more than $300 million. Corn production from irrigated farmland was 15 to 50 percent below average, dry-land corn production was negligible, 19 percent of the winter wheat crop was lost, sunflower crop yields were down 71 percent, and 50 percent of workers in the sod-growing industry were laid off. Ranchers lost about $460 million, and about 45 percent of breeding livestock were sold because of lack of feed. Dairy operations with at least 500 head lost an average of about $15,000 to $20,000 in revenue per month.[10]

In **Idaho**, more than 700 groundwater users who irrigate 46,000 acres narrowly averted shutdown of their pumps due to low snowpack and drought forecasts in 2007.[11] Drought conditions from 2000 to 2002 caused a 12 percent decrease in Idaho's statewide potato harvest. [12]

In **Wyoming**, the 1999 to 2003 drought cost farmers and ranchers an estimated $565.5 million, with a $308.2 million loss in 2002 alone.[13] By 2003, the number of cattle in the state had fallen to the lowest number since 1992 and the number of sheep and lambs to half the number of 1993. Even though 2004 and 2005 brought relief from the drought, cattle numbers did not increase, suggesting that it can be hard for ranchers to recover quickly from losses.[14]

In **Arizona**, drought conditions caused sales of yearlings and calves to drop from $600 million in 2000 to $200 million in 2002. On the Tonto National Forest, grazing permits were reduced to 8 percent of normal capacity.[15]

> *"The devastation of this drought does not end at the front door of our rural homes. This unrelenting drought has taken an enormous economic toll on our communities and it will take years to recover. Businesses are closing their doors, employees are being laid off, and main streets are literally drying up."*
>
> —Senator Max Baucus (2004)[16]

Declines in Fishing and Hunting Activity

The hotter and drier conditions expected to result from human-caused climate change in the West are likely to reduce opportunities for fishing and hunting in western states, which would affect many people and the economies of western states. In 2006 alone, Westerners spent $20.4 billion on equipment and travel to go fishing, hunting, and wildlife watching.[17]

> *"Climate change is not just a problem of the future, but is a growing concern of the present. Our climate already is rapidly changing and we currently are seeing impacts to our stream systems and aquatic communities."*
>
> —Dr. Jack Williams, Trout Unlimited (2007)[18]

The Intergovernmental Panel on Climate Change has concluded that global warming could bring worldwide changes in the distribution and production of fish species.[19] In North America, according to the IPCC, salmonids such as trout and salmon are likely to be most harmed. Cold-water species may not survive except in the deepest lakes, and species currently listed as threatened may face an even greater risk of extinction.[20]

Detailed projections for the American West are dire, with studies predicting losses of western trout populations as high as 64 percent and of Pacific Northwest salmon of 20 to 40 percent by 2050. [21]

LESS FISHING ACROSS THE WEST

Warming temperatures and other manifestations of a changing climate are already diminishing fishing opportunities in the West. Cold- and cool-water fisheries, especially for salmon, have been declining as warmer and drier conditions reduce their habitat. Sea-run salmon stocks are in steep decline throughout much of North America. [22]

In testimony before a U.S. Senate Subcommittee in 2007, a Trout Unlimited scientist described some impacts of the climate disruption already being observed in the West. A "dead zone" of ocean waters with low dissolved oxygen content off the Oregon coast caused by changed weather patterns has grown in four years to cover an area the size of Rhode Island. In Rocky Mountain streams, aquatic insects are emerging earlier because of warmer stream flows and earlier peak runoff. Females are smaller and produce fewer eggs, with cascading implications for fish populations that depend on aquatic insects for food. [23]

IMPACTS ON MONTANA'S SPORTFISHING INDUSTRY

Montana's famous fishing streams support an in-state sport fishing industry valued at upwards of $300 million per year. In eight out of the last 10 years, drought and higher temperatures have led to fishing closures and restrictions to sustain fish populations for the future.

From 2001 through 2004, segments of 17 rivers were either entirely closed to fishing or subject to access restrictions for morning-only fishing or bag limits. The Red Rock River was closed for the entire season all four years. Two others, the Big Hole and Beaverhead, were closed for part of the season all four years. Some of the particular impacts in 2003 and 2004 include:

- In the Middle Fork of the Flathead, Clarks Fork, and Kootenai Rivers, chronically low flows impacted bull trout movements and allowed beavers to build barrier dams in the smaller spawning tributaries, impeding spawning migrations.
- Rainbow trout populations were decreasing in the Bitterroot and Blackfoot Rivers where whirling disease, which thrives in warmer and low-flow conditions, was on the rise and spreading.
- In the Bighorn River, from 1998 to 2002 brown trout numbers plummeted from more than 8,800 per mile to about 800 per mile. By 2002, there were insufficient rainbow trout of any size to allow for a valid estimate.
- The Tongue and Powder Rivers, important spawning tributaries to the Yellowstone River, lost connectivity with the Yellowstone for four years straight, eliminating spawning and rearing habitats for numerous species.
- At Clark Canyon Reservoir, low water levels and warmer temperatures meant that no Eagle Lake rainbow trout were spawned; usually, 500,000 eggs are taken to supply hatcheries. [24]

The summer of 2007, with record-setting temperatures across the state, was even worse. By mid-July, high water temperatures and low flows triggered fishing bans and restrictions on nearly 20 streams and rivers.[25] By August 2, closures were in force on 29 rivers. Thirteen were full 24-hour closures, primarily on tributary streams to larger rivers; seven miles of the Missouri River were also closed due to a wildfire in the area.[26] At some locations, water temperatures were above 80 degrees Fahrenheit, enough to kill thousands of game fish. At Rogers Lake, the state's major native arctic grayling breeding place for fisheries statewide, thousands of grayling died. Some biologists are worried that the arctic grayling, already at the southern edge of its range, may disappear entirely from Montana.[27]

Based on outfitters' reports, business was down 10 percent in 2007 on three prime fishing rivers—the Yellowstone, Clarks Fork, and Bitterroot—all of which were closed entirely or in the afternoons. Robin Cunningham, president of the Fishing Outfitters Association of Montana, pegs outfitters' one-year income losses for just these three rivers at nearly $323,000.[28]

THE SHRINKING FISH POPULATIONS OF YELLOWSTONE NATIONAL PARK

Since Yellowstone was set aside as the world's first national park in 1872, its abundant native fisheries have attracted people to the park. But in the last decade its fisheries have been in decline, and anglers are now staying away. Since 2000, the number of annual fishing permits issued to park visitors has dropped by nearly a quarter, from 67,700 to 51,900, even as total park visitation remained steady.[29] One fly fisherman who has traveled from California each of the past 15 years to fish the Yellowstone River reacted to the decline: "I decided yesterday that I won't be back anymore. There just aren't enough fish to make it worthwhile." [30]

One major cause of the reduction in fishing is a large population in Yellowstone Lake of illegally introduced lake trout, which eat the native trout. But other reasons for the decline are climate-related. Drought and lower water levels greatly reduce reproduction rates in spawning streams that feed the lake. In Clear Creek, where 70,000 cutthroat trout were counted in 1979, only 500 were found in the drought year of 2007.[31] Whirling disease was first found in Yellowstone cutthroats in 1998 and has since become established in two spawning tributaries to Yellowstone Lake, with significant declines in the numbers of spawning cutthroats. [32]

> *"I think it's a very real possibility that fish kills like the one in Yellowstone will become more widespread. It seems like the climate changes are becoming pretty dramatic."*
>
> —Steve Gunderson, Water Quality Division, Colorado Department of Public Health and Environment (2007)[33]

The extreme heat of 2007 led the National Park Service to close Yellowstone's streams to fishing. By the end of July, the park had closed 232 miles on 17 prime fishing rivers after 2:00 p.m. each day, when stream temperatures are highest.[34] Hundreds of rainbow and brown trout died in Pelican Creek, and a park biologist predicted that it would become the norm for the future.[35] In the Firehole River, temperatures topped 80 degrees Fahrenheit for several days and as many as a thousand trout died in Yellowstone's largest documented fish kill in its 135 year history. [36]

SALMON PARTICULARLY HARMED BY WARMING

The IPCC has reported that in North America "[c]old- and cool-water fisheries, especially salmonids, have been declining as warmer/drier conditions reduce their habitat," and that "[e]vidence for impacts of recent climate change is rapidly accumulating."[37]

California's Klamath River, once one of the mightiest salmon rivers in the West, is a prime example of how warmer and drier conditions and competing water uses have devastated a salmon fishery, with significant environmental, economic, and social consequences.

During the severe drought year of 2002, water levels in the Klamath River were unusually low. Irrigators in the basin were given their normal allotment of water, leaving salmon to bear the brunt of the drought. Tens of thousands of juvenile Chinook salmon died upstream in the Klamath; up to 80,000 adult fish were killed near its mouth in the largest salmon die-off ever recorded in California.[38] The California Department of Fish and Game found that the primary cause for the kills was disease, brought on by crowding and warm water temperatures connected to low water flows.[39]

By 2005, the numbers of Klamath Chinook salmon had fallen so low that allowable salmon fishing off California and Oregon was cut in half; the following year, the number of salmon fell a further 75 percent.[40] The impacts on the industry were so severe that the U.S. Department of Commerce declared a fishery resource disaster, leading to $60 million in disaster relief payments to affected industries and Indian tribes.[41]

> *"The lower [Klamath River] basin has been plunged into permanent drought that is costing fishing-dependent communities thousands of jobs and threatens closures of ports all the way to San Francisco."*
>
> —Glen Spain, Pacific Coast Federation of Fishermen's Associations (2004)[42]

LESS HUNTING ACTIVITY AND REVENUE

Hotter and drier conditions in the West are also likely to diminish opportunities for hunting.[43] Here, too, the types of impacts that have been predicted are already being seen.

- For example, wildfires in northern Nevada in 2006 disrupted so much pronghorn antelope winter range that wildlife officials conducted an emergency antelope hunt and relocation effort for more than half of the regional herd.[44] In the same area in 2007, more than one-half million acres were charred in one week, affecting wildlife habitat.[45] The same fire, burning into Idaho, disrupted sage grouse habitat enough that the grouse season was canceled.[46]

- In Arizona, the effects of drought on food sources in 2006 were estimated to reduce deer fawn survival rates by 25 to 80 percent, to be followed by more declines in 2007 in the adult deer population. Since the early 1980s, mule deer numbers statewide have dropped about 33 percent and white-tailed deer numbers by 5 percent.[47]

- In 2005, after repeated years of drought in south-central Montana, wildlife officers reported declines in mule deer numbers as high as 65 percent due to depleted summer forage, causing the deer to go into the winter season in weakened physical condition.[48]

- In northeastern Utah in 2002, the fourth straight year of drought, depleted water sources and loss of forage led to a 75 percent drop in pronghorn antelope numbers.[49]

- The summer of 2007 was so hot and dry in Nevada that volunteers organized to bring water to remote watering stations to help the state's signature animal, the desert bighorn sheep, survive.[50] In 2006, the Arizona Elk Society solicited volunteers and funding to construct artificial water sources near the Grand Canyon to sustain deer and elk populations in danger of dying from thirst.[51]

In recent years, fishing and hunting expenditures and license revenues have been affected across the West.

- Because of deer herd reductions from chronic drought, in 2006 the Arizona Game and Fish Department issued 46 percent fewer deer hunting tags than in 1994. That cost the state about $788,000 in lost deer license revenues and nearly $2.4 million more in federal matching contributions.[52]

- In Colorado in 2002, the drought reduced business for outfitters by an estimated 40 percent. About one million fishing recreation days were lost and 93,000 fewer fishing licenses were sold, with a corresponding $1.8 million loss for the Colorado Division of Wildlife.[53]

- In Wyoming in 2002, the Game and Fish Department reported a loss of 400,000 deer and pronghorn antelope compared to 1999, reducing hunting enough to cost the state about $4 to 6 million in license revenues and hunters about 250,000 to 300,000 recreation days. Wyoming businesses lost $65 to 75 million annually from reduced hunting expenditures.[54]

Shorter and Less Profitable Seasons for Skiing and Winter Sports

Outdoor winter sports are highly vulnerable to warming. The IPCC concluded, "Without snowmaking, the ski season in western North America will likely shorten substantially."[55] Most vulnerable are skiing and similar activities in low-elevation, mild-winter areas, where small increases can often push temperatures above freezing, replacing snow with rain and melting accumulated snow. But even high-elevation areas are at risk. One study projected that the ski season in California's Sierra Nevada could be trimmed three to six weeks by 2050 and seven to 15 weeks by 2080.[56] A sophisticated assessment done for the city of Aspen, Colorado, projects that the local ski season could be a week and a half shorter by 2030 and four to ten weeks shorter by 2100. Under most climate projections, snow would no longer accumulate at the base of Aspen Mountain by 2100.[57]

> *"[S]ki resorts operate in deficit until March, when we make most of our profit. If you shorten our season on either end—take away March, for example—and we go out of business. The problem: a shortened season is one of the most reliable predictions of the climate modeling and science."*
>
> —Auden Schendler, Aspen Skiing Company (2007)[58]

Ski resorts in Europe are already being affected. A 2003 study by the United Nations Environmental Program found that 15 percent of Swiss ski areas already suffer from unreliable snow conditions.[59] In the French Alps, snowfall levels decreased by 25 inches between 1960 and 2007, and in 2007 a major French ski area closed permanently because of disappearing snow.[60] In North America, unseasonably warm temperatures in January 2007 forced Blue Mountain Resort, Ontario's largest ski area, to close midseason for the first time in its 65-year history. The IPCC reports that from 1975 to 2002 the number of ski areas in New Hampshire decreased from 58 to 17.[61]

In the West, ski areas in lower-elevation areas have recently suffered from less snow, with the Northwest and the Southwest taking turns having very bad years. In the 2004 to 2005 season, northwestern ski resorts had one of their worst seasons on record. The next year set an overall record for skier visits across the country, but in the Southwest low snowfall brought ski visits in New Mexico down by almost 50 percent and in Arizona down by more than 80 percent compared to the previous year.[62] The 2006 to 2007 season was another good year overall, but skier visits fell in the Pacific states by 16.5 percent.[63]

Ski Areas Struggle to Adapt to Warming Weather

In Washington, the Summit at Snoqualmie, located about 50 miles east of Seattle, ranges from 2,610 feet to 5,420 feet above sea level. In 2002, lack of snow delayed the opening of the season by one month. Two years later, during the 2004 to 2005 winter, warm temperatures kept the area closed for most of the season. Much of its winter precipitation fell as rain, including 8.5 inches over a four-day period in January 2005.[64] On March 15, 2005, when average snowpack at Snoqualmie Pass typically peaks at 92 inches, no snowpack was recorded.[65]

Arizona ski areas have struggled for nearly a decade to keep snow and skiers on the slopes. The Arizona Snowbowl used to get about 22 feet of snow and have seasons that began in December and lasted more than three months.[66] In the 2005 to 2006 season, Snowbowl received only enough snow to open for three weeks in March and April, resulting in its worst season in nearly 70 years of operation.[67] During the 2006 to 2007 season, Snowbowl could not open until January 24, the sixth time in the last 10 ski seasons that its opening has been delayed until after the start of the new year.[68]

The low-elevation Durango Mountain Resort in southwest Colorado has recently had shorter seasons, and has considered asking schools in Arizona to shift their spring breaks from March to February to coincide with more reliable skiing conditions.[69]

> *"If we don't have snow, our whole economy is dead. . . . Everybody is hurt."*
>
> —Lisa Isaacs, Mammoth Mountain Ski Resort, California (2007)[70]

Less skiing can have significant social and economic impacts. During the 1990s, Snowbowl attracted an average of 125,000 skiers each season. In a normal year, skiers generated $30 million of revenue for the town of Flagstaff. In the six recent sub-par seasons, attendance fell short of 100,000; in three of those seasons the area had 35,000 or fewer skiers. Snowbowl's neighbor, Williams Ski Area, was recently sold and its new owners are considering hosting activities other than skiing, such as snow tubing. And Sunrise Park Ski Resort, located in eastern Arizona at 9,200 feet, has been unable to acquire $11 million in loans to build an adequate snowmaking system.[71]

CHAPTER 6

Immediate Action Can Curb Global Warming

Contributed by Theo Spencer

Unlike many other pollutants, carbon dioxide (CO_2) and other heat-trapping gases can remain in the atmosphere for hundreds of years. With current trends in coal and oil consumption, we are headed for a doubling of CO_2 concentrations before mid-century unless we shift U.S. and global energy investments to low-carbon technologies as soon as possible.

The United States is expected to invest $9 trillion over the next 20 years in the energy sector—electric power plants, fuel refineries, transmission infrastructure—as well as billions more on energy-consuming buildings, appliances, and vehicles. While some of these investments are already aimed toward technologies that will help slow global warming, we must accelerate the transformation of our energy sector and adopt sound energy policies in the next few years if we are to turn the corner on emissions and avoid locking ourselves and future generations into a dangerously disrupted climate.

National Climate Initiatives

Policies designed to slow, stop, and reverse emissions of global warming pollution are most needed at the federal level. The energy legislation enacted in December 2007 requiring increased use of cleaner biofuels and ensuring that new cars will go farther on a gallon of gas is a meaningful down payment on combating global warming. Several recently introduced bills have proposed creating a cap-and-trade system, where a regulatory cap limits overall emissions while trading of emission allowances provides flexibility and market incentives to invest broadly in cost-effective opportunities to reduce emissions. This is a step in the right direction, but we still need the political will to further strengthen and pass comprehensive global warming legislation that will reduce emissions at least 80 percent below current levels by 2050 to stave off the most severe impacts of global warming.

A new study by the business consulting firm McKinsey & Company, co-sponsored by NRDC, examines the cost and market potential of more than 250 greenhouse gas abatement technologies and concludes that the United States can do its part to stabilize the climate at little to no net cost, considering energy-efficiency savings.[1] In sharp contrast, estimates of the annual benefits from stopping global warming range as high as 20 percent of total economic output. Moreover, the transition to a cleaner and more efficient energy economy will improve air and water quality, protect public health, and increase our energy security and productivity, all while we continue to grow our economy as forecasted, decade after decade.

Business has gotten the message. As of the publication of this report, 35 major U.S. corporations—including industry giants such as General Electric, General Motors, DuPont, AIG, Caterpillar, and Shell—have joined together with six non-profits (including NRDC) to form the U.S. Climate Action Partnership (USCAP) to advocate for federal legislation to cut emissions by 60 to 80 percent by 2050.

Momentum is building in the courts as well. The U.S. Supreme Court issued a landmark ruling in early 2007 that CO_2 is subject to regulation under the Clean Air Act. This ruling provides a critical legal backstop to state policy victories and adds momentum to the push for federal legislation.

Regional Climate Initiatives

Regional Greenhouse Gas Initiative (RGGI)

To date 10 states (Connecticut, Delaware, Massachusetts, Maryland, Maine, New Hampshire, New Jersey, New York, Rhode Island, and Vermont) and the District of Columbia have signed on to this historic effort, the first in the nation to establish a regional market trading system covering CO_2 emissions from power plants. The RGGI agreement calls for states to stabilize emissions at roughly current levels from 2009 through 2015, and for reductions reaching 10 percent by 2019.

RGGI states have undertaken economic analyses that show their efforts will deliver enormous economic benefits to their states and cities. The Northeast states discovered that by promoting energy efficiency at the same time they implemented a cap on power plant emissions, they could actually reduce the average residential customer's energy bill by more than $100 per year.[2] As a result, the states have decided to auction almost all of their pollution allowances and use the proceeds to promote energy efficiency.[3]

Western Climate Initiative (WCI)

On February 26, 2007, the Governors of Arizona, California, New Mexico, Oregon, and Washington signed an agreement to reduce emissions as a region, through a market-based system—such as a cap-and-trade program covering multiple economic sectors. To date, Utah and Montana have also joined the WCI, along with the Canadian provinces of British Columbia and Manitoba. The partners agreed to reduce their emissions 15 percent below 2005 levels by 2020, or approximately 33 percent below business-as-usual levels, with a commitment to reduce emissions further by 2050. The regional target is designed to be consistent with existing targets set by individual member states and does not replace these goals. A blueprint of the cap-and-trade system is set to be released this August by the member states. Idaho, Wyoming, Colorado, Nevada, and Alaska are observing the WCI process.

Midwest Regional Greenhouse Gas Reduction Accord

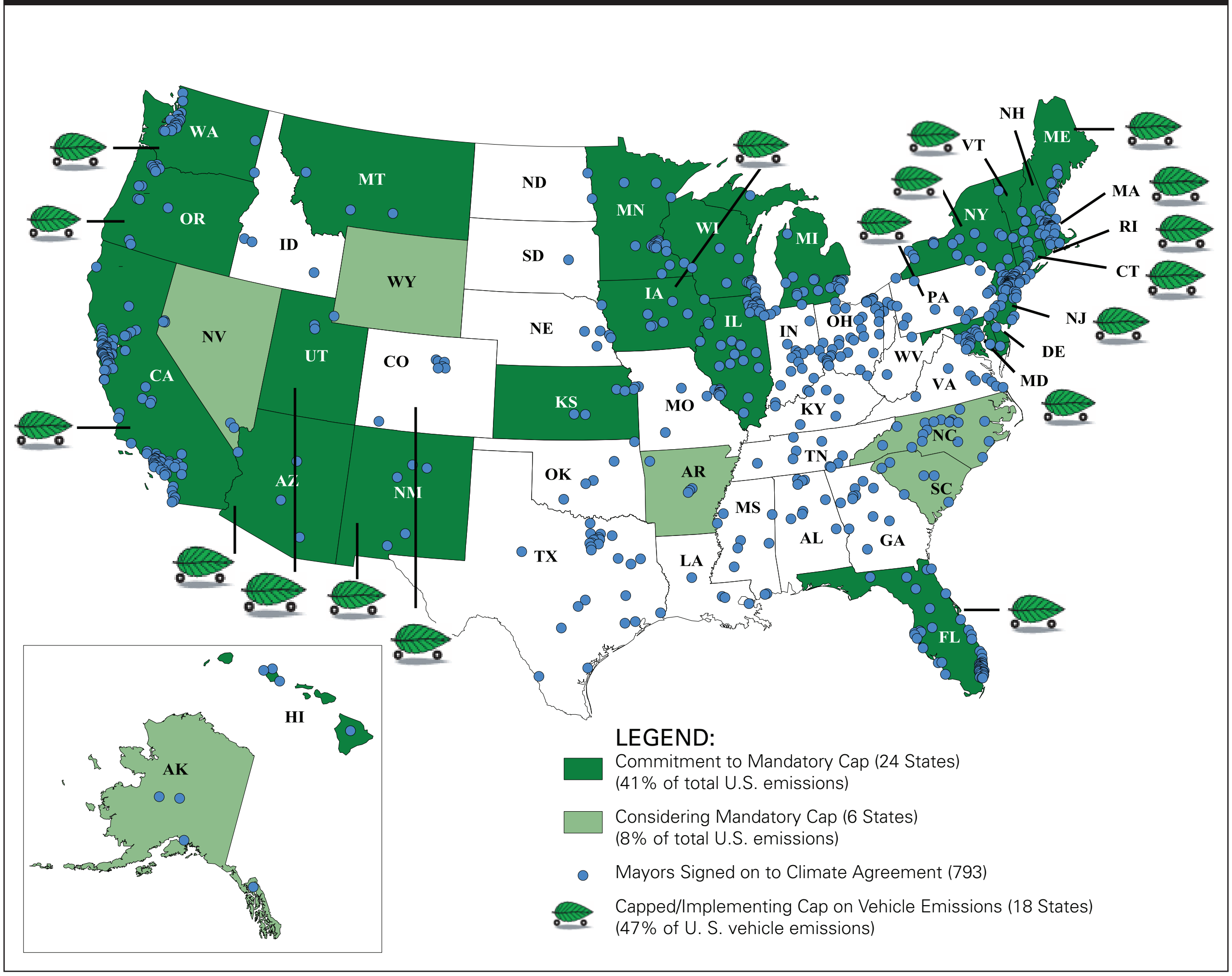
On November 15, 2007, six states (Iowa, Illinois, Kansas, Michigan, Minnesota, and Wisconsin), and the Canadian Province of Manitoba agreed to reduce their emissions 60 to 80 percent below current emissions levels, and develop a multisector cap-and-trade system to help meet the targets. The states and Manitoba also agreed to pass complimentary policies such as low-carbon fuel standards. Indiana, Ohio, and South Dakota have joined as observers. Parties to the Accord agreed to fully implement it within 30 months of the signing.

> *"This simple fact reflects a challenge that we ignore at our own peril. I am persuaded that global climate change is one of the most important issues that we will face this century …With almost 1,200 miles of coastline and the majority of our citizens living near that coastline, Florida is more vulnerable to rising ocean levels and violent weather patterns than any other state. Yet, we have done little to understand and address the root causes of this problem, or frankly, even acknowledge that the problem exists."*
>
> —Florida Governor Charlie Crist (2007)[4]

State Climate Initiatives

Beginning with California's global warming pollution standards for new cars, which created a drumbeat of policy action and momentum for delivering global warming solutions at the federal level, the year 2002 brought the beginning of a multi-year effort to advance real, mandatory emissions limits at the state level. Since then, other states and cities have developed global warming policies of their own. As of January 2008, 12 additional states adopted California's clean car standards,

Figure 6. The Rising Tide for Global Warming Solutions



accounting for 40 percent of the U.S. car market. (However, the U.S. Environmental Protection Agency recently denied California's application for a waiver required to enforce its stiffer vehicle emissions standards. That decision is being appealed by the states.) And 25 states have committed to mandatory limits, either power sector or comprehensive: 10 in the Northeast, seven in the West, six in the Midwest, plus Hawaii and Florida.

Highlights include:

California

In June 2005, Governor Arnold Schwarzenegger called for a reduction of state greenhouse gas emissions (GHG) to 2000 levels by 2010, 1990 levels by 2020, and 80 percent below 1990 levels by 2050. In September 2006, the Governor signed a comprehensive emissions reduction bill known as AB 32, which makes the 2020 target mandatory and outlines a path to help meet those goals. By January 1, 2009, the state Air Resources Board must adopt a "Scoping Plan," the main plan for reducing California's GHG emissions. Then the Board has until January 1, 2011, to adopt the Plan's various regulations and other initiatives reducing GHG emissions. These various reduction strategies will start going into effect by January 1, 2012.

Additionally, in December 2004, the California Public Utilities Commission approved a requirement that power companies consider the financial risk associated with carbon emissions from power plants when comparing prices of fossil fuel and renewable generation, as well as demand-side management investments. In 2005 the state established a greenhouse gas performance standard requiring that any new long-term power purchase contracts meet strict global warming pollution standards.

California has also undertaken economic analyses that show these efforts will deliver enormous economic benefits to the state. The state currently spends more than $30 billion a year to import fossil fuel—by keeping more of that money in state and investing it in efficiency and clean technologies, the state would realize billions in net economic benefits and create more than 80,000 new jobs.[5]

Florida

On July 10, 2007, Governor Charlie Crist announced a suite of initiatives, including a requirement to lower the state's emissions to 2000 levels by 2017, 1990 levels by 2025, and 80 percent below 1990 levels by 2050. Florida will also require utilities to get 20 percent of their fuel from renewable sources.

At the local level, the U.S. Conference of Mayors adopted a Climate Protection Agreement in June 2005 that replicates the Kyoto Protocol's goal of reducing greenhouse gas emissions 7 percent below 1990 levels by 2012. All told, more than 800 cities have pledged to cut emissions and called for federal legislation.

CHAPTER 7

Policy Conclusions and Recommendations

Contributed by Theo Spencer

With the evidence in hand that our planet is getting warmer—and that the West is being affected by a changed climate more than any other part of the United States outside Alaska—we must immediately adopt comprehensive policies that will reduce emissions of global warming pollutants.

The good news is we can meet the challenge of reducing global warming pollution to needed levels through:

- *Building efficiency* that lowers building emissions—the largest source of global warming pollution in the United States. Global warming pollution avoided: 1.7 billion tons per year by 2050.
- *Vehicle efficiency* and smart growth communities that reduce vehicle miles traveled and help cars go farther on less fuel. Global warming pollution avoided: 1.4 billion tons per year by 2050.
- *Industrial efficiency* such as combined heat and power will help reduce industrial energy use. Global warming pollution avoided: 1.2 billion tons per year by 2050.
- *Renewable electricity* from alternative energy sources such as wind power and solar power has the potential to supply a large portion of our energy needs. Global warming pollution saved: 1.4 billion tons per year by 2050.
- *Low-carbon transportation fuels* such as biofuels made from agricultural waste and switchgrass can replace imported oil. Global warming pollution avoided: 1.1 billion tons per year by 2050.
- *Carbon capture and storage*, a technology that captures the CO_2 emitted from coal-fired power plants and pumps it into natural geologic structures deep in the Earth, where it is gradually absorbed. Global warming pollution avoided: 1.1 billion tons per year by 2050.

To move markets to deploy these solutions, we need comprehensive and effective policy action within the United States. Members of regional climate initiatives must ensure that aggressive targets for emissions reductions are met on or ahead of schedule. At the national level, legislators must support and strengthen legislation such as S. 2191, the Lieberman-Warner bill on global warming (also knows as "America's Climate Security Act"), which would get the United States started on addressing global warming. Three essential steps will put us on the right path:

1. Enacting mandatory greenhouse gas limits to stimulate investment and ensure that polluters pay. A mandatory cap will guarantee that we meet emissions targets, and a well-designed program can reduce energy bills for consumers and businesses. Such a cap should have a target of reducing U.S. emissions at least 80 percent below current levels by 2050.

2. Overcoming barriers to investment in energy efficiency. Relying on price signals alone to drive investment is not enough; state and federal policies are also needed to promote building and transportation efficiency at lowest cost—for example, by reforming perverse regulations and allowing energy efficiency to compete on a level playing field against electricity and gas supply.

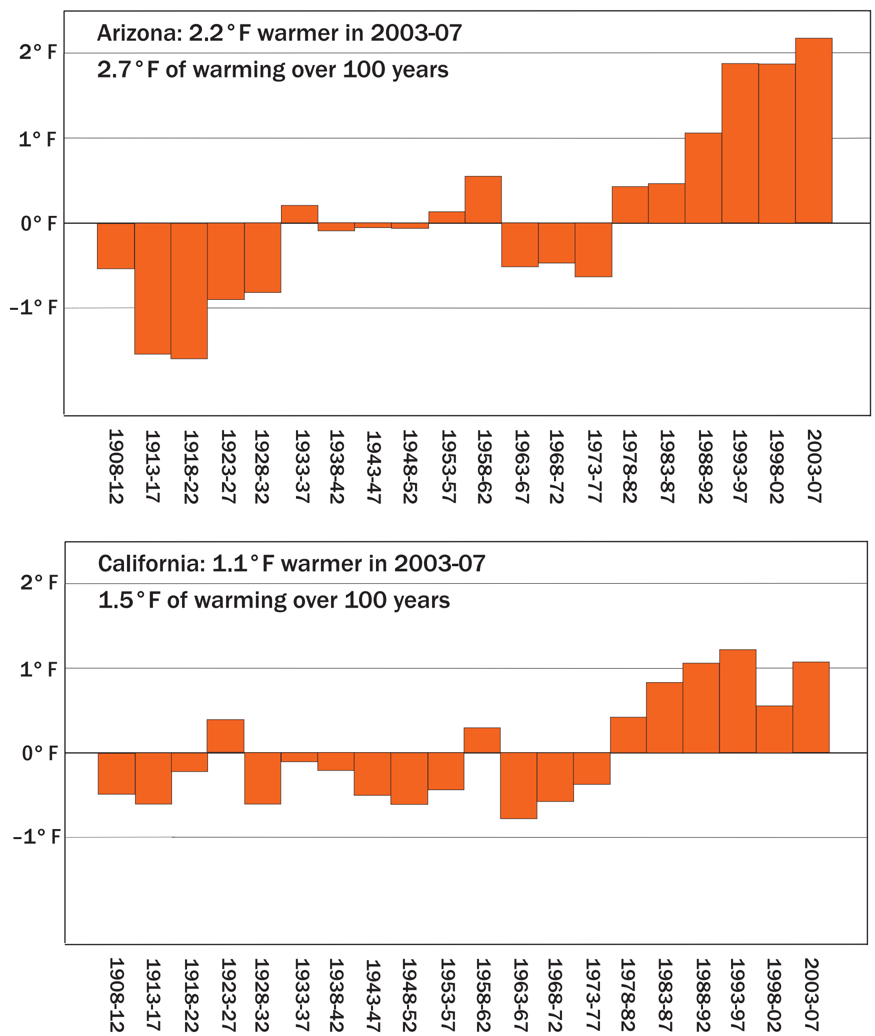
3. Harnessing innovation spillovers to commercialize emerging low-carbon solutions. The government must adopt performance standards and other policies to promote "learning by doing" and rapid development and deployment of emerging technologies such as low-carbon fuels, renewable electricity, and carbon capture and disposal.

We must also simultaneously move to adopt a strict international system to control global warming pollution. The cost of inaction—to our health, our environment, and our economy—is a price that we cannot afford to pay. We must act now, and act decisively, to prevent the dangerous impacts of global warming and to drive investment in the next generation of buildings, vehicles, fuels, and power production.

Appendix: A State-by-State Analysis of Warming in the West

For this report, the Rocky Mountain Climate Organization analyzed the past 100 years of temperatures for each of the 11 western states, comparing the average temperature for each five-year period in a state to its average temperature for the 20th century—just as was done for the West as a whole and shown in Figure 2 (see page 3). The indicated extent of warming over 100 years for each state represents the difference between the initial five-year period and the latest five-year period.

Figure 7. Warming in the Western States, 1908 - 2007
(5-Year Average Temperatures Compared to 20th Century Averages)



Temperatures in each of the western states, averaged over five years, compared to that state's average temperature for 1901 - 2000. Data from the National Oceanic and Atmospheric Administration's climate-division series. Analysis by the Rocky Mountain Climate Organization.

Figure 7
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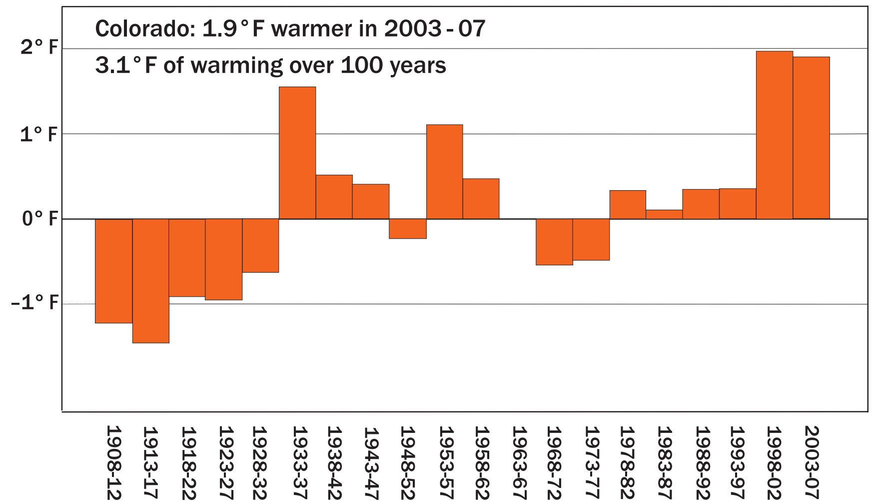

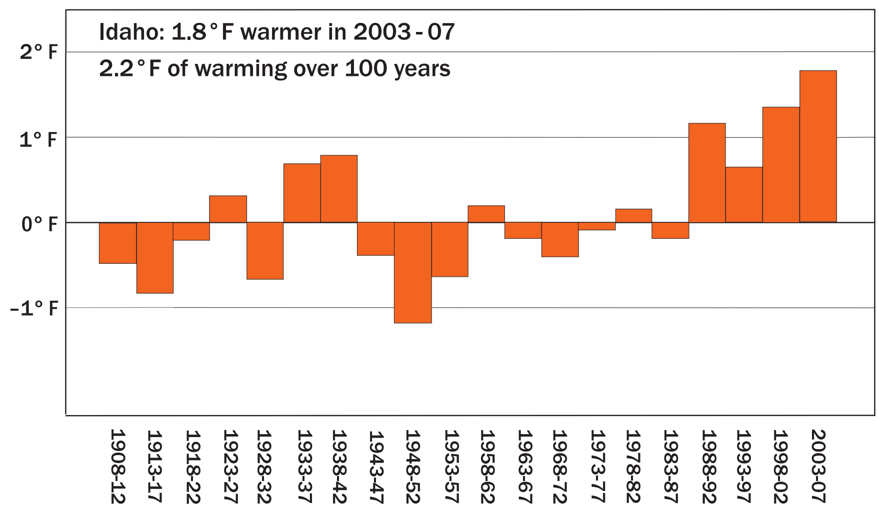

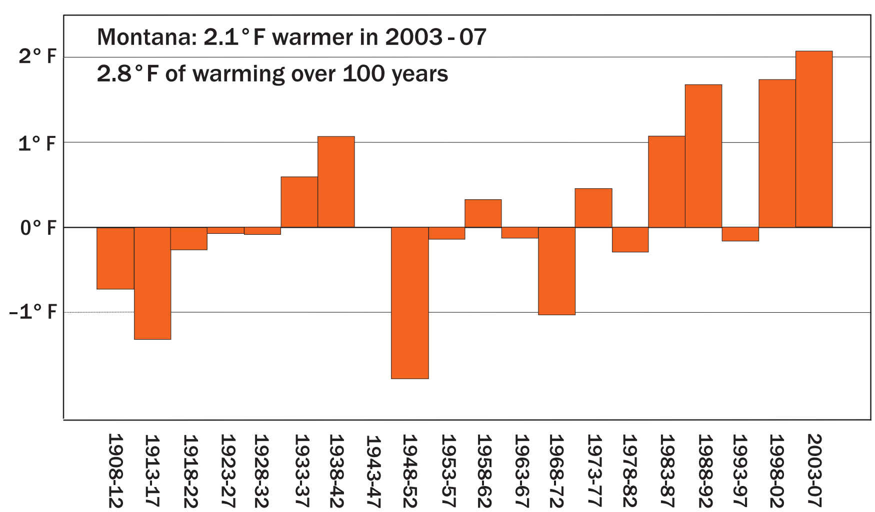

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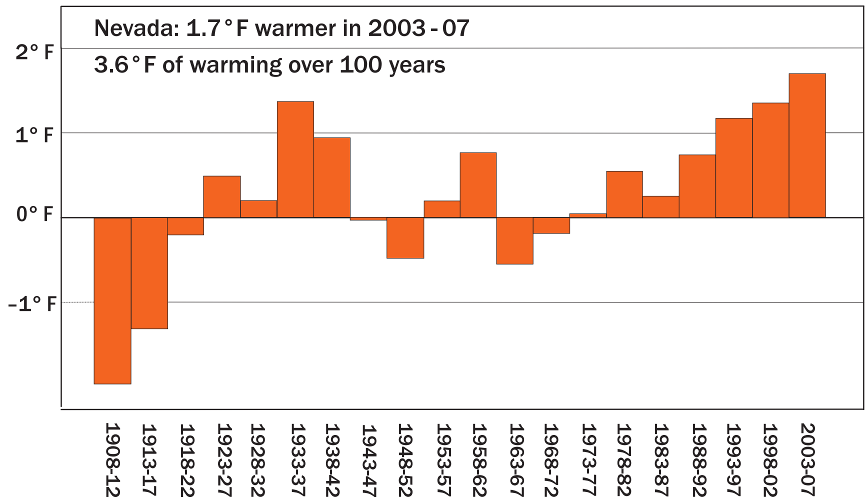

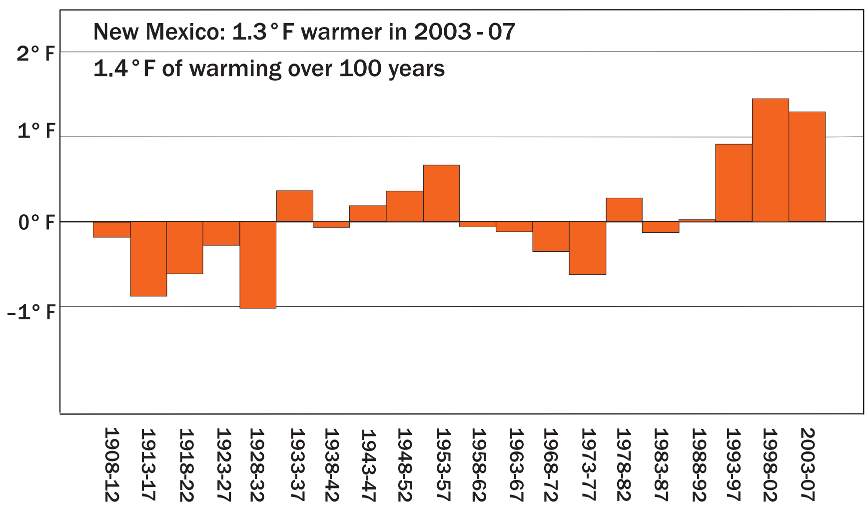

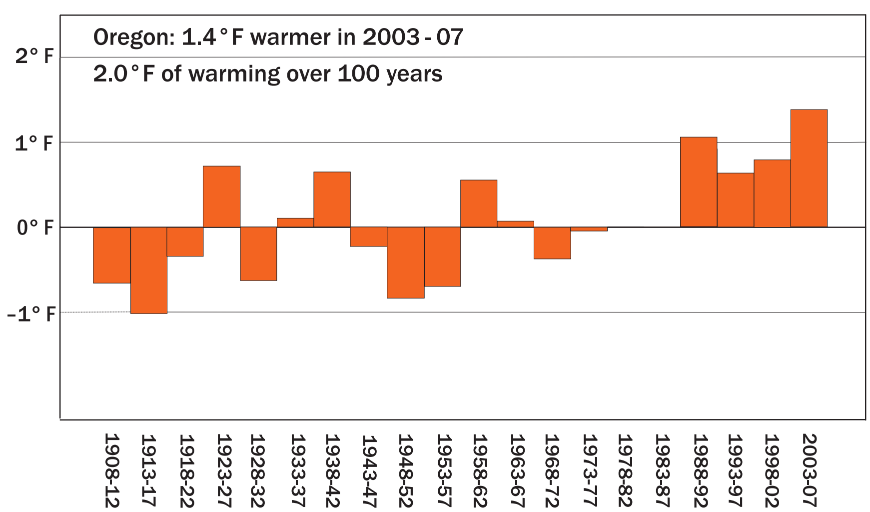

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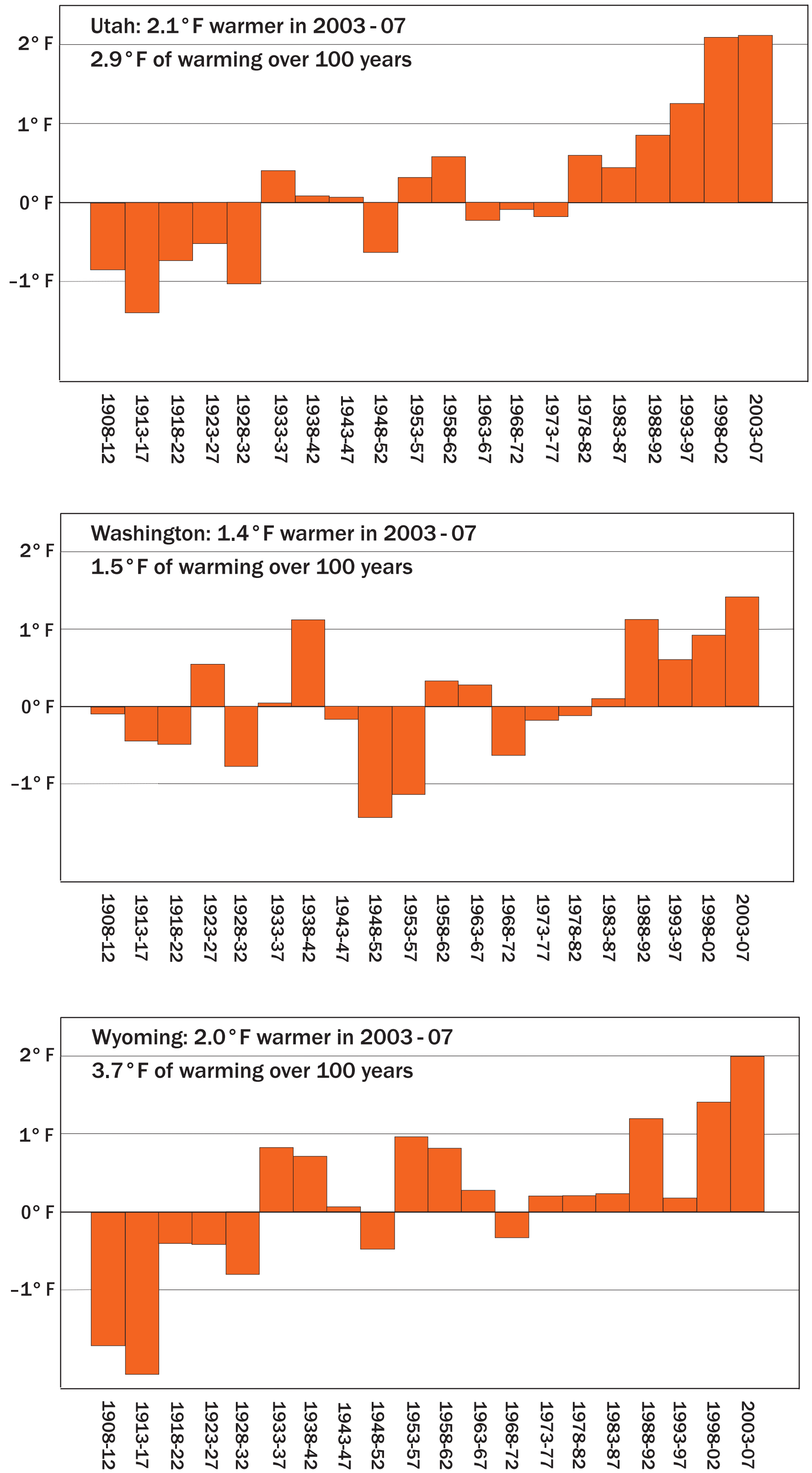

ENDNOTES

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[3] Auctioning allowances and using the proceeds for energy efficiency ensures that the significant monetary value of global warming allowances benefits the public. In contrast, past programs including the EU Emissions Trading Scheme and the U.S. Acid Rain program, as well as several pending climate change bills, give allowances away for free to power plant owners who nevertheless pass the "opportunity cost" onto consumers. This creates windfall profits for the shareholders of those power plants, while doing nothing to advance low-cost global warming solutions.

[4] C. Crist, governor of Florida, "2007 Florida State of the State Address," March 6, 2007, http://www.flgov.com/pdfs/2007sos.pdf.

[5] California consumes 28.6 billion gallons (or 680 million barrels) of petroleum every year, of which 58% is imported. Energy Information Administration, *Petroleum Profile*: California, January 2006, http://tonto.eia.doe.gov/oog/info/state/ca.html. California Energy Commission, *Questions and Answers: California Gasoline Price Increases*, August 9, 2005, www.energy.ca.gov/gasoline/gasoline_q-and-a.html. In 2005, the price of crude oil averaged $56.64 per barrel, so Californians paid $22.4 billion to out-of-state petroleum providers. Energy Information Administration, *Petroleum Navigator*: Spot Prices, March 1, 2006, http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_a.htm. California consumes 6.3 Bcf per day of natural gas (or 2.3 Tcf per year), of which 85% is imported. The wellhead price of natural gas supplied to California averaged $3.87/Mcf (based on a weighted average of 41% of imports from San Juan and Permian basins at $3.43/Mcf, 29% from the Rocky Mountains at $4.25/Mcf, and 29% from Canada at $4.10/Mcf). California Energy Commission, *Final Reference Case in Support of the 2005 Natural Gas Market Assessment*, Staff Report, Publication CEC-600-2005-026-REV, November 2005, pp. x, 27, 29, 41. California imports 54,503 GWh of coal-fired power and 10, 326 GWh of natural gas-fired power every year. California Energy Commission, 2004 *Net System Power Calculation*, Publication CEC-300-2005-004, April 2005, p. 3. Assuming a heat rate of 7200 Btu/kWh for natural gas based on an emission rate of 0.42 tons CO_2/MWh, and a heat rate of 9615 Btu/kWh for coal based on an emission rate of 1 ton CO_2/MWh. California Energy Commission, *A Preliminary Environmental Profile of California's Imported Electricity*, Staff Report, Publication CEC-700-2005-017, p. 11. The wellhead price of natural gas is $3.87/Mcf as noted above. Coal prices in 2004 averaged $13.67 per short ton (based on an average of Wyoming coal at $7/short ton, Montana coal at $10/short ton, New Mexico coal at $24/short ton). U.S. Energy Information Administration, *Average Open Market Sales Price of Coal by State and Mine* Type, 2004, www.eia.doe.gov/cneaf/coal/page/acr/table28.html.