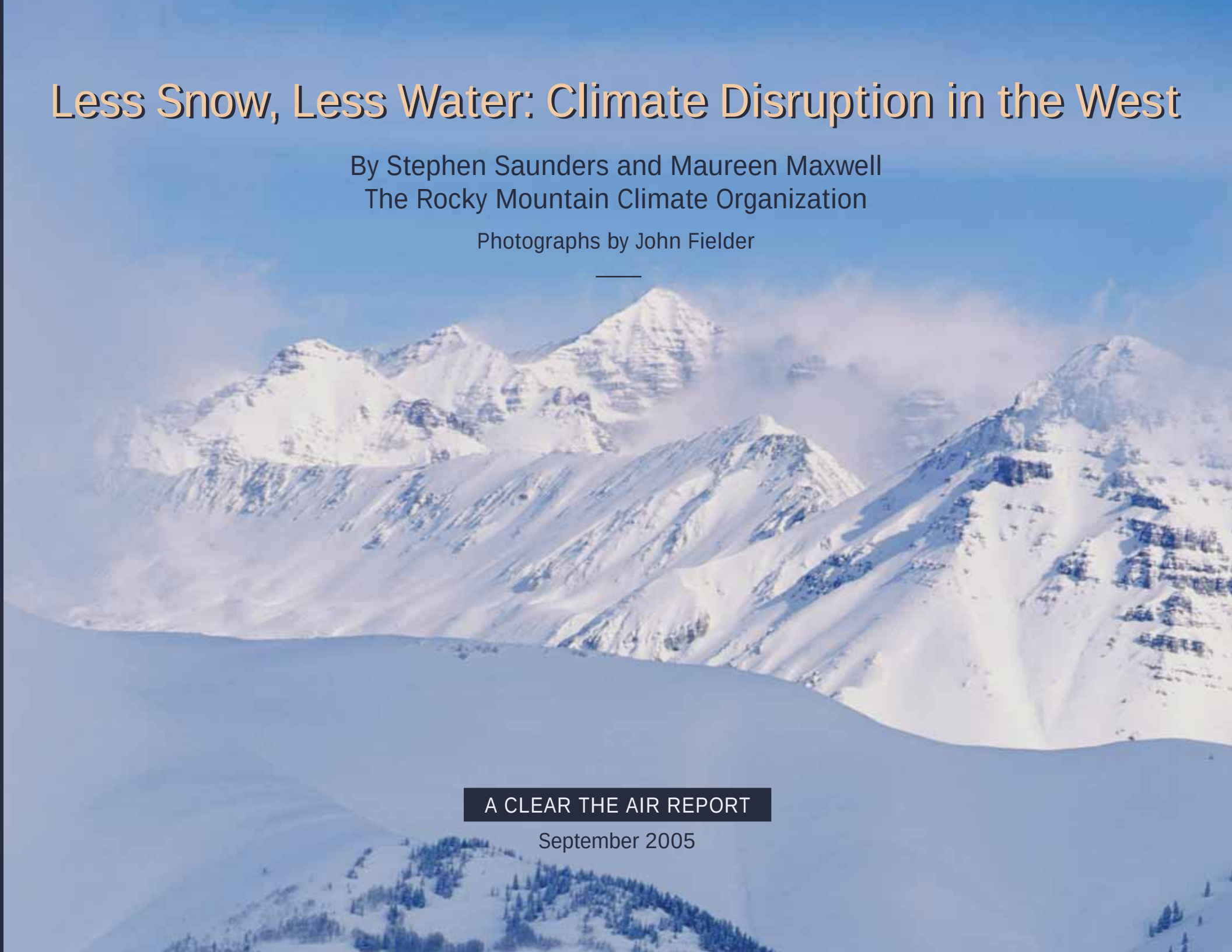
Less Snow, Less Water: Climate Disruption in the West

By Stephen Saunders and Maureen Maxwell
The Rocky Mountain Climate Organization

Photographs by John Fielder



A CLEAR THE AIR REPORT

September 2005

Table of Contents

Executive Summary 1

Section 1 – Water — the West's Great Vulnerability 3

Section 2 – Climate Disruption's Likely Effects on the West's Water 5

Section 3 – Climate Disruption is Under Way in the West 9

Section 4 – New Findings: Changes in the West's River Basins 11

Section 5 – Projections of Future Changes 17

Section 6 – Changing the Odds in the West 21

Appendix: Research Methodology 26

Endnotes 27

Figures, Maps & Tables Index

Figure 1: River Basins in the RMCO Analysis 12

Figure 2: Warming Where Snow Falls 14

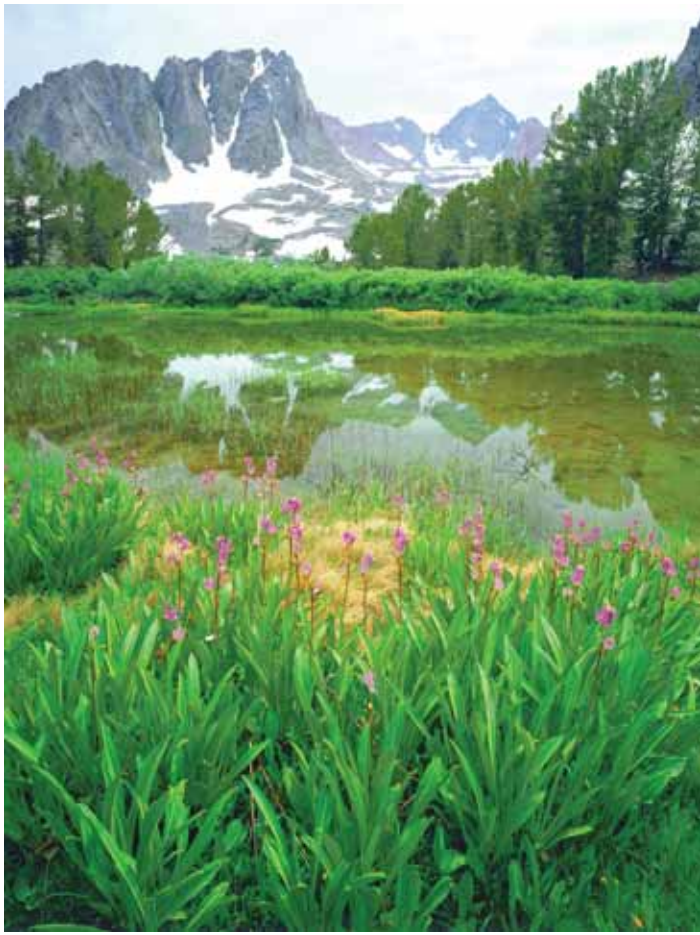
Figure 3: Consistent with Global Warming: Warming Greatest in Winter, Early Spring 15

Figure 4: Declining Snowpacks by River Basin 16

Table 1: Climate Disruption's Effects in the Colorado River Basin 17

Table 2: Climate Disruption's Effects in California 18

Table 3: Western States Pollute More than Most Nations 21



Acknowledgements

The authors wish to acknowledge the assistance of those who supplied information for this report or who reviewed and commented on a draft of it, including Barry Baker, The Nature Conservancy; Dr. Peter H. Gleick, Pacific Institute for Studies in Development, Environment, and Security; K. C. Golden, Climate Solutions; Dr. Noah Knowles, Scripps Institution of Oceanography; Kyle Martin, Columbia River Inter-Tribal Fish Commission; Dr. Philip Mote, Climate Impacts Group, University of Washington; Dr. Jonathan Overpeck, Institute for the Study of Planet Earth, University of Arizona; Dr. Kelly Redmond, Western Regional Climate Center; Dr. Jacob Sewall, University of California at Santa Cruz; Dr. Lisa Sloan, University of California at Santa Cruz; Joel Smith, Stratus Consulting, Inc.; Dr. Kevin Trenberth, National Center for Atmospheric Research; Brad Udall, Western Water Assessment, University of Colorado; and the staffs of the Clean Air Task Force, Clear the Air, Denver Water, National Environmental Trust, and the U.S. Public Interest Research Group. Their contributions helped improve this report.

We thank John Fielder for letting us use his photographs, which uniquely capture the beauty of the West.

We also express our particular appreciation to Abigail Taplin, research assistant at the Rocky Mountain Climate Organization; without her efforts, the new analysis of temperature and snowpack data contained in this report would not have been possible.

This report was made possible with funding from The Pew Charitable Trusts. The opinions expressed in this report are those of the authors and do not necessarily reflect the views of The Pew Charitable Trusts.

Stephen Saunders, *President*
Maureen Maxwell, *Senior Fellow*
The Rocky Mountain Climate Organization
Louisville, Colorado

Printed on paper with 50% recycled content including 15% post consummer waste.

the ROCKY MOUNTAIN CLIMATE Organization

The Rocky Mountain Climate Organization spreads the word about what climate disruption can do to us here and what we can do about it. The initial partners in our year-old, mainstream coalition include five local governments, Colorado's largest water provider, seven businesses, and five non-profit organizations.

PO Box 270444, Louisville, CO 80027
303-880-4598
www.rockymountainclimate.org

CLEAR THE AIR

Clear the Air is a national public education campaign to improve air quality by reducing emissions from coal-burning power plants. Clear the Air brings together grassroots organizations, national environmental groups, and policy experts to make the case for stricter pollution controls to communities, government agencies, elected representatives, and the media. Clear the Air is a joint project of three leading clean air groups, the Clean Air Task Force, The National Environmental Trust and the U.S. PIRG Education Fund.

1200 18th Street, NW, Washington, DC 20036
202-887-1715
www.cleartheair.org

For more of John Fielder's photography, go to www.johnfielder.com.

Executive Summary

In the American West, no other effect of climate disruption is as significant as how it endangers the region's already scarce snowpacks and water supply. With the inherent vulnerability of the dry West to even small changes in the snow-water cycle, these risks alone present ample reason for Westerners to take action to protect this special region.

The Likely Effects of Climate Disruption on the West's Water

Scientists believe that climate disruption in the West likely will result in more heat, less snowpack, and earlier snowmelt and runoff. This may be accompanied by other adverse effects, including increased intensity, frequency, and duration of drought.

- More heat. Temperature increases in the West are likely to be even greater than the projected 3° to 10°F worldwide increase by the end of the 21st Century, compared to 1990. The heating is likely to be greater in the winter than in the summer and at higher elevations than in lowlands, with significant implications for snowpacks and water availability.
- Smaller snowpacks. It is very likely that more winter precipitation will fall as rain instead of snow, periods of snowpack accumulation will be shorter, and snowpacks will be smaller.
- Earlier snowmelt. Warming earlier in the year very likely will melt snowpacks sooner. Peak water flows would occur that much sooner than the summertime peak water needs of cities, farmers and ranchers, and others.
- More evaporation and dryness. Higher temperatures would increase evaporation from streams and reservoirs, soil dryness, and the needs of crops and other plants for supplemental water.
- More flood-control releases. Warming in the mountains in late winter and early spring very likely will increase snowmelt and river flows then, and reduce them later in the year. The risk of flooding likely will increase, and water managers may be forced to make flood-control releases more often from reservoirs, leaving less water to be stored for summertime needs.
- Less groundwater. Snowpacks also are essential contributors to the West's groundwater, so reduced snowpacks could reduce groundwater supplies, too.
- More legal restrictions. Environmental constraints, which sometimes now limit the water available for consumptive use in the West, may be triggered more often as a result of climate disruption. Changes in water supplies also may trigger water-use restrictions under interstate compacts.
- More droughts. Climate disruption could lead to more intense, frequent, and longer-lasting droughts in the interior West.

More heat, less snowpack, less available water, and possibly more droughts are likely to lead to other changes across the West. Most significantly, wildfires are likely to increase in number and severity.

Climate Disruption Is Under Way In the West

It is now accepted by the scientific community that, worldwide, the climate is changing as a result of human activities. In the American West, too, climate disruption is under way.

- More heat. The United States, along with the rest of the world, has warmed, with temperature increases in the West greater than in other regions of the contiguous states.

■ Less snowfall. As the West has warmed, less winter precipitation now is falling as snow and more as rain.

■ Smaller snowpacks. At most snowpack-measurement sites across the West, snowpack levels have declined over the period 1950 to 2000.

■ Earlier snowmelt. Across the West, springtime peak streamflows are earlier than 50 years ago. In many cases, the peak snowmelt advanced by 10 to 30 days.

■ More wildfires. Wildfire in the West has increased, particularly in the last two decades. Researchers have identified climate factors as being a significant contribution to this trend.

New Findings

For this report, the Rocky Mountain Climate Organization (RMCO) conducted a new analysis of government temperature and snowpack records for the upper basins of the Columbia River, Missouri River, Colorado River, and Rio Grande for evidence of human-caused climate change.

■ Increased temperatures. In each river basin, the most recent five-year period was the hottest in the past 110 years. In the upper Columbia River basin, 2000-2004 was 1.5°F hotter than the historic average; in the upper Missouri basin, 1.5°F hotter; in the upper Colorado basin, 2.1°F hotter; and in the upper Rio Grande, 2.5°F hotter. These temperature increases coincided with and worsened the effects of the recent West-wide drought, by increasing evaporation rates from streams and reservoirs, soil dryness, and the water needs of crops and other plants.

■ Greatest warming in winter and spring. In all four basins, the monthly pattern of the warming that occurred in 1995 through 2004 reveals what could be regarded as a signature of climate disruption: The warming has been greatest in January, February, and March. This timing is consistent with predictions that warming resulting from climate disruption will be greatest in winter and spring. Also, this is when warming has the greatest effects on the size of snowpacks and the timing of snowmelt.

■ Reduced snowpacks. At government snowpack-measurement sites with records going back to 1961, from 1990 on snowpack levels have been below average for 13 of the last 16 years in the Columbia River basin, 11 of 16 years in the Colorado River basin, 14 of 16 years in the Missouri River basin, and 10 of 16 years in the Rio Grande basin.

In sum, the RMCO analysis offers further evidence that climate disruption is already under way in the West in ways that jeopardize the region's snow and water resources.

Projections of Future Changes

Scientists believe that the changes in climate observed so far are just a mild foretaste of what is likely to come if global-warming emissions continue to increase. A few illustrative examples of climate projections for the West from recent scientific studies include:

- For the Colorado River basin, losses of 24% of the basin's snowpack are predicted by 2010-2039 and 30% by 2040-2069.
- For the Columbia River basin, losses of 35% of the basin's snowpack are predicted by 2050 and 47% by 2090. For the milder-winter Cascade Mountains, the predicted losses are nearly 60% by 2050 and 72% by 2090.
- For California, losses of 29 to 89% of the state's snowpack are predicted by 2070-2099.

Changing the Odds

With all that the West has at risk, the region has good reason not only to do its share to deal with climate disruption, but also to be a leader in showing the rest of the nation and world what can be done. Encouragingly, there are growing signs of new western leadership and action in addressing climate disruption. Much more needs to be done, but these first steps suggest that Westerners are beginning to choose a new path to keep the region such a special place.

1 Water – the West's Great Vulnerability

"Today, in some areas of the West, existing water supplies are, or will be, inadequate to meet the water demands of people, cities, farms, and the environment even under normal water supply conditions."

— U.S. Department of the Interior, "Water 2025: Preventing Crisis and Conflict in the West" (2003)[1]

For those of us who live in, visit, or marvel at the American West this region is special because of its large, grand landscapes, with mountains reaching to the sky, plains unfolding to the horizon, and vistas exceeding the imagination. The West's abundance, though, is accompanied by scarcity. Water is as essential to life here as it is everywhere, but scarcer here than elsewhere in the United States. It is the West's inherent, continuing vulnerability.

The lack of water has even been used, literally, to define the West. In a report to Congress written in 1878, John Wesley Powell fixed a boundary to the West that still stands, identifying it as beginning at the 100th Meridian. This line of longitude, running north-south through Dodge City, Kansas, bears a nice, round number, but Powell chose it as best approximating the fundamental difference between the wet East and the dry West. East of the line, precipitation generally exceeds 20 inches a year, enough to grow most crops without supplemental water. To the west, precipitation is generally less, and irrigation is usually needed.

Precipitation in the West is not just scarce, it is scarcest where and when it is most needed. Westerners, whether in cities and suburbs or on farms and ranches, need water where they are, which is overwhelmingly in the region's lowlands. And they need water in the heat of summer, when everything – people, crops, livestock, lawns, and even power plants – needs water the most. Perversely, most of the West's precipitation falls in a different place and at a different time.

Western precipitation falls mostly in the mountains, not the lowlands. Driven by the winds, air meets the mountains and is forced higher to pass over them; as it rises, it cools. Air when it cools can no longer hold as much moisture. So when air rises to pass over mountains, its moisture is forced out as precipitation. This process works so efficiently that the small area represented by the mountains gets blessed with the lion's share of the West's precipitation. As long as the water is on top of the mountains, it is useless for the city dwellers, farmers, and ranchers who need it below. Gravity, so long as it wins a race against evaporation and thirsty plants along the way, saves the day by bringing the water downhill.

The other complication is that western precipitation falls disproportionately in the winter, not in the summer, when heat makes it more needed. In California, about 80% of the state's precipitation falls between October and March, but about 75% of all water use occurs in the rest of the year.[2] The city of Portland, Oregon, gets only one-tenth of its precipitation in the summer.[3] If the region's precipitation were to run off the mountains when it falls in the winter, it would be gone before summer.

The West's saving grace is that winters in the mountains are cold enough that the precipitation falls as snow, not rain, and stays in the high country in snowpacks through the winter. These snowpacks – the region's largest reservoirs, dwarfing those people have built – conveniently delay the runoff until spring's warmth releases it as snowmelt to flow to the lowlands, often months after it fell as snow. This essential serendipity of the West, the age-old cycle of winter snowfall and accumulation and spring runoff, provides nearly three-quarters of the West's water.

Because the natural water cycle does not meet all of the region's needs, people have augmented it through extensive engineering. In the water-rich Columbia River basin, reservoirs capture about 30% of the annual runoff. In the arid Colorado River basin, reservoirs can hold four times the river's annual flow. Conveyance systems deliver the water where it is needed when natural watercourses fail to do so. Water from the Colorado River is diverted through tunnels under the Continental Divide to meet the need of the cities and farms and ranches at the edge of the Great Plains, and through an aqueduct across the California desert to supply much of southern California's water needs.

"The most significant threat to our economic security is not having a secure future water supply."

Denver Mayor John Hickenlooper (2004)[4]

Even with these Herculean engineering efforts, demand for water in the West often exceeds supply. Now evidence is mounting that people's actions are affecting the region's water in another, altogether different way, this time making it harder to meet our water needs. Pollutants from human actions are changing our atmosphere so it traps more heat, unnaturally warming our planet. This is a global phenomenon having many serious effects. In the West, no other effect of climate disruption rivals in importance how it endangers our already too-scarce snowpacks and water supplies. With the inherent vulnerability of the dry West to even small changes in the snow-water cycle, these risks alone present ample reason for Westerners to take action to protect this special region, and these risks are the subject of this report.

2 Climate Disruption's Likely Effects in the West

"Temperature increases in mountainous areas with seasonal snowpack will lead to increases in the ratio of rain to snow and decreases in the length of the snow storage season (very high confidence). It is likely that reductions in snowfall and earlier snowmelt and runoff would increase the probability of flooding early in the year and reduce the runoff of water during late spring and summer. Basins in the western United States are particularly vulnerable to such shifts."

— Dr. Peter H. Gleick, "Water: The Potential Consequences of Climate Variability and Change for the Water Resources of the United States" (2000)[5]

Predicting future climate is difficult, and scientists are uncertain about many of the ways that human-caused climate changes will manifest themselves. But the degree of uncertainty varies. Most scientists believe that some predicted changes, such as temperature increases, are likely, and that others, such as projections about how precipitation may change in a particular region, are still unreliable. In the West, scientists consider some key changes to be either very likely or likely, including more heat, less snowpack, increased runoff in winter and early spring, and reduced runoff in late spring and summer. These and other possible but less certain changes are summarized in this section.

More Heat

The scientific community expects that global warming likely will raise the world's average temperatures by 3° to 10°F by the end of the 21st Century, compared to 1990.[6] Such a broad range in the predictions comes half from uncertainty about what future levels of climate-changing emissions will be, and half from uncertainty in the various models used, which yield different results. In any event, the American West is likely to heat up more than the worldwide average, as there likely will be more warming over land than over water and in the northern hemisphere than in the southern.[7] As a result, regional climate models suggest that the temperature increases in the West could be 4° to 13°F.[8]

At first blush, being several degrees warmer might not sound like much. But an 8°F increase in average temperatures would make:

- Seattle as warm as Sacramento now is.
- Portland as warm as Los Angeles now is.
- Missoula as warm as Denver now is.
- Aspen as warm as Colorado Springs now is.

Less Snowpack

As startling as these higher average temperatures would be, they actually understate what could happen. Low temperatures in the nighttime are likely to increase more than high temperatures in the daytime.[9] Warming is also projected to be greater in the mountains than in lowlands and, particularly in the mountains, greater in the winter than in the summer. (In part, this will be because if there is a reduction in mountain snow cover in the winter, there will be less

reflection and more local absorption of the sun's heat.[10]) This means that heating likely will be particularly pronounced where and when snow falls, making less common the conditions necessary for snowfall and snowpack accumulation.

If the West gets less snow, one obvious effect would be less skiing and other snow sports. The season for skiing, snowboarding, and other snow-dependent winter recreation could be shorter and the snow slushier – reducing enjoyment for skiers, profits for skiing-dependent businesses, and tax revenues for state and local governments. If the changes are extreme, skiing could be eliminated at low-elevation resorts.[11]

> [A] significant decline in skiing, or certainly its complete demise, would mean serious economic loss to the resorts, and to the economies of communities heavily dependent on skiing. (*Rocky Mountain/Great Basin Regional Climate Change Assessment*[12])

"This is not something we treat as a tertiary issue. This is front and center."

Michael Berry, president, National Ski Areas Association (2003)[13]

Less Available Water

While some avid skiers may care more about what happens to their sport, for most Westerners a larger concern is that changes in snowpack, together with other climate changes, may lead to less water being available where and when we need it. In most places around the world, higher temperatures likely will lead to more evaporation of surface water, more moisture in the air, and more precipitation, and therefore to increased water supplies. But in some places, potentially including the West, climate changes could instead lead to less available water.

> Climate change is projected to substantially reduce available water (as reflected by projected runoff) in many of the water-scarce areas of the world, but to increase it in some other areas. (Intergovernmental Panel on Climate Change[14])

Several factors put the West at risk of being one of the water-scarce areas ending up with less available water.

- Smaller snowpacks. As a result of increased warming, especially in the winter and at high elevations, it is very likely that more winter precipitation will fall as rain instead of snow, periods of snowpack accumulation will be shorter, and springtime snowpacks will be smaller.[15]

- Earlier snowmelt. Warming earlier in the year very likely will melt snowpacks sooner.[16] Peak water flows would occur that much sooner than the summertime peak water needs of cities, farmers, ranchers, and others.

  > Current water source management along the eastern edge of the Rocky Mountains depends on the storage of winter precipitation as high elevation snowpack well into the growing season. Under a climate shift to earlier snowmelt runoff, not only would there be a great demand for water to irrigate during the extended growing season, but water would be released from its very efficient high-elevation natural seasonal reservoir well before the July and August interval of peak irrigation. (*Central Great Plains Regional Climate-Change Assessment*[17])

- More evaporation and dryness. Higher temperatures would increase evaporation from streams and reservoirs.[18] According to one study, in the Colorado River basin, a 7.2°F increase in temperature – by itself, without any changes in snowpack – would increase evaporative losses enough to reduce snowmelt runoff by 9 to 21%.[19] Higher temperatures also would increase soil dryness and the needs of crops and other plants for supplemental water.[20]

- More flooding and flood-control releases. Warming in the mountains in late winter and early spring very likely will increase snowmelt and river flows then, and reduce them later in the year.[21] The volumes of springtime peak flows likely will increase, and with them the risk of flooding. Water managers may be forced to make flood-control releases more often from reservoirs, leaving less water to be stored for summertime needs.[22]

Key Collaborative Scientific Reviews

The Intergovernmental Panel on Climate Change assesses information on climate change. Thousands of scientists and others have contributed to this international effort.

Hundreds of specialists worked on a water-sector report for a national assessment of climate-change impacts in the United States. The report is "Water: The Potential Consequences of Climate Variability and Change for the Water Resources of the United States;" its lead author is Dr. Peter H. Gleick.

The U.S. government also organized regional assessments of how climate change could affect different parts of the country. Five regional assessments covered parts of the West.

■ Less groundwater. Scientists recently learned that snowpacks are essential contributors to the West's groundwater, which supplies 28% of the region's water needs.[23] So smaller snowpacks could reduce groundwater supplies as well.

> Because mountains are generally wetter and cooler than adjacent basins, groundwater in the West is derived mainly from mountain precipitation. Because large and intense infiltrations of water are required to break through the region's thick unsaturated zones, and because snowpacks store and then release precipitation from several storms at once, snowmelt provides more recharge than does rain. Isotopic studies in western settings have suggested that 50 to 90% of [groundwater] recharge is from snowmelt. (Earman and Dettinger, "Warming Trends and Groundwater Recharge in Western Mountains, With Implications for Groundwater and Surface-Water Resources"[24])

■ More legal restrictions. Environmental constraints, which sometimes now limit the water available for consumptive use in the West, may be triggered more often as a result of climate disruption. More aquatic species are likely to be listed as endangered and threatened because of changed water temperatures and flows and other stresses, and so restrictions under the Endangered Species Act are likely to be imposed more often.[25] Reduced summer water flows also may increase salinity levels and aggravate other water-quality problems that already limit water use.[26] And as described on page 20, changes in water supplies may trigger water-use restrictions under interstate compacts.

■ More droughts. Climate disruption could lead to more droughts in the interior West.[27] The projected combination of earlier snowmelt, more heating, and increased soil dryness could lead to less summertime evaporation, recycled moisture, and precipitation, and so "is a recipe for increased intensity, frequency and duration of drought."[28] Reconstructions of western droughts over the past 1,200 years show that the region's driest periods were all in the period 900 to 1300 AD, coinciding with what climatologists call the Medieval Warming Period, suggesting a linkage between heat and drought.[29]

> If elevated aridity in the western US is a natural response to climate warming, then any trend toward warmer temperatures in the future could lead to a serious long-term increase in aridity over western North America. (Cook and others, "Long-Term Aridity Changes in the Western United States[30])

"The most simple thing I can think of as a definition of drought is not enough water to meet needs. Under that definition, the recent years of rapid growth in the Southwest are tipping the region further into drought."

Dr. Kelly Redmond, Deputy Director and Regional Climatologist, Western Regional Climate Center (2004)[31]

More Wildfire

More heat, smaller snowpacks, less available water, and possibly more droughts are likely to lead to additional changes across the West. Most significantly, wildfires are likely to increase in number and severity as higher temperatures likely will lengthen fire seasons and make fires worse.[32] In addition, an increased level of carbon dioxide, by itself, is predicted to change the atmospheric chemistry in a way that will increase lightning, which starts most wildfires.[33]

Increases in Rainfall?

It is possible that the risks outlined above could be largely overcome if climate disruption leads to sufficient increases in rainfall. As pointed out above, higher temperatures likely will increase overall levels of precipitation in most, but not all, areas of the world. Counting on a large enough increase in rainfall in the West to head off the adverse impacts of climate disruption would be risky, though, for at least three reasons.

"We've already got our hands full with trying to provide enough water to the region to keep up with population growth. To add the additional problem of climate change just exacerbates an already difficult situation."

Marc Waage, Manager of Raw Water Supply
Denver Water (2005)[34]

"Global warming threatens California's water supply, public health, agriculture, coastlines and forests — our entire economy and way of life."

Governor Arnold Schwarzenegger (2005)[35]

First, models of future climate changes, while improving, are still unreliable about predicting changes in regional and local precipitation. Eighteen different projections for California, for example, range from 14 inches less overall precipitation per year to 11 inches more.[36]

Second, to offset the very likely effects of more heat and smaller snowpacks, much more rainfall would be needed. For instance, a study concluded that if Colorado River basin temperatures were to increase 7.2°F, a precipitation increase of 15 to 20% would be needed to offset evaporation losses enough to keep flows at previous levels.[37]

> In the arid and semi-arid western United States, it is well established that relatively modest changes in precipitation can have proportionately large impacts on runoff. Even in the absence of changes in precipitation patterns, higher temperatures resulting from increased greenhouse gas concentrations lead to higher evaporation rates, reductions in streamflow, and increased frequency of droughts. In such cases, increases in precipitation would be required to maintain runoff at historical levels. (Gleick, "Water: The Potential Consequences of Climate Variability and Change for the Water Resources of the United States"[38])

Third, climate disruption may set in motion cascading changes with additional effects on western water beyond those identified above. One study has suggested that reductions in Arctic sea ice (which are already well underway) could change the track of winter snow storms, pulling them far enough to the north to bypass the American West, reducing western precipitation by as much as 30%.[39]

3 Climate Disruption Is Under Way In the West

"It's kind of taken us all aback. It's kind of hard to see all this happening right under our nose without us noticing."

— Dr. Kelly Redmond, Deputy Director and Regional Climatologist Western Regional Climate Center (2004)[40]

The previous section identified what climate disruption may do to the West's snow and water. An obvious next question is whether these changes are already occurring. In the last few years, evidence has mounted that, indeed, climate disruption is under way across the West, as it is across the world.

It is now accepted by the scientific community that, worldwide, the climate is changing as a result of human activities.

> There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities. (Intergovernmental Panel on Climate Change[41])

"The IPCC's conclusion that most of the observed warming of the last 50 years is likely to have been due to the increase in greenhouse gas concentrations accurately reflects the thinking of the scientific community on this issue."

National Academy of Sciences (2001)[42]

In the American West, too, climate disruption is under way.

- More heat. The United States, along with the rest of the world, has warmed. Increases in annual temperatures have been greater in the West than in other regions of the contiguous states, according to National Weather Service data.[43]
- Less snowfall. As the West has warmed, snowfall and snowpack trends have begun changing as predicted. A new study shows that at more than two-thirds of 200 western mountain sites, less winter precipitation is falling as snow and more as rain. The greatest changes have been at lower-elevation sites – where winters are milder than higher elevations, and therefore where the effects of warming are predicted to show up first.[44]
- Smaller snowpacks. In the most thorough review yet of changes in the West's snowpacks, an analysis of the records of 824 government snowpack-measurement sites across the West with records from 1950 to 1997 shows that snowpack levels have declined at most of those sites over that period.[45]

> Much of the mountain West has experienced declines in spring snowpack, especially since mid-century, and despite increases in winter precipitation in many places. Analysis and modeling shows that climate trends are the dominant factor, not changes in land use, forest canopy, or other factors... Taken together, these results emphasize that the West's snow resources are already declining as Earth's climate warms. (Philip Mote and others, "Declining Mountain Snowpack in Western North America"[46])

■ Earlier snowmelt. Western snowpacks are now melting earlier in the year. A study shows 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 peaks coming 10 to 30 days earlier in many cases.[47]

■ More wildfires. Wildfire in the West has increased, particularly in the last two decades. A study of wildfire on western federal lands over the period 1916-2002 showed that the five years with the largest number of acres burned were all in the period 1987-2002. The researchers identified climate factors as being significant.[48]

"Forget talk of global warming and speculation of what it might do in 50 years, or 100. Here and across the West, climate change already is happening. Temperatures are warmer, ocean levels are rising, the snowpack is dwindling and melting earlier, flowers bloom earlier, mountain glaciers are disappearing and a six-year drought is killing trees by the millions."

Angie Wagner, Associated Press (2003)[49]

4 New Findings: Changes in the West's River Basins

"Certainly, in the Pacific Northwest we are seeing climate change."

— Karl Dreher, Director, Idaho Department of Water Resources[50]

For this report, the Rocky Mountain Climate Organization (RMCO) analyzed government temperature and snowpack records for the upper basins of the Columbia River, Missouri River, Colorado River, and Rio Grande for evidence of climate disruption. These rivers are among the West's major sources of water, and each has its particular vulnerabilities to climate change.

- The Columbia River basin, despite its reputation as a wet area, is dry in the summer and depends on upper-basin snowmelt for much of its summer water. Changes in the amount and timing of water flows also could affect hydroelectric production and ongoing multi-billion dollar efforts to recover endangered salmon populations.
- The Colorado River basin is dry, averaging less than four inches of rainfall a year, and hot, with 87% of its precipitation evaporating and only 13% becoming runoff.[51] Snowmelt produces 70 to more than 86% of the river's flow.[53] The river supplies water to more than 25 million Americans, not only in the basin but beyond, from Denver to San Diego. Despite the basin's scarcity of water, this is one of the fastest growing areas of the country. Three states in the basin – Nevada, Arizona, and Utah – are among the five states in the nation expected to grow the fastest.[54]
- The Missouri River provides water for the ten states in its basin. About 70% of the river's flow comes from melting snow in Montana. Barge traffic on the river, one of the nation's critical transportation systems, is also dependent on the river's volume.[55]
- The Rio Grande provides water to Colorado, New Mexico, Texas, and Mexico. This is one of the most water-short river basins in the country, and highly vulnerable to drought. In 2002, Rio Grande flows in New Mexico fell to only 13% of normal.

"The Colorado River is the canary in the coal mine for global warming."

Eric Kuhn, General Manager Colorado River Water Conservancy District (2004)[52]

It's not just the drought, it's the heat.

The RMCO analysis of climate changes in these river basins began with an examination of temperature changes over the past 110 years. RMCO aggregated into a basin-wide average the temperature data reported by the National Oceanic and Atmospheric Administration (NOAA) for its climate divisions that correspond to the upper portion of each river basin – the portion that includes mountain snowpacks. (For an explanation of the methodology used in the analysis of both temperature and snowpack data, see the Appendix.) A historical average temperature for each upper basin was calculated for the period 1895-1990, and the average temperatures for each five-year period from 1895-2004 – for 1895-1899, 1900-1904, and so on – were compared with the historical average, showing temperature variations over the period of the NOAA instrumental record.

River Basins in the RMCO Analysis

Figure 1

The results are shown in Figure 2. In each river basin, the most recent five-year period was the hottest on record. In the upper Columbia River basin, 2000-2004 was 1.5°F hotter than the historical average; in the upper Colorado basin, 2.1°F hotter; in the upper Missouri basin, 1.5°F hotter; and in the upper Rio Grande, 2.5°F hotter.

These recent temperature increases coincided with the much more widely noted recent West-wide drought. Heat and drought always go together; heat increases evaporation and therefore dryness, and a lack of moisture reduces the cooling effect of precipitation and evaporation. But other severe droughts have occurred since 1895 without the high temperatures of 2000-2004. The heat that accompanied the West's recent drought made it worse, by increasing evaporation rates from streams and reservoirs, soil dryness, and the water needs of crops and other plants. Future droughts accompanied by even more heat could be even worse.

A possible signature of global warming.

RMCO next examined the monthly pattern of the recent warming in each basin, to determine whether the warming has been uniform across all months, random, or, as predicted to result from human-caused climate change, greater in winter and early spring.

As shown in Figure 3, in all four basins, the monthly pattern of recent warming reveals what could be regarded as a signature of climate disruption: The warming has been greatest in January, February, and March. This timing is consistent with predictions that the warming resulting from climate disruption will be greatest in winter and spring. Also, this is when warming has the greatest effects on the size of snowpacks and the timing of snowmelt.

Snowpacks are declining.

As a final step in this analysis, RMCO analyzed records of the Natural Resources Conservation Service (NRCS), part of the U.S. Department of Agriculture, of April 1 snowpacks (measured as snow-water equivalent, the depth of water that the snow would represent if melted) for each basin's snow-measurement sites with data for 1961 through 2005. Using sites with records going back to 1961 made it possible to establish a historical baseline for the analyzed sites in each basin for the period 1961-1990, covering the 30-year length of time climatologists generally consider necessary to avoid distortion from short-term variations. For each basin, the total April snow-water equivalent for the analyzed sites for each year from 1961 through 2005 was calculated as a percentage of the 1961-1990 historical average.

This analysis differs from the average snowpack values reported by NRCS, which uses a 1971-2000 baseline in calculating how snowpack values compare to historical averages. By including recent years in its baseline for historical averages, NRCS masks the changes that are occurring as snowpacks have declined in recent years in response to increasing temperatures. The RMCO analysis makes possible a comparison with a statistically sound, 30-year historical average ending in 1990, before changes in temperature likely began having larger effects on western snowpacks.

The RMCO analysis, represented in Figure 4, shows that, for each of the four basins, in a significant majority of the years from 1990 on the total snowpack volumes of the analyzed sites have been below the historical averages.

In sum, the new RMCO findings offer further evidence that climate disruption is already under way in the West in ways that jeopardize the region's snow and water resources.

Warming Where the Snow Falls

5-Year Average Temperatures, 1895 to 2004, Compared to Historical Averages

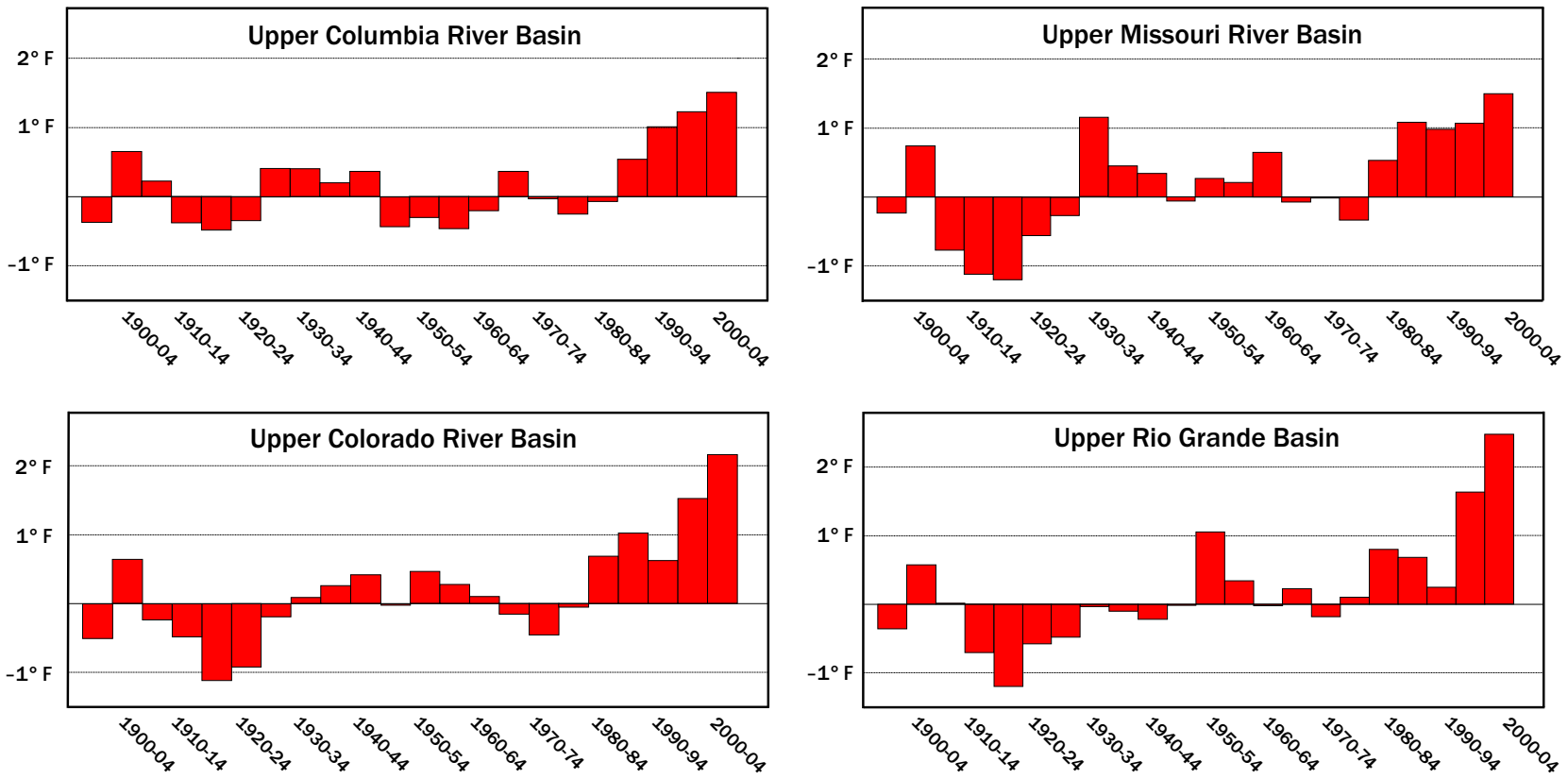


Figure 2 — *Data from the climate- division series, National Oceanic and Atmospheric Administration. Analysis by the Rocky Mountain Climate Organization. The historical average is for the period 1895-1990.*

Consistent With Global Warming: Warming Greatest in Winter, Early Spring

Average Monthly Temperatures in 1995-2004, Compared to Historical Average Monthly Temperatures

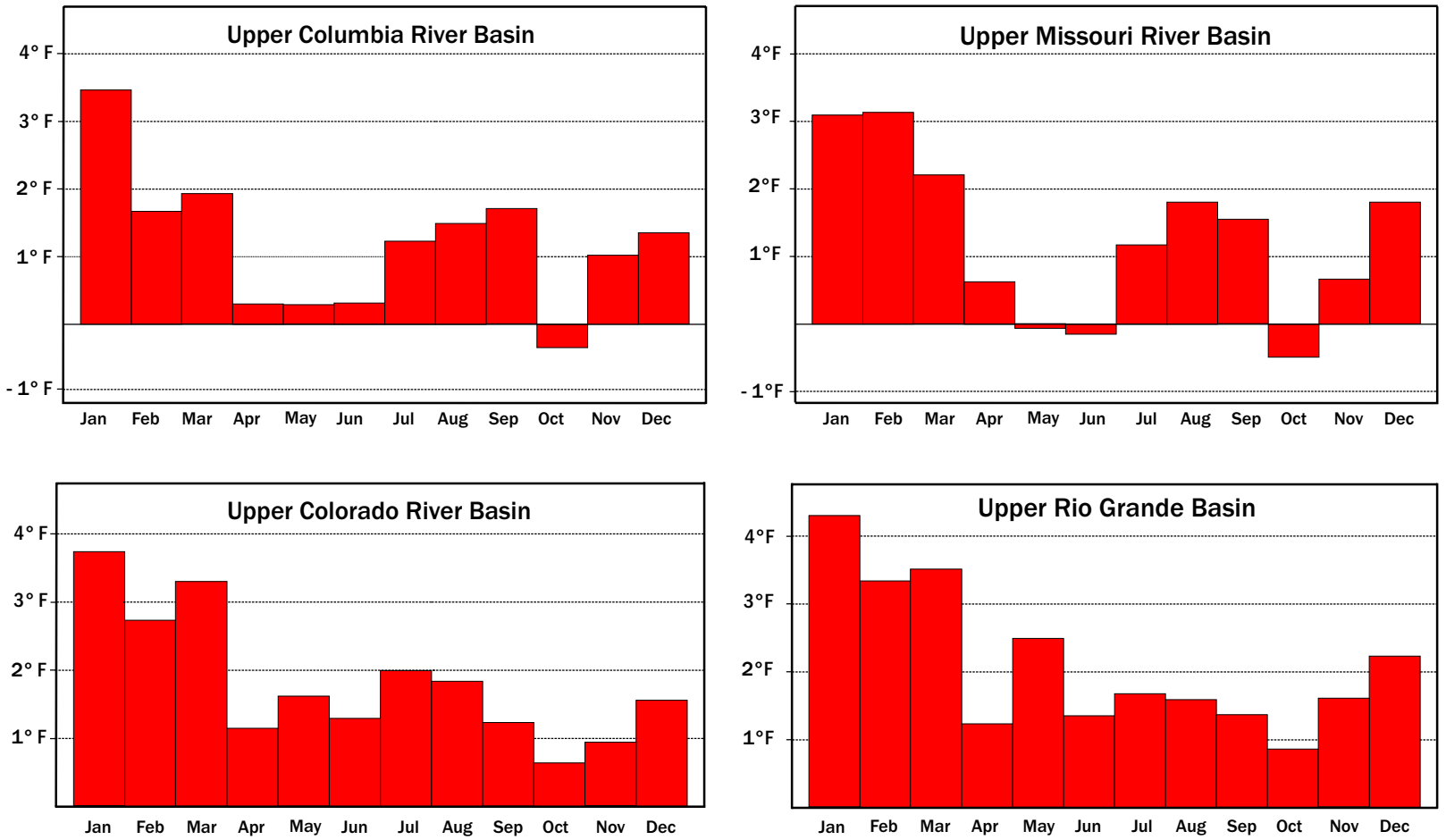


Figure 3 — *Data from the climate division series, National Oceanic and Atmospheric Administration. Analysis by the Rocky Mountain Climate Organization. Historical average monthly temperatures are from the the period 1961-1990.*

Declining Snowpacks By River Basin

April 1 Snowpacks, 1961-2005, Compared to Historical Averages

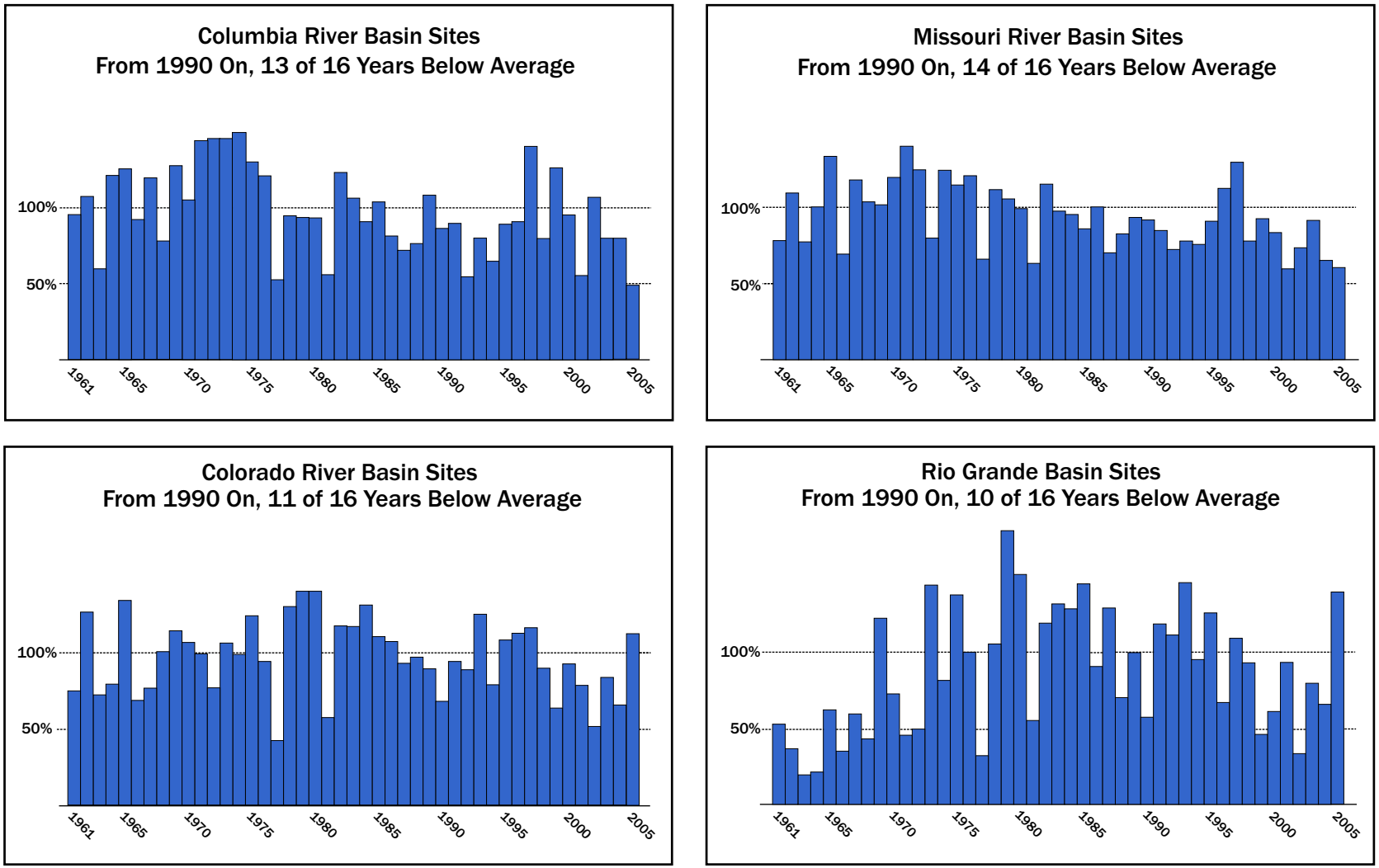


Figure 4 — *April 1 snowpacks compared to historical averages. Data from the Natural Resources Conservation Service. U.S. Department of Agriculture. Analysis by the Rocky Mountain Climate Organization. Historical averages are for the period 1961-1990.*

5 Projections of Future Changes

"What this work shows is that, even with a conservative climate model, current demands on water resources in many parts of the West will not be met under plausible future climate conditions — much less the demands of a larger population and a larger economy."

— Dr. Tim P. Barnett and others, "The Effects of Climate Change on Water Resources in the West: Introduction and Overview" (2004)[56]

Having identified the likely effects of climate disruption in the West and shown that they are already occurring, the next question is, what changes might the future hold?

Scientists believe that the changes in climate observed so far are just a mild foretaste of what is likely to come if global-warming emissions continue to increase. This section considers how some projections using climate models suggest the extent to which climate disruption could change the region.

As scientists using climate models are quick to point out, models are much cruder than the world's actual geography and climate and at best can only approximate plausible future conditions. This is particularly true with respect to the West, where the varied terrain that influences climate is not yet well represented in climate models. Models, for instance, sometimes treat the Rocky Mountains as a single very wide, low rise. Still, when different projections are in general agreement with one another, they can provide a reasonable picture of what could be in store for the West (depending on, among other things, the future levels of global emissions).

A few illustrative examples of climate projections for the West are summarized here.

Colorado River

As part of a coordinated series of studies on the possible effects of climate disruption on western water resources, a team of researchers used a state-of-the-art climate model developed by the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, to project possible changes in the Colorado River basin. Because the NCAR model predicts relatively small temperature changes, the researchers

Climate Disruption's Effects in the Colorado River Basin: A "Best-Case" Scenario

Projected Changes	Time Period	
	2010-2039	2040-2069
Temperature	+ 1.8°F	+ 3.6°F
Precipitation	- 3%	- 6%
Snowpack	- 24%	- 30%
Runoff	- 14%	- 17%
Water Storage	- 36%	- 40%

Table 1 — *Source: Christensen and others (2004).[57] Predicted impacts are compared to average observed values through 1995.*

called their projections a "best-case" scenario. Particularly as a best case, their results, summarized in Table 1, are far from reassuring.

> Basically, we found the fully allocated Colorado system to be at the brink of failure, wherein virtually any reduction in precipitation over the Basin, either natural or anthropogenic, will lead to the failure to meet mandated allocations. (Barnett and others, "The Effects of Climate Change on Water Resources in the West: Introduction and Overview")[58]

Columbia River

In parallel with the Colorado River study just referred to, another group of researchers used the same NCAR climate model to project possible changes in the Columbia River basin. They projected a loss of 35% of the Columbia River's snowpack by 2050 and 47% by 2090. Within the basin's Cascade Mountains, snowpack losses could reach nearly 60% by 2050 and 72% by 2090. The milder winters there mean temperatures will get pushed above freezing more often.[60] The study also projected that earlier snowmelt would require changes in reservoir operations that could reduce hydropower production by 9 to 35%.[61]

> In the Columbia River systems, residents and industries will likely be faced with the choice of water for summer and fall hydroelectric power or spring and summer releases for salmon runs, but not both. (Barnett and others, "The Effects of Climate Change on Water Resources in the West: Introduction and Overview")[62]

California

Several studies have identified the vulnerability of California's in-state water supplies to climate disruption. (The southern part of the state depends on the Colorado River for much of its water, as previously noted.) California is particularly at risk, as its water demand already substantially exceeds available supplies, and a predicted population growth of more than 15 million additional people by 2020 could increase urban water use by 30%.[63]

- Two climate models – the NCAR model and one developed by the Hadley Climate Centre – were used to predict impacts on California under two different levels of global emissions: a higher-emissions future that could occur if we continue on a "business as

Climate Distruption's Effects in California Under Higher vs. Lower Emission Levels

Predicted Effects in California in 2070-2099

	NCAR Model		Hadley Climate Centre Model	
Projected Changes	**Lower Emissions**	**Higher Emissions**	**Lower Emissions**	**Higher Emissions**
Temperature	+ 4°F	+ 7°F	+ 6°F	+10°F
Precipitation	+ 7%	-17%	-22%	-30%
Snowpack	-29%	-73%	-72%	-89%
River Flows	- 7%	-14%	-23%	-33%

Table 2 — *Source: Hayhoe and others (2004).*[59] *"Lower emissions" reflect aggressive but realistic action to reduce greenhouse gas. "Higher emissions" reflect a business-as-usual approach. Predicted impacts are compared to historical averages for the period 1961-1990.*

usual" course, and a lower-emissions future that assumes the world takes aggressive but realistic actions to reduce global warming. Their conclusions about the effects on water resources are summarized in Table 2. This study illustrates that the effects will be substantial either way, but much less if we slow down the growth of emissions rather than let them continue increasing as they have been.

- Another study concluded that the snowpacks supplying water to California's Central Valley, the source of much of the nation's food, could decline by 26% in the period 2010-2039, by 38% in 2040-2069, and by 52% in 2070-2098. The number of "critically dry" years was predicted to more than double by the last three decades of the century.[64]

  In the Central Valley of California, it will be impossible to meet current water system performance levels; impacts will be felt in reduced reliability of water supply deliveries, hydropower production and in-stream flows. (Barnett and others, "The Effects of Climate Change on Water Resources in the West: Introduction and Overview")[65]

- A parallel study predicted that by 2070-2098, the winter-long average amount of snow in California's Merced River basin could decline by 51%; in the Carson River basin by 67%; and in the American River basin by 21%. The changes projected in this study, unlike those in most other studies, are in total season-long volumes of snow, not in the levels of snowpack at the end of the season (typically measured on April 1).[66]

Future California Impacts: California Water

- *"Total water availability is likely to be reduced*
- *"Timing of water delivery will be disrupted, as snow volume and the snow year decreases and the rain season is shortened*
- *"Storage and delivery of water throughout the state will be challenged*
- *"Snowmelt runoff will decrease and will occur earlier in the spring with less flow in the summer"*

Sloan, "Regional Climate Modeling Studies for California: Future Scenarios and Impacts" (2004)[67]

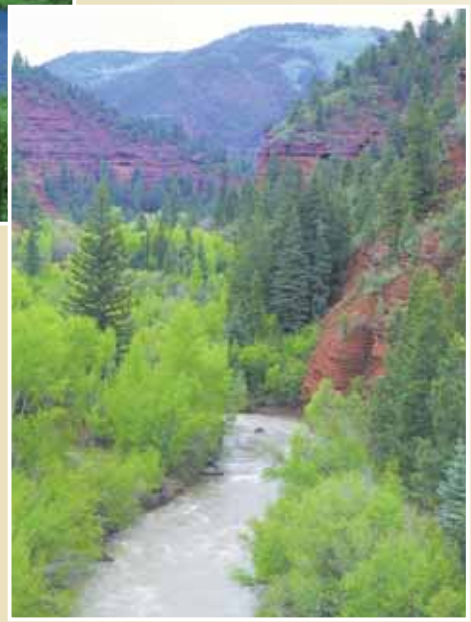
"In California, climate change is likely to severely exacerbate the existing mismatch between where and when rain falls and where and when people need to use water."

Dracup and others, "Climate Change and Water Supply Reliability" (2004)[68]

Interstate River Compacts: A Complicating Factor

Interstate compacts often allocate the authority to use a river's water among the different states through which the river flows. These compacts could end up aggravating in particular states the effects of climate disruption on river flows. The Colorado River Compact is a good illustration.

The Colorado River Compact of 1922, negotiated when river flows were believed to be greater than they actually have been, puts the primary burden of water shortages on the upper basin (portions of Colorado, Utah, Wyoming, New Mexico and Arizona). The compact guarantees that the upper basin will allow the delivery of a minimum amount of water – 75 million acre-feet every ten years, plus an additional amount for Mexico – to the lower basin (portions of Nevada, Arizona, California, Utah and New Mexico), regardless of how much water is needed in the upper basin.



Lake Powell, the largest reservoir in the upper basin, is designed to store surplus water that ensures adequate releases to the lower basin in water-short years. Lake Powell's level declined from 95% of capacity in 1999 to 34% in early 2005, raising for the first time a realistic prospect that the reservoir may not always hold enough water to fulfill the lower basin's entitlement. That could lead to a compact "call" from the lower basin for the release of additional water from the upper basin. According to David Getches, dean of the University of Colorado Law School, "If there is a compact call, we hit the wall. We wouldn't be able to use water called by the lower basin."[69] Providing water to the lower basin in this scenario could lead to widespread water restrictions throughout Colorado, Utah, Wyoming, and New Mexico.

"Imagining a worst-case scenario, Bill McEwen, water commissioner for the Eagle River district, said that, with not all its Colorado River Compact water available, impacts to this state could include massive rationing, taking out all nonnative landscaping or eliminating half the farming in Colorado."

Summit Daily News (2004)[70]

6 Changing the Odds in the West

"I say the debate is over. We know the science, we see the threat, and the time for action is now."

— Governor Arnold Schwarzenegger (2005)[71]

With all that the West has at risk, the region has good reason not only to do its share to deal with climate disruption but also to be a leader in showing the rest of the nation and world what can be done. The federal government, the region's elected representatives to Congress, state and local governments, and the private sector need to act on two fronts – first to reduce the extent to which the climate is disrupted, and second to prepare for and deal with the impacts likely to occur anyway.

To reduce climate disruption, actions to reduce greenhouse gases will be necessary. The most prevalent greenhouse gas is carbon dioxide, primarily from the combustion of fossil fuels. Other greenhouse gases, such as methane, occur in smaller quantities but, molecule for molecule, can have a stronger greenhouse effect than carbon dioxide. Evidence is also growing that another category of global-warming pollution – certain aerosols, particularly black carbon (or soot) – may have a particularly potent climate-changing effect. To reduce climate disruption, reducing emissions of all these pollutants will be necessary.

What is done to reduce emissions in western states is important. The United States, as a whole, emits one-quarter of the world's global-warming pollutants.[72] The emissions of western states, together and individually, are significant, too, as Table 3 shows. The emissions of carbon dioxide from fossil-fuel combustion in each

Western States Pollute More Than Most Nations

Emissions of Carbon Dioxide From Fossil Fuels in 2000
State Emissions Compared to Those of 212 Nations

State	Exceeds Emissions of:
California	211 nations
Arizona	174 nations
Colorado	174 nations
Washington	174 nations
Utah	171 nations
Wyoming	170 nations
New Mexico	163 nations
Nevada	155 nations
Oregon	151 nations
Montana	142 nations
Idaho	129 nations

Table 3 — *Source: Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory.*

western state are greater than those from each of over half the nations in the world.

Reducing the impacts of climate disruption also will be necessary. It is impossible either to immediately eliminate new emissions of global-warming pollution or to remove pollutants already in the atmosphere, so further climate change is almost certainly coming (with the extent to be determined by what is done to reduce emissions). The West, in particular, needs to prepare. Since water is an all-important resource for this region, public officials and water providers need to consider the likely effects on future water supplies and determine how to manage water supplies and demand to meet future needs.

All this will take a lot of leadership and work. Encouragingly, there are growing signs of new western leadership and action in addressing climate disruption. The primary sponsors of two leading climate-protection measures in the U.S. Congress are Westerners, Senator John McCain of Arizona and Senator Jeff Bingaman of New Mexico. Increasingly, western state and local governments are stepping up to reduce greenhouse gases. Protecting the West's interests will take much more, but these first steps suggest that Westerners are beginning to choose a new path to protect their interests.

"We must take action, and act appropriately. Many have hidden for too long behind what we do not know or the uncertainties around climate change. Their shield is shrinking. The time has come for us to accept what is known and start to solve this highly complex problem. As many of the top scientists throughout the world have stated, the sooner we start to reduce these emissions, the better off we will be in the future."

Senator John McCain (2004)[73]

National Action

(Contributed by Jonathan Banks, Clean Air Task Force / Clear the Air)

Much time and many resources have been committed over the past two decades to an international debate on what the world, and specifically the United States, should do to address the threats posed by climate disruption. Much of this debate focused on proposals to establish binding international emissions-reduction requirements and the prospects for and costs of meeting such requirements. Recently, the U.S. Senate took up several different proposals to begin addressing the climate problem. While none of the proposals fully address the need for deep reductions in global-warming emissions, they represent, nonetheless, steps in the right direction, some greater than others.

The United States can produce substantial, near-term reductions in domestic greenhouse-gas emissions. An effective near-term climate policy would:

- Enact comprehensive power-plant emissions-reduction requirements that include a power-system carbon cap.
- Enact simple-to-implement policies to expand production of electricity from renewable sources.
- Adopt a stronger federal fuel-economy standard to improve light-vehicle fuel efficiency.
- Aggressively implement existing federal authority to set equipment and building energy-efficiency standards and codes.
- Adopt either a manufacturer's agreement or other measures to reduce greenhouse-gas emissions from the automotive sector.
- Increase the energy efficiency of power generation through the cogeneration of electricity and useful heat.

In addition, the United States should begin to lay the groundwork for much deeper reductions in global-warming emissions. These actions should include:

- Replacing the highest emitting sources with cleaner sources, such as renewable-energy or advanced fossil-energy systems with low or no greenhouse-gas emissions.
- Researching and developing technologies that permanently capture and sequester carbon from commercial fossil-fueled energy sources.
- Developing action plans for significantly reducing several non-carbon-dioxide greenhouse emissions or concentrations (methane and ozone formation), along with emissions of black-carbon aerosols.
- Reengaging in the international dialogue to effectively construct an international policy to address climate change worldwide.

Comprehensive State Climate Plans

California, Oregon, Washington, Arizona, and New Mexico are among the states that have adopted or are developing climate-action plans to reduce global-warming pollutants and reduce the likely impacts.

- Governor Ted Kulongoski of Oregon appointed a broad-based advisory group that in December 2004 developed a state strategy for reducing global-warming pollutants.
- In February 2005, Arizona Governor Janet Napolitano issued an executive order creating an advisory panel to develop a state climate-protection strategy.
- In June 2005, California Governor Arnold Schwarzenegger signed an executive order establishing state goals of bringing levels of global-warming pollutants back down to 2000 levels by 2010, to 1990 levels by 2020, and 80% below 1990 levels by 2050. The executive order directs state agencies to develop plans to achieve these targets.
- Also in June 2005, New Mexico Governor Bill Richardson signed an executive order setting state goals for global-warming pollution reductions – by 2012, bring emissions back down to 2000 levels; by 2020, 10% lower; and by 2050, 75% lower. The governor appointed a broadly representative advisory panel to come up with ways to meet the goals. The first four reasons cited by the governor in his executive order for taking action are that climate disruption in New Mexico is likely to lead to:
  - "A reduction in water supplies
  - "Shorter and warmer winters with winter precipitation falling more often as rain
  - "Earlier snowmelts
  - "Greater water loss due to evaporation."[74]

Regional Initiatives

States in the West are beginning to work together on a regional basis to address climate disruption.

- The governors of California, Oregon, and Washington have entered into a West Coast Governors' Initiative on Global Warming to cooperate regionally to reduce climate-changing pollution.

The U.S. Mayors Climate Protection Agreement

"We urge the federal government and state governments to enact policies and programs to meet or beat the Kyoto Protocol target of reducing global warming pollution levels to 7% below 1990 levels by 2012...

"We urge the U.S. Congress to pass the bipartisan Climate Stewardship Act sponsored by Senators McCain and Lieberman and Representatives Gilchrest and Olver...

"We will strive to meet or exceed Kyoto Protocol targets for reducing global warming pollution by taking actions in our own operations and communities."[75]

Specific State Actions

State governments also have begun taking specific steps to reduce climate-changing pollutants.

- Under Governor Schwarzenegger, last year California adopted the world's first global-warming emission standards for motor-vehicles, to reduce emissions by 30% by 2016. The federal Clean Air Act allows other states to adopt California's motor vehicle emission standards. Washington has conditionally adopted them, and Oregon is among other states considering doing so.
- The California Public Utilities Commission adopted a new requirement that the state's electric utilities should assume that new power plants will have to meet future carbon-dioxide emission standards, and include the likely costs of doing so in determining which future sources of power meet the state's least-cost standard.
- Arizona, California, Colorado, Nevada, and New Mexico are among states that have adopted requirements that utilities use clean energy sources, such as wind, solar, and biomass, to produce at least a certain amount of their electricity.

Local Government Actions

- Many western cities are among the 152 local governments in the United States participating in the ICLEI Local Governments for Sustainability's Cities for Climate Protection Campaign, in which they commit to take inventory of their global-warming emissions, set a target for future reductions, develop a local action plan to achieve the target, and monitor their progress. Participating western cities include Albuquerque, Denver, Missoula, Portland, Salt Lake City, San Diego, San Francisco, and Seattle.
- Portland, which in 1993 became the first local government in the country to adopt a local plan to address climate disruption, recently documented that it has reduced citywide global-warming emissions below 1990 levels. The city's achievement has resulted from such actions as the installation of a major light-rail public-transit system, renewable energy purchases, expanded recycling, the construction of nearly 40 high-performance green buildings, the planting of more than 750,000 trees and shrubs, and the weatherization of 1,000 multifamily residential units and more than 800 homes.
- Seattle Mayor Greg Nickels challenged America's mayors to sign his U.S. Mayors Climate Protection Agreement, which commits cities to take local action to meet or exceed Kyoto Protocol targets for reducing global-warming pollution. As of August 24, 2005, the agreement has been signed by the mayors of 176 cities – 64 of them from the West – exceeding Mayor Nickels' initial goal of having the agreement endorsed by as many cities as the 140 nations that ratified the Kyoto Protocol. The U.S. Conference of Mayors also unanimously adopted a resolution endorsing the agreement in June 2005.
- Salt Lake City Mayor Rocky Anderson, actor Robert Redford, and ICLEI Local Governments for Sustainability held a July 2005 conference in Utah where 45 mayors spent three days learning about local actions they can take to reduce climate disruption.

Seattle Mayor Nickels: "his focus on global warming has local roots"

Profiling Seattle Mayor Greg Nickels' leadership on climate protection, a newspaper wrote:

"Nickels, who does not face well-funded opposition in his re-election bid this year, says his focus on global warming has local roots.

"Here in Washington, the warming effect is seen in rising temperatures and declining mountain snowpacks.

"A first, Nickels said he was not distressed by these trends. 'I think like most Americans I sort of said, "So what? It would be nice if it were a few degrees warmer."'

"But then he learned more about how Seattle's water and electricity supplies could be hurt by a shrinking snowpack. In meetings with Seattle's water and electricity department chiefs, Nickels said he heard repeated forecasts for below-average snowpack. Eventually he said he realized 'we're never going to get average again.'"

— *Seattle Times* (2005)[76]

Water Managers

Some western water providers are beginning to consider the effects that climate disruption will have on their future water supplies.

- The Northwest Power Planning Council and the Idaho Department of Water Resources have worked with scientists at the Climate Impacts Group at the University of Washington to consider the effects of climate disruption on hydropower operations, irrigation, and other water needs.
- The Portland Water Bureau arranged for Climate Impacts Group researchers to evaluate in a 2002 report the effects that climate disruption will have on its ability to reliably provide water to its customers.
- Denver Water will include in its 2006 update of its Integrated Resources Plan, its primary planning document, consideration of climate disruption's impacts on its ability to provide water to its users.
- With funding from the National Oceanic and Atmospheric Administration, a team of consultants will evaluate the potential effects of climate disruption on the water supply system of Boulder, Colorado.

As important and encouraging as these actions are, they are just first steps. The risks to the West outlined here have been created by the emissions of global-warming pollution resulting from millions of decisions and millions of actions, and it will take broad-based, far-reaching actions by all levels of government, businesses, other organizations, families, and individuals to reduce those risks. Fortunately, there are many common-sense, no-regrets steps that can be taken, amply detailed elsewhere, that will not only limit the extent of damage threatened by climate change but also serve other important national and regional goals, from reducing our dependence on foreign oil to strengthening our national and local economies. Those of us who live in and love the West have more reasons than most to lead the way in taking these steps. The West is a special place to live, and we want to keep it that way.

"There are many benefits of reducing greenhouse gases that go beyond doing our part to stem the tide of climate change. Many actions outlined in this plan have significant local environmental and energy benefits. These benefits range from reduced air pollution, reduced energy bills for businesses and families, expanded recycling opportunities, new jobs, reduced urban sprawl and traffic congestion, and decreased reliance on non-renewable energy sources. If implemented, these actions will preserve and even improve the quality of life in our community."

"Local Action Plan to Reduce Greenhouse Gas Emissions"
City of Fort Collins, Colorado (1999)[77]

Appendix: Research Methodology

For the new analysis of temperatures and snowpacks in four river basins, reported in Section 4 of this report, RMCO used the following methodology.

For the temperature analysis, RMCO examined National Oceanic and Atmospheric Administration (NOAA) data from its climate-division series, using climate divisions corresponding to upper portions of each of the four studied river basins, i.e., the portions of the basins in which mountain snowpacks are located. For the upper Columbia River basin, a total of 21 climate divisions in Montana, Wyoming, Idaho, Washington, and Oregon were analyzed. (The portion of Canada comprising 15% of the Columbia basin was excluded, as the same data are not available for it.) For the upper Missouri River basin, nine climate divisions in Montana, Wyoming, and Colorado were used; for the upper Colorado River basin, six climate divisions in Wyoming, Utah, Colorado, and New Mexico; and for the upper Rio Grande basin, two climate divisions in Colorado and New Mexico. For all calculations, the temperature data for the appropriate climate divisions were aggregated into basin averages, weighting the data from each division based on its area, just as NOAA does in aggregating data from the climate divisions in a state into a statewide average.

For the temperature analysis reflected in Figure 2, for each basin a historical average temperature was calculated as a benchmark using the period from 1895, the first year for which NOAA reports temperatures, to 1990. Basin-wide average temperatures for each five-year period – 1895-1899, 1900-1904, and so on – were calculated and compared with the historical average, showing variations from that historical average over the period 1895-2004.

For the monthly temperature analysis reflected in Figure 3, for each basin a historical average was determined for each month, again using the period 1895-1990. The average basin-wide temperatures for each month over the most recent ten years, 1995-2004, were calculated and compared to the historical monthly averages, showing monthly departures over the past 10 years from those historical averages.

For the snowpack analysis reflected in Figure 4, RMCO analyzed April 1 snow-water-equivalent values reported by the Natural Resources Conservation Service (NRCS), U.S. Department of Agriculture, for all snow-measurement sites in the each basin with data for 1961 through 2005. When NRCS reports estimated values for sites, those estimated values were used. Sites were included in the analysis if there were no more than five years of missing data over the 45-year period of the analysis. A total of 163 sites meeting these criteria were examined for the Columbia basin, 109 for the Missouri basin, 59 for the Colorado basin, and 19 for the Rio Grande basin.

When data were missing for a site included in the analysis, RMCO estimated values for the missing year(s) based on the average percentage of snow-water equivalent represented by that site of the total snow-water equivalent for all sites in that state included in the analysis for all years in which all sites had complete data; of 15,750 total data points in the snowpack analysis, 173 were estimated this way. Using sites with records going back to 1961 made it possible to establish a historical baseline for the sites in each basin for 1961-1990, covering a period of 30 years, the length of time climatologists generally consider necessary to avoid distortion from short-term variations.

Endnotes

1 U.S. Department of the Interior, "Water 2025: Preventing Crisis and Conflict in the West" (2003), 3. http://www.doi.gov/water2025/Water2025.pdf.

2 J. A. Dracup, S. Vicuna, and R. Leonardson, "Climate Change and Water Supply Reliability," report for California Climate Change Center, California Energy Commission (Contract No. 500-02-004, 2004), 5. See also D. Cayan, California's vulnerability to climate change (presentation at Climate Change Symposium, John Muir Institute of the Environment, University of California at Davis), May 12, 2005, slide 2, http://johnmuir.ucdavis.edu/activities/CCS_presentations/Cayan.pdf.

3 R. F. Service, "As the West Goes Dry," *Science* 303 (2004): 1124-1127, 1124.

4 J. Smith, "Hickenlooper Says City Will Lead Way on Water," *Rocky Mountain News*, January 30, 2004.

5 P. H. Gleick, lead author, "Water: The Potential Consequences of Climate Variability and Change for the Water Resources of the United States; The Report of the Water Sector Assessment Team of the National Assessment of the Potential Consequences of Climate Variability and Change," report for the U.S. Global Change Research Program (2000), 4.

6 Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2001: Synthesis Report; Summary for Policymakers,* ed. R. T. Watson and the core writing team (Geneva: IPCC, 2001), 7. http://www.ipcc.ch/pub/un/syreng/spm.pdf.

7 IPCC, *Climate Change 2001: The Scientific Basis,* ed. J. T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P. J. van der Linden, and D. Xiaosu (Cambridge University Press, 2001), 13; 69, fig. 21.

8 Service, "As the West Goes Dry," 1126.

9 IPCC, *The Scientific Basis*, 528.

10 IPCC, *The Scientific Basis*, 540, fig. 9.4; 596; 615; J. C. Fyfe and G. M. Flato, "Enhanced Climate Change and Its Detection over the Rocky Mountains," *Journal of Climate* 12, no. 1(1998), 230-243; F. Giorgi, J. W. Hurrell, M. R. Marinucci, and M. Beniston, "Elevation Dependency of the Surface Climate Change Signal: A Model Study," *Journal of Climate* 10, no. 2(1997), 288-296.

11 F. H. Wagner, ed. and principal author, *Rocky Mountain/Great Basin Regional Climate-Change Assessment*, report for the U.S. Global Change Research Program (Logan, Utah: Utah State University, 2003), 138-141.

12 Wagner, *Rocky Mountain/Great Basin Regional Assessment*, 14.

13 Associated Press, "Global Warming Seen as Threat to Ski Areas," December 3, 2003.

14 IPCC, *Summary for Policymakers*, 12.

15 Gleick, "Water: The Potential Consequences," 4, 37-39; Climate Impacts Group, University of Washington, "Overview of Climate Change Impacts in the U.S. Pacific Northwest, report for the West Coast Governors' Climate Change Initiative, 2004, 2.; N. L. Miller, K. E. Bashford, and E. Strem, "Potential Implications of Climate Change on California Hydrology," *Journal of American Water Resources Association* 39, no. 4(2003), 771-784.

16 Gleick, "Water: The Potential Consequences," 37-39; Climate Impacts Group, "Overview," 2; K. Hayhoe, D. Cayan, C. B. Field, P. C. Frumhoff, E. P. Maurer, N. L. Miller, S. C. Moser, and others, "Emissions Pathways, Climate Change, and Impacts on California," *Proceedings of the National Academy of Sciences*, 101(2004): 12422-12427, 12423, table 1; 12425.

17 D. S. Ojima and J. M. Lacket, comps., *Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change – Central Great Plains* ("Central Great Plains Regional Climate-Change Assessment"), report for the U.S. Global Change Research Program (Fort Collins: Colorado State University, 2002), 45.

18 Gleick, "Water: The Potential Consequences," 48.

19 L. L. Nash and P. H. Gleick, "The Colorado River Basin and Climatic Change: The Sensitivity of Streamflow and Water Supply to Variations in Temperature and Precipitation," report for the Environmental Protection Agency (Washington, D.C.: EPA, 1993), ix.

20 Gleick, "Water: The Potential Consequences," 49-52; 53, figure 7; Ojima and Lackett, "Central Great Plains Regional Assessment," 26-29.

21 Gleick, "Water: The Potential Consequences," 27, 37-39.

22 Hayhoe and others, "Emissions Pathways," 12426.

23 S. Earman and M. Dettinger, Warming trends and groundwater recharge in western mountains: With implications for groundwater and surface-water resources, presentation at MTNCLIM 2005, Pray, Montana, March 2005, slide 5. http://www.fs.fed.us/psw/mtnclim/talks/EarmanREVISED.pdf.

24 S. Earman and M. Dettinger, Warming trends and groundwater recharge in western mountains: With implications for groundwater and surface-water resources (abstract of presentation at MTNCLIM 2005, Pray, Montana, March 2005), http://www.fs.fed.us/psw/mtnclim/pdf/MTNCLIM2005_Abstracts022805.pdf.

25 Wagner, *Rocky Mountain/Great Basin Regional Climate-Change Assessment*, 193-197.

26 Gleick, "Water: The Potential Consequences," 53-58.

27 IPCC, *Summary for Policymakers,* 31, table SPM-3; Gleick, "Water: The Potential Consequences," 48, 60. G. J. McCabe, M. A. Palecki, and Julio L. Betancourt, "Pacific and Atlantic Ocean Influences on Multidecadal Drought Frequency in the United States, *Proceedings of the Academy of National Sciences* 101(2004): 4136-4141; E. R. Cook, C. Woodhouse, C. M. Eakin, D. M. Meko, and D. W. Stahle, "Long-Term Aridity Changes in the Western United States," *Science* 3006(2004): 1015-1018; S. D. Schubert, M. J. Suarez, P. J. Pegion, R. D. Koster, and J. T. Bacmeister, "On the Cause of the 1930s Dust Bowl," *Science* 303(2004): 1855-1859; M. Hoerling and A. Kumar, "The Perfect Ocean for Drought," *Science* 299(2003): 691-694.

28 "A multi-millennia perspective on drought and implications for the future," summary of a workshop by the World Climate Research Program's program on Climate Variability and Predictability, International Geosphere Biosphere Program's program on past global changes, and the Intergovernmental Panel on Climate Change, Tucson, Arizona, November 18-21, 2003, 10, http://www.ipcc.ch/pub/tucson.pdf.

29 E. R. Cook, C. Woodhouse, C. M. Eakin, D. M. Meko, and D. W. Stahle, "Long-Term Aridity Changes in the Western United States," *Science* 306 (2004): 1015-1018.

30 Cook and others, "Long-Term Aridity Changes," 1015.

31 T. Soussan, "Drought Focus of Summit," *Albuquerque Journal*, September 28, 2004.

32 D. McKenzie, Z. Gedalof, D. L. Peterson, and P. Mote, "Climatic Change, Wildfire, and Conservation," *Conservation Biology* 18, no. 4(2004), 890-902; D. Bachelet, R. P. Neilson, J. M. Lenihan, and R. J. Drapek, "Climate Change Effects on Vegetation Distribution and Carbon Budget in the United States," Ecosystems 4(2001): 164-185, 177.

33 C. Price and D. Rind, "The Impact of 2xCO_2 Climate on Lightning-Caused Fires," *Journal of Climate* 7(1994): 1484-1494.

34 J. Erickson, "Blame It on Global Warming, Scientists Say," Rocky Mountain News, April 20, 2005.

35 Associated Press, "Schwarzenegger Urges Global Warming Action," July 4, 2005.

36 M. D. Dettinger, "From Climate Change Spaghetti to Climate-Change Distributions for 21st Century California," *San Francisco Estuary and Watershed Science*, 3(March 2005), vol. 1, article 4, p. 6.

37 Nash and Gleick, "The Colorado River Basin and Climatic Change," ix.

38 Gleick, "Water: The Potential Consequences," 48.

39 J. O. Sewall and L. C. Sloan, "Disappearing Arctic Sea Ice Reduces Available Water in the American West," *Geophysical Research Letters* 31(2004): L06209.

40 L. Thackeray, "The New Forecast: Shorter Winters, Drier Summers Hint at Climate Change," *Billings Gazette*, April 8, 2004.

41 IPCC, *Synthesis Report; Summary for Policymakers*, 5.

42 Committee on the Science of Climate Change, Division of Earth and Life Studies, National Research Council, *Climate Change Science: An Analysis of Some Key Questions* (Washington, D.C.: National Academy Press, 2001), 3.

43 Climate Prediction Center, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Temperature and Precipitation Trends: Annual, http://www.cpc.ncep.noaa.gov/anltrend.gif.

44 N. Knowles, M. D. Dettinger, and D. R. Cayan, "Trends in Snowfall versus Rainfall for the Western United States, 1949-2004," *Journal of Climate* (2005, in review).

45 P. W. Mote, A. F. Hamlet, M. P. Clark, and D. P. Lettenmaier, "Declining Mountain Snowpack in Western North America," *Bulletin of the American Meteorological Society* 86(2005): 39-49.

46 P. W. Mote, A. F. Hamlet, M. P. Clark, and D. P. Lettenmaier, abstract of "Declining Mountain Snowpack in Western North America," *Bulletin of the American Meteorological Society* (2005), http://ams.allenpress.com/amsonline/?request=get-abstract&doi=10.1175%2FBAMS-86-1-39.

47 I. T. Stewart, D. R. Cayan, and M. D. Dettinger, "Changes in Snowmelt Runoff Timing in Western North America Under a 'Business as Usual' Climate Change Scenario," *Climatic Change* 62(2004): 217-232.

48 J. S. Littell, D. McKenzie, and D. L. Peterson, Ecological context of climate impacts on fire: Wildland fire area burned in the western U.S. 1916-2003 (presentation at MTNCLIM 2005, Pray, Montana, March 2005), www.cses.washington.edu/cig/outreach/seminarfiles/2005seminars/littell042005.ppt.

49 A. Wagner, "West Withers, Wonders about Warming," Associated Press, May 7, 2004.

50 R. Barker, "Global Warming or Not, Our Climate is Changing, *Idaho Statesman*, May 15, 2005.

51 C. W. Stockton, D. M. Meko, and W. R. Boggess, "Drought History and Reconstructions from Tree Rings" (1991), referred to in F. Gregg and D. H. Getches, "Severe, Sustained Drought in the Southwestern United States," report to the U.S Department of State, Man and Biosphere Program (1991); N. S. Christensen, A. W. Wood, N. Voison, D. P. Lettenmaier, and R. N. Palmer, "The Effects of Climate Change on the Hydrology and Water Resources of the Colorado River Basin," *Climatic Change* 62(2004): 337-363, 349-350.

52 A. Best, "Area's Water Future Looks Like 2002," *Vail Daily*, August 27, 2004.

53 Christensen and others, "Effects on the Colorado River Basin," 338; Stockton, Meko, and Boggess, "Drought History and Reconstructions from Tree Rings," referred to in D. Pontius, "Colorado River Basin Study," report to the Western Water Policy Review Advisory Commission (1997), 6, http://wwa.colorado.edu/in_focus/colorado_river/pontius%20colorado.pdf.

54 U.S. Census Bureau, "Florida, California and Texas to Dominate Future Population Growth, Census Bureau Reports," press release (April 21, 2005), http://www.census.gov/Press-Release/www/releases/archives/population/004704.html.

55 P. O'Driscoll and T. Kenworthy, "Montana's Water Problems Spilling Over into Other States," *Great Falls Tribune*, May 2, 2005.

56 T. Barnett, R. Malone, W. Pennell, D. Stammer, B. Semtner, and W. Washington, "The Effects of Climate Change on Water Resources in the West: Introduction and Overview," *Climatic Change* 62(2004): 1-11, 6.

57 Christensen and others, "Effects on the Colorado River Basin."

58 Barnett and others, "The Effects of Climate Change," 7.

59 Hayhoe and others, "Emissions Pathways, Climate Change, and Impacts on California."

60 J. T. Payne, A. W. Wood, A. F. Hamlet, R. N. Palmer, and D. P. Lettenmaier, "Mitigating the Effects of Climate Change on the Water Resources of the Columbia River, *Climatic Change* 62(2004): 233-256; Service, "As the West Goes Dry," 1124.

61 Payne and others, "Mitigating the Effects of Climate Change."

62 Barnett and others, "The Effects of Climate Change," 7.

63 N. T. Vanrheenen, A. W. Wood, R. N. Palmer and D. P. Lettenmaier, "Potential Implications of PCM Climate Change Scenarios for Sacramento-San Joaquin River Basin Hydrology and Water Resources," *Climatic Change* 62(2004): 257-281, 258.

64 Vanrheenen and others, "Potential Implications," 266-268.

65 Barnett and others, "The Effects of Climate Change," 7.

66 M. D. Dettinger, D. R. Cayan, M. K. Meyer, and A. E. Jeton, "Simulated Hydrologic Responses to Climate Variations and Change in the Merced, Carson, and American River Basins, Sierra Nevada, California, 1900-2099," *Climatic Change* 62(2004): 283-317, 307.

67 L.C. Sloan, Regional climate modeling studies for California: Future scenarios and impacts (presentation at 1st annual conference on climate change, California Climate Change Center, June 10, 2004), slides 30-31, http://www.climatechange.ca.gov/events/2004_conference/presentations/2004-06-10_SLOAN.PDF.

68 Dracup and others, *Climate Change and Water Supply Reliability*, 7.

69 T. Stein, "Water Ebbs, Worry Flows," *Denver Post*, April 4, 2004.

70 B. Berwyn, "The Big Gulp: Troubles with Lake Powell," *Summit Daily News,* July 7, 2004.

71 M. Bustillo, "Gov. Vows Attack on Global Warming," *Los Angeles Times*, June 2, 2005.

72 In 2001, U.S. emissions of carbon dioxide, the most prevalent greenhouse gas, represented 23.8% of total world emissions. Energy Information Administration, U.S. Department of Energy, "Emissions of Greenhouse Gases in the United States 2003," http://www.eia.doe.gov/oiaf/1605/ggrpt/pdf/tbl1.pdf.

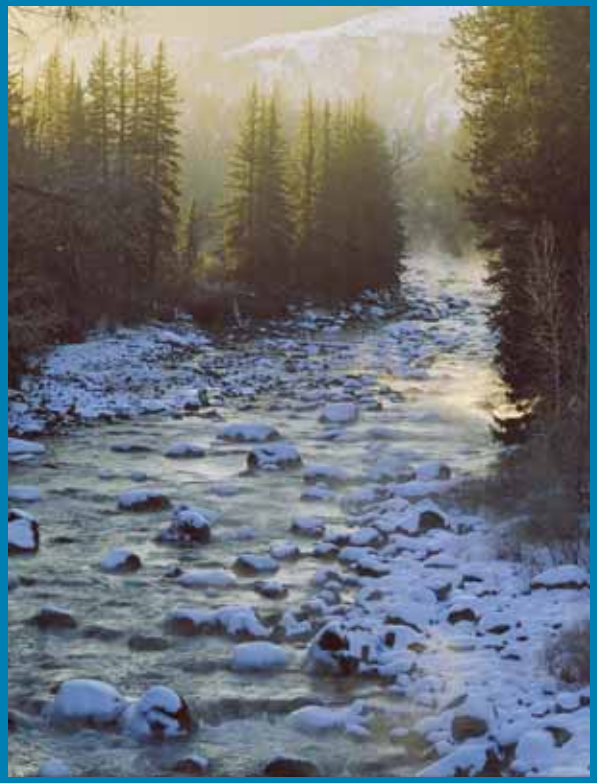
73 Office of U.S. Senator John McCain, "Senate Casts Historic Vote on McCain-Lieberman Global Warming Bill," press release, October 31, 2003, http://mccain.senate.gov/index.cfm?fuseaction=Newscenter.ViewPressRelease&Content_id=1171.

74 Office of New Mexico Governor Bill Richardson, "Climate Change and Greenhouse Gas Reduction," executive order 05-033, June 9, 2005.

75 Office of Mayor of Seattle Greg Nickles, http://seattle.gov/mayor/climate/PDF/USCM_AgreementOnly.pdf

76 B. Young, "Nickels Pushing Pro-Kyoto Resolution to Mayors," *Seattle Times*, June 9, 2005.

77 Natural Resources Department, City of Fort Collins, *Local Action Plan to Reduce Greenhouse Gases* (1999), 9-10. http://www.ci.fort-collins.co.us/airquality/lap.php.



The Rocky Mountain Climate Organization
PO Box 270444
Louisville, CO 80027
303-880-4598

Clear the Air
1200 18th Street, NW / Suite 500
Washington, DC 20036
202-887-1715