

Proceedings of the
**ROCKY MOUNTAIN/GREAT BASIN
REGIONAL CLIMATE-CHANGE
WORKSHOP**

**February 16-18, 1998
Little America Hotel
Salt Lake City, Utah**

U.S. National Assessment of
The Consequences of Climate Change



Convened By

**Frederic H. Wagner
Ecology Center
Utah State University
Logan, Utah**

**Jill Baron
Biological Resources Division
U.S. Geological Survey
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Plenary Meeting Room

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ACKNOWLEDGEMENTS, RELEASE, AND DISCLAIMER

This workshop was convened as part of the U.S. National Assessment of the Consequences of Climate Change, with oversight nationally by the U.S. Global Change Research Program and the White House Office of Science and Technology Policy. The meeting was supported financially by a grant from the U.S. Geological Survey to Utah State University.

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Workshop photographs by John Kermond, Office of Global Programs, National Oceanic and Atmospheric Administration.

COVER PHOTOS

The Loch Vale watershed in Rocky Mountain National Park is a long-term ecological research and monitoring site ranging from the Continental Divide at 4,100 m down to spruce-fir forest at 3,100 m. The research since 1983 has studied biogeochemical processes in order to differentiate natural from human-caused disturbances. A major question confronting regional climate-change assessment is the effects of warming on the snowpacks that provide water for agricultural, hydropower, industrial, and municipal uses. Photo by Jill Baron.

Curlew Valley in northwestern Utah, once a bay of glacial Lake Bonneville, has a 50-year research history on ecosystem structure and function. Fire, both lightning and human-caused, is a major disturbance altering Great Basin ecology. A question confronting climate-change assessment is what effect altered precipitation will have on fire frequencies which are rising exponentially. Photo by Fred Wagner.



Loch Vale

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Curlew Valley

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INTRODUCTION

Fred Wagner and Jill Baron

What's It About?

This report summarizes the proceedings of a workshop held during February 16-18, 1998 at the Little America Hotel in Salt Lake City, Utah to discuss the consequences of climate change on the Rocky Mountain/Great Basin region. The workshop was part of a national effort ordered by Congress in the Global Change Research Act of 1990 to assess the effects of climate change on the nation. A group of nine agencies in the Executive Branch of the government were assigned the task of carrying out the congressional charge. Such agencies as the Department of Interior, U.S. Forest Service, National Science Foundation, Environmental Protection Agency, and Department of Energy were among the nine. A member of each agency sits in the coordinating group termed the United States Global Change Research Program.

At an early date it was decided that the general public had to be fully involved in the effort if it was to be successful. It is the working people in the socio-economic sectors most likely to be affected by climate change - - farmers, ranchers, miners, ski-industry operators, energy companies, people along the sea coasts - - who can best judge how they will be affected if and when the predicted changes occur. At the same time, the scientists whose research indicates that change may be taking place can best inform the public directly rather than going through government officials.

As a result, the nation has been divided into 20 geographic regions. The assessment is being carried out by scientists in universities and public agencies in the regions who are in close contact with the people likely to be affected, the stakeholders. Thus the work is being done by people who are most likely to be familiar with the stakeholders' operations, and at the same time be able to develop rapport with and cooperation of the stakeholders.

The first step in the process was to bring together the scientists and stakeholder representatives into regional workshops. The purposes of the workshops have been to bring the two groups together in first-person exchanges. The scientists could inform the stakeholder communities of what the evidence shows about the likelihood of climate change. And the meetings would give the stakeholders the opportunity to start thinking about and inform the scientists of how the changes would affect their operations. Stakeholders nationally have been asked to think about and respond to four questions:

- (1) What are the major climate-related stresses affecting your operations at present?
- (2) How might these stresses be intensified or eased by the climate changes predicted to take place in the future?
- (3) How might you cope or adjust your operations to reduce or eliminate, or take advantage of, the predicted changes?
- (4) What additional information or research data are needed to give a better understanding of the effects, and facilitate better planning of coping strategies?

As of the last week in July, 1998, 18 of the 20 regions nationally had held their workshops.

About the Salt Lake Workshop

Fred Wagner of Utah State University and Jill Baron of the U.S. Geological Survey based at Colorado State University were asked to convene the Rocky Mountain/Great Basin (RMGB) Regional Workshop. The region (see the map in Figure 1) encompasses parts of nine western states.

Fred and Jill first contacted 18 people in nine socio-economic sectors in 5 of the 9 states and asked them to serve on a workshop steering committee. All 18 agreed to serve (see Appendix A). Steering Committee members were asked to provide names of persons in the sectors who would attend the workshop and participate in the activities.

Names were provided, and invitations were sent to approximately 300 people in the following 18 sectors:

Academia	Mining Industry
Climatologists	Native Americans
Cultivated Agriculture	Skiing Industry
Community Welfare	State Departments of Natural Resources
Public Education	U.S. Bureau of Land Management
Energy	U.S.D.A. Forest Service
Environmental Advocacy Groups	U.S. National Park Service
Livestock Industry	Water Resources
The Media	Wildlife Advocacy Groups

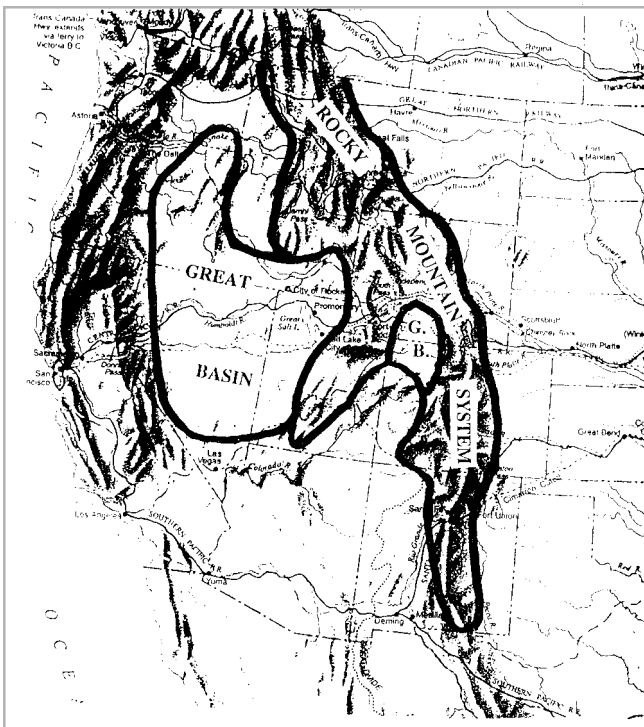


Figure 1. The Rocky Mountain/Great Basin Region.

Some 150 replied that they would come, and approximately 100 attended. The costs of the meeting were borne by a grant to Utah State University from the U.S. Geological Survey. Participants were asked to pay their own travel expenses, but costs were covered for those who could not cover the costs themselves.

We intend for this document to serve at least three purposes. First, it is a report to the 100-plus people who gave of their time and energy so willingly to participate in the Workshop, and contributed so constructively and positively. They are certainly due this accounting. The cheerful spirit of group participation was very gratifying.

Second, distribution of the proceedings document is a second, major step (the Workshop was the first) in an outreach effort to keep people in the RMGB region informed of progress in assessing the effects of climate variability and change,

and of new findings of the extensive research effort underway. An important part of that is to have the stakeholders likely to be affected thinking about how they might be influenced, positively or negatively, if the projected changes come about, and how they would cope. Forewarned is forearmed. The Proceedings will be distributed widely to the 300 people originally invited, other representatives of stakeholder groups, and local, state, and federal government officials.

Third, the information provided by the panel members and participants in the breakout sessions provide scientists who are assessing the likely effects of projected change, a better understanding of those effects. Thus, communication is a two-way process.

About the RMGB Region

The RMGB region encompasses major portions of nine, large western states. The Rocky Mountain area consists of the mountainous zone extending from northern New Mexico northwestward to western Montana and the Bitterroot Range of the eastern Idaho panhandle. The Wasatch Mountains, north-south backbone of Utah, are commonly considered part of the Rocky Mountain system. The Great Basin portion is physiographically that region between the Wasatch and the Sierra Nevada of California, encompassing primarily the western half of Utah, and all of Nevada from about 100 km north of Las Vegas northward. But southern Idaho southward from the Snake River plains, the Columbia Plateau of eastern Oregon, and a portion of southwestern Wyoming are ecologically similar and commonly included with the Great Basin ecological type.

The climate varies across this extensive region. At its northwestern extreme, the climate is a Mediterranean one with precipitation largely coming from frontal moisture occurring between fall and spring. Southeastward, the precipitation shifts increasingly toward a late-summer (July-September), monsoonal pattern and away from winter moisture. Since, except for the higher elevations, the region is semiarid, a major concern for climate change is on the effects of global warming on the region's precipitation patterns.

The topographic diversity adds further complexity to the region, and to possible climate-change effects. The region is bounded on the east and west by major Cordilleran chains rising to between 4,000 - 5,000 m at their highest points. The intervening Great Basin is dotted with lesser mountain ranges producing the Basin and Range Province of geological parlance.

In the western U.S. there is a strong correlation between elevation and annual precipitation. As a result, the mountain ranges in the RMGB region capture a disproportionate fraction of the total precipitation falling over the region. Given lower temperatures at higher elevations, montane precipitation accumulates as snow between fall and spring supporting the ski industry of particular economic importance in Colorado and Utah, but contributing in most of the other states as well. And the melt and run-off provide agricultural, municipal, industrial, and recreational water for the fast-growing populations of the lower elevations.

The importance of the montane snow accumulations is not confined to the RMGB region, however. Lying within the region are the head-waters of the Colorado, Columbia, Missouri, Rio Grande, Platte, and Arkansas Rivers with their values extending to the distant down-stream uses of these streams.

Where water, soil, topography, and climate permit, a limited amount of cultivated agriculture is possible including potatoes in southern Idaho, small grain in many areas,

and forage crops for the ubiquitous livestock industry and dairying near the cities. But over most of the region where cultivated agriculture is not possible, livestock grazing is practical as is mining of hard-rock minerals. Timber harvest is locally important in the northern Rockies.

Since most of this region is not productive by standards elsewhere in the U.S, the region was not heavily populated, homesteaded, or otherwise settled by Europeans and transferred into private ownership during its early history. Consequently, three-fourths or more remains in Public Domain. Some 85% of Nevada and two-thirds of Utah are in public ownership. There are 15 national parks, monuments, and other natural-area units of the National Park System in the region. In the Intermountain Region of the USDA Forest Service, encompassing all of Utah and Nevada, and major parts of Idaho and Wyoming, there are 16 national forests. Extensive as these holdings are, the Bureau of Land Management administers substantially more public land than either the Park Service or the Forest Service.

Similarly, the state departments of natural resources have a wide array of resource-management responsibilities in the western states for such common-property resources as wildlife and air, and especially water with its great demand and unique laws characteristic of the region. And they have substantial acreages of state lands under their jurisdictions including their own state-park systems and the School Trust Lands that typically occupy over 10 percent of the townships administered by the federal agencies.

Since all of these agencies have responsibility for managing the lands under their jurisdictions, they will be responsible for administering any land-use changes induced by climate change and mitigating any negative effects. Their actions will affect private ranchers who graze their livestock both on their own land and on public land, and as well the miners and recreationists who use the public lands. Thus the public agencies become stakeholders as surely as the entrepreneurs of the private sectors.

The possible effects of changes in precipitation patterns are complex and likely to result from changes both in variability and in amount, and from interaction with temperature change. Globally, precipitation is more variable in a relative sense in arid areas than in the other climatic types. Hence land uses depending on precipitation already cope with extreme variation, and any increased variability could create further difficulties for the ski industry, ranchers, and farmers.

Variations in precipitation also interact with fire in the region, the drier years making higher-elevation forested areas more fire prone; and the wet years increasing fire frequencies in arid, low-elevation zones. Fire is perhaps the major factor altering the shrub-steppe type of the Great Basin, removing the native vegetation, and converting it to monotypes of exotic annuals. The result is drastic reduction in biodiversity and usefulness to livestock and wildlife.

One climate-change scenario projects long-term increase in summer moisture in the Great Basin as a result of climate change. This would tend to increase the perennial grass component of the shrub-steppe. But if the vegetation has been converted by fire, it is extremely difficult for the native perennial grasses to succeed the exotic annuals.

The RMGB region has the fastest growing human population in the country which increases demands on already over-subscribed water resources. Currently, between two-thirds and three-fourths of the water use is agricultural. Most of the region's water is

heavily subsidized. If subsidies were removed, as some advocate, and water prices were set by the free market, some of agriculture would not be able to compete and water would be released to other sectors in the region's economy in the short term. But if climate change also increased precipitation in the region, as it is predicted to do globally, this could ease competition and perhaps lower costs.

Economic realities of the region are declining income from the resource-extractive economies (mining, ranching, timber) and increasing importance of tourism, investment income, retirement income, services, and small industries. These changes also alter the character of demand for water, and the relative economic significance of the climate-change effects on natural-resource-based economic sectors.

PROCEEDINGS OF THE WORKSHOP

PLENARY SESSION:
Introductions and Panel
of
Resource-Based Stakeholders

Monday Morning, February 16, 1998

Fred Wagner, Chair



Panel of Resource-based Stakeholders

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WELCOME AND INTRODUCTION

*Ted Stewart, Director
Utah Department of Natural Resources
Salt Lake City, Utah*

[Editorial Note: Ted welcomed the group, complimented it on an excellent example of public service in which scientists and members of non-science sectors in society meet together to exchange knowledge and understanding on how to address a potentially important problem that could affect all of society. Ted indicated that he felt the reality of climate change has yet to be demonstrated, and itemized a number of predictions that have been made through history that failed to eventuate. But he welcomed the group to Salt Lake City and wished it success in its deliberations.]



Nancy Maynard

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INTRODUCTION TO NATIONAL ASSESSMENT

*Nancy Maynard, Acting Director of Science Division
Office of Earth Science
National Aeronautics and Space Administration
Washington, D.C.*

[Editorial Note: Dr. Robert Corell, Director of the U.S. Global Change Research Program and Assistant Director for Geosciences at the National Science Foundation was scheduled to describe the National Assessment to the Workshop. But because of illness, he was not able to come and Dr. Maynard provided the description. On short notice she did not have time to provide a written version of her comments. But most of those comments are encapsulated in the "Background" section (p. 2) of the Climate Change/State of Knowledge publication sent to all participants in the Workshop. That section is reproduced below.]

During the 1980s, scientific evidence about global climate change and its consequences led to a growing concern among scientists, policy makers, and the public. In 1988, the United Nations Environmental Programme (UNEP) and the World Meteorological Organization (WMO) jointly established the Intergovernmental Panel on Climate Change (IPCC). Through the IPCC process, scientists representing more than 150 countries have assessed the available information on climate change and its environmental and economic effects and have provided the scientific understanding needed to help formulate appropriate responses. A series of IPCC reports, incorporating extensive peer review and a commitment to scientific excellence, have provided the most authoritative and comprehensive information available on the science of climate change. In 1996, the IPCC published its Second Assessment Report, which summarizes the most recent information on climate change science and the vulnerability of natural and socioeconomic systems.

In 1990, the United Nations (UN) General Assembly established the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change (FCCC). The FCCC was adopted in 1992, and over 160 signatories have now become parties to the agreement. The agreement was signed by the President of the U.S. and ratified by the U.S. Senate in 1992. The ultimate aim of the FCCC is to stabilize greenhouse gas concentrations "at a level that would prevent dangerous anthropogenic interference with the climate system." This stabilization should be achieved within a time frame that (1) allows ecosystems to adapt naturally to climate change, (2) ensures that food production is not threatened, and (3) enables sustainable economic development to proceed. In the United States, climate change research is overseen by the U.S. Global Change Research Program (USGCRP), which was established in 1989. Since its inception, the USGCRP has strengthened research on key scientific issues and has fostered improved understanding of Earth processes. New directions for the USGCRP include identifying and analyzing regional vulnerabilities to climate variability and climate change. The results of the research it supports have played an important role in the work of the IPCC and other national and international bodies.

MEETING PURPOSE AND CLIMATE-CHANGE OVERVIEW

*Frederic H. Wagner, Director
Ecology Center
Utah State University
Logan, Utah*

As Jill Baron and I organized this workshop, it became clear that there is a fair amount of skepticism about the reality of climate change. That skepticism ranges from “agnosticism” (one Utah rancher) to outspoken denial (one coal-company executive). Moreover, the scientific jargon gets opaque at times. One Workshop attendee commented “You scientists have to learn to speak in language that we nonscientists can understand.” Another did not understand the purpose of the meeting and therefore questioned its organization. Much of this was based on misunderstanding and in some cases inadequate knowledge about the subject. So it seemed worth devoting some space at this point in the program to try to get us all on the same page, and to try to make sure that people’s opinions are well informed.

First, it is important to make a clear distinction between two aspects of this issue:

- (1) Is the climate changing, and if so is it due to human activities?
- (2) If so, what, if anything, should be done about it?

The first is a scientific question of fact and evidence. Subject to the ability of our technology to measure, it is what we can establish as fact. The second is a value and policy question: Should there be action, given all the ways all the components of society would and would not be affected by no action or a range of action alternatives. The answer is a socio-economic and political one.

The Global Change Research Act directs a scientific effort. It does not direct any action on the policy aspects. Thus the major concern of the National Assessment, and the Salt Lake City workshop, is the scientific factual questions. Is the climate changing? How would such change, if it is occurring, affect the stakeholder groups? How might they adjust their operations to mitigate, or take advantage of, the effects?

Please also note that this is not an organized effort in environmental advocacy. If evidence tells us that changes are taking place, that those changes may be the result of human actions, and that the changes may continue to the point of having serious repercussions for the people living on this globe, we would be derelict in our responsibilities as public servants, and violating our professional ethics, if we did not inform the public of what may lie ahead. We then leave it to the political systems to decide if something should be done about it, and if so, what?

Climate-change research is an international effort. Climatologists in Australia’s Commonwealth Scientific and Industrial Research Organization, in the Max Planck Institute in Germany, in the United Kingdom, and in the Climate Modelling group in Canada are all working intensively to get at the answers we need on this subject. In the United States, some of the nation’s top climatologists and atmospheric physicists at the National Center for Atmospheric Research in Boulder, Colorado are working as intensively as their international colleagues.

So rest assured that a large number of the world's top scientists are sufficiently persuaded that significant changes may be underway that they are willing to commit their time and effort to the problem. People are welcome to question the science, but they need to know that when they do so they are challenging some of the top atmospheric physicists, climatologists, and oceanographers in the world.

Given that the assessment is primarily an effort in science and communication with publics likely to be affected, we need to make clear distinctions between three aspects of the science:

- (1) What do we know to be valid on the basis of measurements and facts that we have observed?
- (2) What is the basis for inferring that there is cause and effect between temperature trends and trends in the amount of greenhouse gases in the atmosphere?
- (3) What are the predictions of climate changes in the future and what are they based on?

What Do We Know?

Physicists have studied the characteristics of carbon dioxide (CO₂) in the air we breathe. The science has learned that CO₂ functions like glass in terms of what energy it allows to pass through it. Short wavelengths like light can pass through both glass and CO₂ easily. They are transparent to light. But most of the long wavelengths of energy, like heat (also called infrared), cannot pass through readily. Glass and CO₂ are mostly opaque to heat.

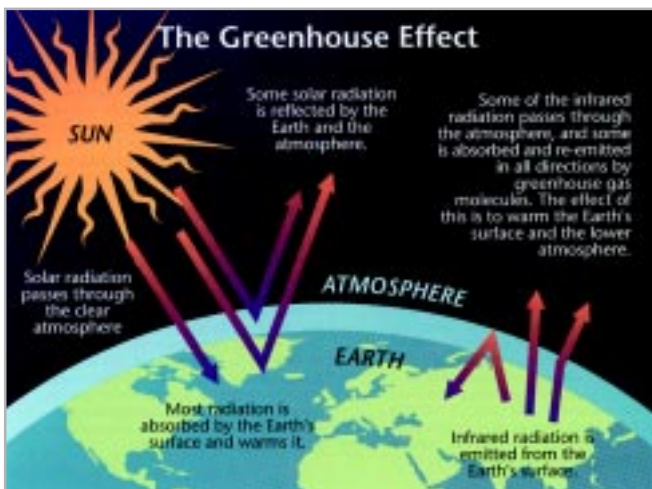


Figure 2. Schematic representation of the heat budget of the earth.

This is why your car heats up when the windows are shut on a July day. Sunlight comes in through the glass and is converted to heat when it strikes the objects in the car. That heat is then trapped inside by the glass, and the temperature rises.

In order to understand how CO₂ in the atmosphere affects the earth's climate, we need to look at the heat budget of the earth. This is shown in the schematic in Figure 2 below. Nearly all of the energy needed to drive physical processes on the earth (like weather, erosion, ocean currents) and biological processes (like plant and animal life, growth, reproduction, and movement) comes from

the sun. The only exceptions are the energy coming from the earth's molten center that is released through volcanoes and geysers, and the energy in radio-active materials like uranium. So in order to understand the earth's heat budget, we need to know about the arrival of solar energy and where it goes after arrival.

As light energy comes in from the sun, three things happen to it. Some is reflected by the atmosphere back into space. Some passes through the atmosphere, hits the earth's surface, and is reflected back into space. But some is absorbed by the earth, is converted to heat, and warms our globe.

The earth, like any object with heat, radiates its heat away from itself. Some gets through the atmosphere and is radiated into space because the CO₂ is not totally opaque to heat. But some is absorbed by the atmosphere which also radiates what it absorbs. Some of this goes out to space, but some is radiated back to the earth's surface and has a further warming effect.

The CO₂ in the atmosphere has a powerful influence in all of this, far out of proportion to the amount of it in the air we breathe. In recent years, CO₂ has made up only about 3.5/100 of 1 percent of the atmosphere (or about 350 parts per million, that is 350 ppm). Yet atmospheric physicists calculate that the greenhouse effect of that tiny amount of CO₂ warms the earth 60°F above what the earth's temperature would be without it. Without that influence, our earth would be uninhabitable to life as we know it.

It is this powerful influence on the earth's climate of a very small component of the atmosphere that has raised physicist's concerns about climate effects. CO₂ is released into the atmosphere by the respiration of all living organisms, plants and animals. Bacteria which decompose all dead plant and animal material—leaves, grass, logs, garbage, dead animals—release CO₂. And the burning of any organic substance—wood, paper, forest fires, fossil fuel—releases CO₂.

CO₂ is taken out of the atmosphere by plant photosynthesis that produces the growth of trees, grass, flowers, shrubs, agricultural crops, and yes the tiny algal cells in the ocean. The ocean covers about three-fourths of the earth's surface. So the amount of CO₂ in the atmosphere results from the balance between those things that add it to the atmosphere, and those forces that remove it. Evidence to be described below indicates that the CO₂ content of the air has been roughly stable, subject to minor, short-term ups and downs, over the last 100,000 years until just about the last 150. That means that for 100,000 years the CO₂ produced by decomposition of dead material, respiration of plants and animals, and burning of all substances was just about equaled by the CO₂ uptake through photosynthesis and growth of the world's vegetation.

In 1957, astronomers in the observatory on top of Mauna Loa in Hawaii began measuring CO₂ content of the atmosphere twice a year. Within a very few years it became obvious from these measurements that CO₂ in the atmosphere was rising sharply (see Figure 3). At the same time, scientists knew that the world population was growing and the globe was becoming more industrialized. The world's Industrial Revolution began about 150 years ago, and it has been powered by mining and burning huge amounts of coal, oil, and natural gas. Over

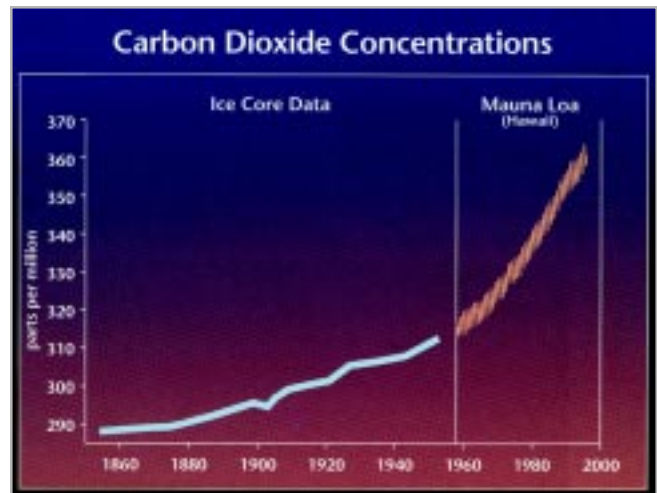


Figure 3. Since the beginning of the Industrial Revolution in the middle of the 19th century, the concentration of carbon dioxide in the atmosphere has steadily increased. Beginning in 1957, regular measurements of atmospheric CO₂ concentrations have been made by scientists at an observatory on Mauna Loa, Hawaii. The seasonal cycle of vegetation in northern latitudes "inhales" and absorbs CO₂ in spring, and each autumn most of it is released back into the atmosphere. But these seasonal cycles are lesser variations on an exponentially rising CO₂ curve over the last 150 years.

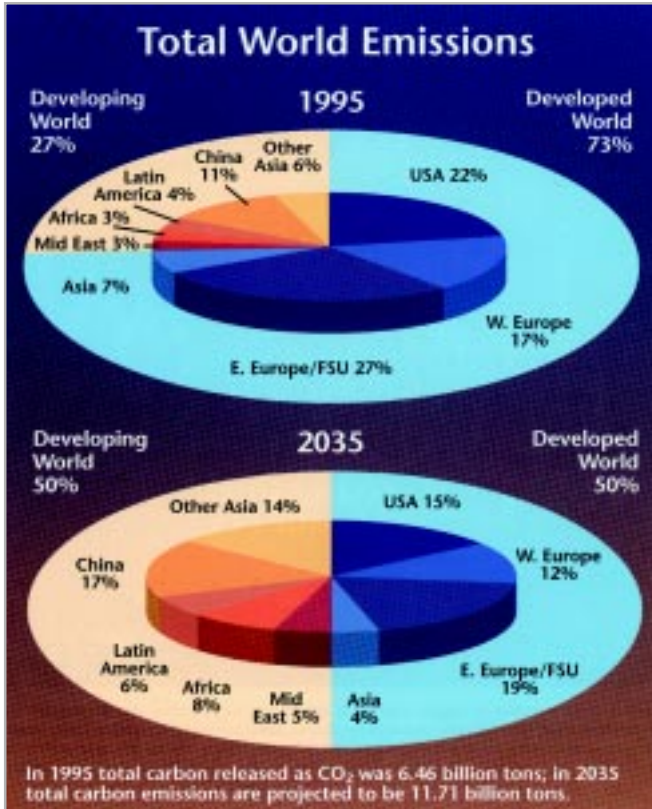


Figure 4. In 1995, the industrialized nations of the world contributed nearly 75% of the global emissions of CO₂, with the U.S. being the largest emitter. By 2035, developing nations will catch up and contribute half of the global emissions, with China becoming the largest, single emitting country. Rapid population growth, industrialization, and increasing consumption per person in the developing world will contribute to this shift.



Figure 5. The global average temperature has risen by approximately 1°F over the last century.

the same period, the world's human population has increased 8- to 10-fold which has vastly increased the demand for wood, paper, heat and power, and other resources, all of which release CO₂ in their production and use (see Figure 4).

And, perhaps confirming expectations, climatologists have been analyzing weather records and showing that the earth's temperature has risen about 1°F, on average, over the past 140 years (see Figure 5). Temperature increases have now been measured on every continent of our globe. A number of things were coming together to form a consistent picture. Was there really cause and effect?

What is the Basis for Inferring Cause and Effect?

Everything just described under "What Do We Know" is fact based on our experiments in physics, our measurement of CO₂ content in the air, and temperature recordings at thousands of weather stations over the earth. And we measure CO₂ emissions into the atmosphere, and from what sources. The CO₂ content has risen over the past 140 years, and the global temperature has increased over the past 140 years. The next question is whether the CO₂ rise has caused the temperature rise. Is there cause and effect? Five lines of evidence make us think there is.

First the correlation between CO₂ and temperature rise. One could say with appropriate skepticism that the rise in global temperature and CO₂ content of the atmosphere over the last century is a chance correlation. The fact that the two rose at the same time doesn't necessarily mean that the one caused the other. Maybe it was coincidence that a temperature rise due to geophysical processes just happened to occur at the same time as the CO₂ increase.

But geophysicists have measured the CO₂ content of the atmosphere as far back as

160,000 years by analyzing the composition of air in bubbles trapped and encased in the Antarctic ice sheet. They can determine the ages of the bubbles by the ratios of two carbon isotopes. The carbon in the atmospheric CO₂ consists of more than one isotope, and over time these break down to atoms of lower atomic weight at a known rate. By measuring the ratios of the heavier to lighter atoms in the bubbles, it is possible to determine their ages. The earth's temperature at points in the past can also be interpreted from the ice cores.

With this information, the CO₂ content of the atmosphere and the earth's temperature can be correlated over a 160,000 year period, and there is a close relationship (see Figure 6). One can be skeptical about cause and effect with a hundred-year correlation. But it is asking a lot of chance to suggest that two phenomena could fluctuate together over 160,000 years by pure chance without there being cause and effect.

A second line of evidence indicating causality is the fact that night-time temperatures have increased faster over the last hundred years than daytime temperatures. I have measured this by analyzing the Salt Lake City weather record, and Figure 7 shows this same effect demonstrated by climatologists in Canada. I have shown one indication that this is not due to a city heat-island effect (resulting from furnaces and heating plants warming the areas around cities) by showing that the differential rise of night-time temperatures is more pronounced in summer than in winter.

Why have the night-time temperatures risen more over the last 100 years than the day-time temperatures, and what does this tell us about the CO₂ greenhouse effect? Remember from the earth's heat budget (Figure 2) that three processes are affecting the earth's temperature during the day: The earth (1) gains heat from incoming solar radiation; (2) loses some by

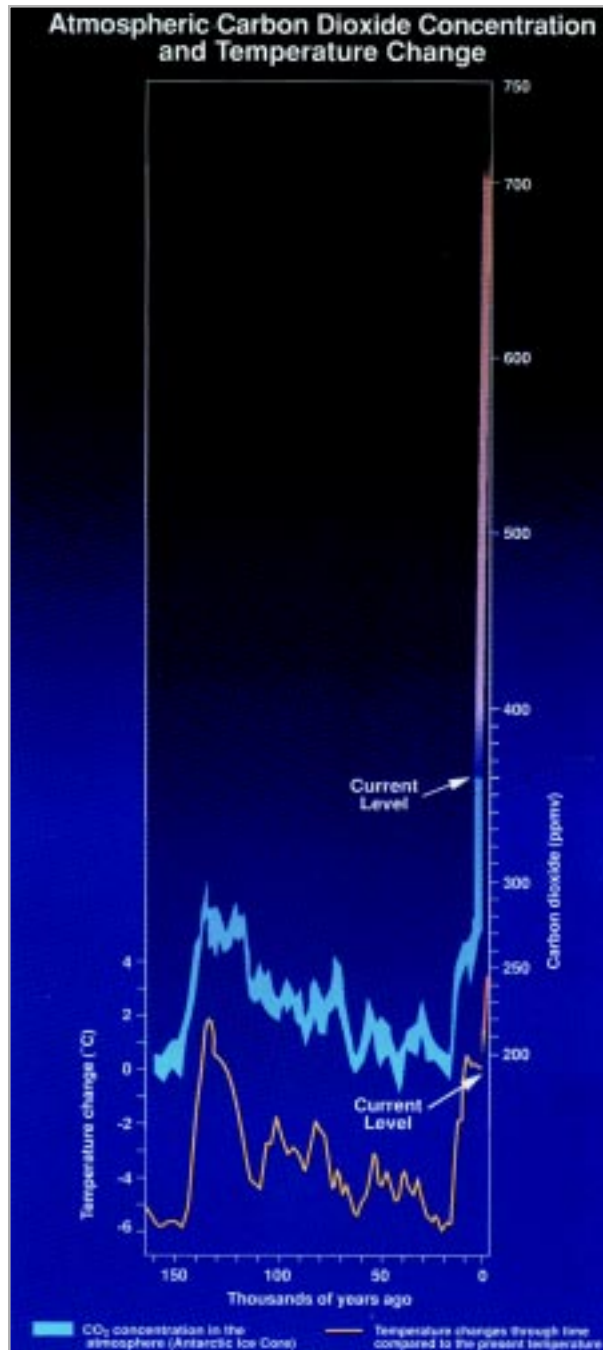


Figure 6. The CO₂ level of the earth's atmosphere has increased, since the beginning of the Industrial Revolution, beyond the bounds of natural variation seen in the climate record of the last 160,000 years. Continued increase at current levels will raise concentrations to over 700 ppm by 2100, a level not experienced by the earth since about 50 million years ago.

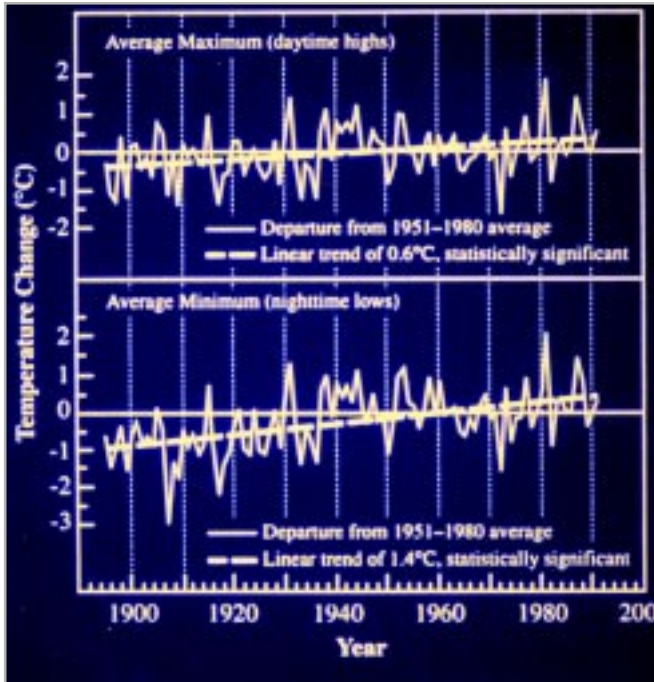


Figure 7. Hundred-year annual averages of Canadian daytime maximum and nighttime minimum temperatures analyzed by the Canadian Climate Modelling Group. The trends in both maxima and minima are statistically significant, with the nighttime minima rising more than twice as much as the daytime maxima.

radiating heat back into space; and (3) regains heat by greenhouse-gas entrapment of some of the earth's heat being radiated into space. (All the emphasis so far has been on CO₂, but there are other, scarcer gases like methane and nitrous oxide that play a lesser role.) The net effect is to raise the earth's temperature during the day.

But at night, as a given side of the earth turns away from the sun, only two of the processes are working: The earth's radiation back into space and the greenhouse effect. Thus the latter plays a proportionately greater role in the nighttime heat budget. And while the net effect on the earth's temperature on any given date is to lose heat and decline at night, the gradual increase in greenhouse gases over time increases night-time temperatures more than day-time.

A third reason why scientists believe there is cause and effect between the CO₂ rise and global temperature rise is that the physics of the CO₂ greenhouse effect has been demonstrated experimentally in the

laboratory. Given that, it would be surprising if the CO₂ increase didn't have an effect on temperatures. No counterforce is known that negates the physical process itself. This does not mean that there are not other factors that affect the earth's temperature. Cloud cover and particulate matter in the atmosphere are examples of things that do. But the latter do not alter the physics of the greenhouse effect. They merely work in the opposite direction, and so far do not appear to have overridden it, as the temperature rise implies.

Fourth, climatologists build computer models out of data on physical processes known to affect global climate: solar energy, wind currents, influences of the oceans, cloud cover, particulate matter, CO₂ effect, etc. These models can then be run on the computer by starting them out ("initializing them") with the temperatures of 150 years ago, and feeding in the measured CO₂ increase that has occurred up to the present (Figure 3). The output from those models (general circulation models, or GCMs) simulates the actual, global temperature trends measured at weather stations quite well. This is called "validating" the models, and it gives some confidence that climatologists have at least a rough understanding of the physical processes driving the global climate, and therefore have some basis for their predictions.

Fifth, and finally, the computer models predict that the world temperatures will rise more sharply toward the poles than toward the equator. Alaskan temperatures have already increased as much as 4°F while the global average has risen 1°F. Alaskan permafrost is starting to thaw (and note that highways and supports for the Alaska pipeline are built on permafrost), and shelf ice along the coast is starting to narrow. Also, large portions of the Antarctic Ice Sheet are beginning to slough off into the ocean. These changes also give confidence in the climatologists' predictions.

In total, there are a number of reasons to infer that the correlation between CO₂ rise and long-term temperature increase is cause and effect. It is not a certainty, and there are scientists who question the connection. But contrary to the general impression among nonscientists, science does not give certainty, only levels of probability. And there is always disagreement among scientists on complex questions.

The important point is that a sufficient majority of the worldwide scientific community considers it a strong enough probability that the CO₂ and temperature increases are causally related that the countries of the world are considering protective action and accelerated research. And the U.S. Congress mandated a national assessment of the potential effects.

What are the Predictions?

Subject to the accuracy of our measurements, we know with reasonable certainty the increase in CO₂ and the global temperature rise, and there are reasonable grounds for judging cause and effect between the two, as just described. The greatest uncertainty is in the predictions for the future. At present emission rates, atmospheric CO₂ is increasing at 1% a year. If it continues at this rate, the CO₂ content of the air will double by the year 2070 (see Figure 6).

The CO₂ content now is higher than it's been in the last 160,000 years (Figure 6). At twice the present amount it will be off the chart. The climatologists' computer models predict that at this CO₂ level, the global average temperature will rise 1.5-4.5°C, or 3-8°F. As mentioned above, the temperature rise will be more pronounced at high latitudes than toward the equator.

The warmer air will absorb more moisture off the oceans, put more water into the global hydrologic cycle, and increase global rainfall. The increase is predicted to be about 2% per degree centigrade rise in temperature. That would imply about a 3-9% increase in global precipitation by the year 2070. There is a suggestion from the world weather records that this increase has begun on some of the continents. The increase will not be uniform over the globe, with some regions within the continents getting more precipitation, and others getting less.

All of this is based on current CO₂ emission rates. As the developing countries of the world increase their standards of living and industrial capabilities, and as the world population increases (at present growth rates, the world population doubles each 40-50 years), the emission rates could increase and the above projections could be conservative.

Predicting what the climate changes will be for the Rocky Mountains and Great Basin is more uncertain than making the global predictions. It involves scaling the global computer models down to the regional level, and this is a more complex problem than the global modelling effort. Particularly in our region, we have the complex mountain-lowland topography and the elevation-snowpack complication. And at the regional scale, precipitation is importantly determined by the positioning of the storm tracks, the regional movement of air masses, and how these might be affected by the global changes.

The people working most intensively on this problem are the climatologists and computer specialists at the National Center for Atmospheric Research at Boulder, Colorado, and similar experts at the Canadian Center for Climate Modelling at Victoria, British Columbia. These people are working intensively on these problems. They are complex and take major amounts of time on large computers. Our understanding now is very preliminary. We will know the answers much better in another 5 years or so.

But subject to all these uncertainties, the following are the highly provisional indications for our region at this point in time. With a 2x increase in CO₂, average winter temperatures in our region are projected to increase up to 7°F, summer temperatures up to 4°F. In general, the pattern could be warmer, wetter winters and hotter, dryer summers. Some reduction of mountain snow packs are a possibility. This would at least include higher elevations for the bottoms of the snow mantles, later formation in the fall, earlier runoff in the spring. These changes are predicted to result in part from projected greater temperature rise at high elevations than at low.

In closing I want to repeat that these forecasts are all provisional. They are based on the science, although it is preliminary. But that basis, and the level of probability that these changes may occur, is considered by the organizers of the National Assessment to be sufficient reason to start thinking about what the effects might be if and when they become reality, and to ask people to start considering how they would cope if it happens. No one is advocating any changes at this point, but we need to be informed. The potential effects could be so great that the issue should be raised.

PANEL: RESOURCE-BASED STAKEHOLDERS

The major portion of the Workshop program began with a panel of individuals representing socio-economic sectors in the region likely to be affected directly by climate change. They were asked to address four questions:

- (1) What are the major climate-related stresses affecting your operations at present?
- (2) How would those stresses be intensified or eased by each of the following climate-change scenarios:
 - (a) No change from the present climate.
 - (b) Increase in average winter temperature of 7°F and average summer temperature of 4°F, no change in precipitation.
 - (c) Same temperature increases, 15% decrease in winter precipitation, 15% increase in summer precipitation.
 - (d) Same temperature increases, 15% increase in winter precipitation, 15% decrease in summer precipitation.
- (3) How might you alter your operations to cope with the effects of these changes?
- (4) What additional information do you need to be able to predict more confidently the effects of climate change on your operations and effective coping measures?

The comments of the panelists follow.



Panel of Resource-based Stakeholders

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Robert Gerard

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CULTIVATED AGRICULTURE

*Robert Gerard, Market Gardener
Mirasol Farm
Chaparral, New Mexico*

Mirasol Farm is a small truck farm specializing in tomatoes, garlic, and other market vegetables. It is located in southern New Mexico on the border with Texas and Mexico. It lies at 4,000 feet altitude with weather that is distinguished by torrid summers, mild falls and winters, and windy springs. The date of the average last freeze of spring is April 11 and that of the first of fall is October 15, but unexpected freezes are not uncommon. Weather at Mirasol farm is often tricky with large extremes of temperature from day to day and sometimes from hour to hour. Violent weather, especially storms with hail, hard rains, and destructive winds, are often a concern. Water is by drip irrigation so there is not much dependence on rainfall.

At Mirasol farm, I aim for spring tomato production in May or fall production for late August, September, and October. These windows of production lead to good fruit set, made possible by temperatures that don't exceed 92°F daytime temperature or 75°F during the night. Of the spring or the fall production times, the better is the fall. It is better because the tomatoes have about two months of good weather in which to bear fruit before frost. The spring production time is a much shorter period of good tomato-producing weather and timing has to be very good: avoiding a late frost in April and getting the fruit set before the wilting heat of June.

Following is a listing of weather-related effects on the plants grown at Mirasol farm:

1990 A hail storm completely wiped out the tomatoes.

1992,1998 I had good garlic due to several winter snows.

1993 A good tomato harvest due to mild days and cool nights among other factors.

1995 A cool dry spring caused the appearance of curly-top virus which is transmitted by a leaf hopper that usually feeds on range plants. In this particular spring, range greenery was hard to find for the little insects so they moved into the vegetables. In our area, all farmers lost some, and some farmers lost all. I lost most of the vegetables that were planted in April and May. I replaced the diseased plants and had several large plantings in June and July to offset my losses. After May the leafhoppers moved off and I had a good rest of the year. The larger farmers as a group chose not to replant. Curly-top virus may be a problem in 1998 with the cool dry spring we're having.

1996 A hail storm skimmed the edge of our land, not destroying the plants completely but shredding leaves. The vegetables never recovered completely and vegetable quality was poor.

1997 The tomatoes set fruit poorly in August. Although the days were quite mild, the humidity was high and the nights did not cool off sufficiently.

In general the weather that I would put on my wish list is one where summers are mild and dry, and winters are cold and wet. If the prognostications for warmer weather in the summer in the next century are correct it would force me to produce tomatoes even earlier in the spring and later in the fall. This would be all right as long as the dates of

the first and last freezes shifted accordingly, giving me time to produce after frost in the spring and before one in the fall. Certainly warmer weather would lead to greater problems with pests. Heat combined with high humidity, would cause diseases to become rampant and weeds more difficult to control. It would also lead to faster organic-matter “burn off,” making it necessary to put more attention to organic-matter management.

The possibility of cooler summers than usual would mean that the tomatoes could be pushed to produce in the usually “too hot” months of June, July, and August. Milder summer temperatures would not necessarily cause greater pest problems but would, especially when combined with high humidity, change the types of pests that I have to combat. Less summer heat would also decrease the rate of organic-matter decomposition which signifies that I would spend less time maintaining organic matter and more on other endeavors. In addition, plants would also not have to be irrigated as often because their water demands would be decreased.

“Winter is a good pesticide” in that it kills off a lot of the pests or at least delays their appearance in the spring. If winter got warmer, a situation would be created where pests would have to be combated earlier in the spring and more vigorously for the rest of the growing season. High humidity added to a warm winter would only intensify pest problems.

A warm winter would certainly hurt my garlic production because this fall-planted, spring-harvested crop needs a cold, wet winter to bulb properly. I assume that mild winter weather might make it feasible to produce cool-season crops such as lettuce and broccoli later into the season.

Extremes of temperature and climate are important in any operation. Since my tomatoes are on drip irrigation, their roots grow in a soil with a limited sphere of moisture. If a sudden rainfall hits them when their fruit are ripening, they will have a burst of growth and mature fruit will crack. Extremes are also important in the context that warm days are great for production but nights need to cool off to give plants a rest.

I believe that forecasts could have saved me at several times on our farm. If there had been a warning that hail was approaching, I could have saved my crop by covering them with plastic sheets. I realize that this is very specific to my small operation and would not be possible on a larger scale. Also as to curly-top virus, I believe it would have been beneficial to me if there were a better understanding of the problem, warnings, and more prediction. As I’ve stated, in 1995, I planted after the curly top passed. With a prediction, I could have placed less emphasis on the vulnerable early plantings in advance and aimed for those later in the season.

Predictions would help me out but then they walk hand in hand with extension and information dispersal. Could there be a better way to get this information out? I believe that regional papers and newscasts have a responsibility to carry this kind of information. Newsletters such as “The Farm Connection” are crucial to small farmers because they are a vehicle whereby farmers can write in and extend their observations and results of “on farm” research to other farmers. As well as different farming methods being introduced, information focused on weather could give a farmer an idea of what, when, how, where to plant, and what to expect.

In general farming is in a vulnerable state in this country. Market forces, such as high equipment costs, gasoline, low prices of the product, and foreign competition, have put

farmers in a bind. High technology with its high price is not feasible for many farmers when the price of their product is so low. Add to that the weather and other natural risks of farming and times can become very hard. Cost-saving measures, such as no or low till, have a place in American research and extension.

To survive the climate changes of the future, American farms need to exchange rigidity for resiliency, flexibility, and diversity. As has been said, “the battle goes to the most nimble.” Other possible measures to help farmers include:

- (1) Breeding of more well-adapted plants (not necessarily hybrids) or the use of those naturally better adapted to the climate and conditions of the area.
- (2) More research and extension of sustainable agricultural practices.
- (3) More research into making farming cheaper. Practices such as no-till or low till, for example, save gas, time, and prevent erosion.
- (4) Reduce the use of pesticides and man-made fertilizers. Practices such as rotations and intercropping with soil-building crops can control pests and maintain soil fertility.
- (5) Consumer education on food, where it comes from, and how it is produced.
- (6) Support of farming through laws to protect land and water rights, “right to farm” laws, and financial incentives.
- (7) Development of good communication avenues between scientists and farmers.

Robert Gerard received an M.S. in Horticulture from New Mexico State University in 1981. From 1981-1985 he worked as an Agricultural Extension Agent in Latin America. From 1985-1988 he held a position as a Greenhouse Researcher at Laval University in Quebec City. Since 1988 he has been working as a Market Gardener on his farm in Chaparral, New Mexico. He is the author of “Gardening the Arid Land” (see Other Reading below).

Sources

“The Farm Connection,” P.O. Box 477, Dixon, NM 87527 (505) 579-4386
Robert Gerard, 441 Paseo Real, Chaparral, NM 88021 (505) 824-0697

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Deloyd Saterthwaite

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LIVESTOCK INDUSTRY

*Deloyd Saterthwaite, Owner-operator
Ellison Ranching Company
Tuscarora, Nevada*

I've been asked to speak today on our ranching operation and how current climatic patterns affect, or could affect, our operation. Located in northeastern Nevada, our cattle and sheep ranges rely heavily on the public lands. Cattle are at 77% public land and our sheep operation is at 100%. One of the most important factors that we deal with is weather conditions, trying to predict the future and sometimes trying to survive the past.

Weather patterns and land-management agencies seem to want to work hand in hand, maybe rightfully so. When the grazing lands are, say, "dry," or in a drought condition, they use that reasoning for the "dear John letter" that asks a permittee to remove his livestock from the public lands. Where do you go with 10,000 sheep? On the other hand, when conditions are great, lots of feed and water, very seldom do you ever get to exceed your stocking preference.

When spring is just around the corner, just a few days variation in range readiness can make a tremendous difference. Cattle that have been on hay all winter are getting ready to go onto summer range at certain dates, and if that date is delayed because of unpredictable weather condition it changes your entire winter-feeding program. Since all years are different, we have learned through experience to build in some flexibility to compensate for Mother Nature.

The worst scenario would be early spring storms coming in March and April. This affects the amount of hay that must be fed that was not planned on, the delay in spring grass starting to grow, and the deadly effects it has on new-born animals. This also creates more livestock stress, added disease, and as mentioned, calf and lamb mortality.

Our area has an average rainfall of about 12" with a high of 22" and a low of 7", and out of the years on record more than half of the years fall below the average. A few high precipitation years create a high average. One reason why Nevada is a sagebrush state is due to the fact that the majority of our moisture comes in the winter. This gives snow storage for later run-off and creates an ideal condition for the starting of spring forage.

Therefore, summer precipitation has very little effect on forage production. Summer to me is June, July, and August and our precipitation during these months is 1.3 inches. So if we look at a 15% precipitation increase (15% of 1.3), it almost means nothing at this point in time. All it really does is get your hay crop wet.

More beneficial to our operation would be the 15% increase in winter precipitation. This would result in almost 1" more moisture, coming at a time when it would result in more late spring run-off. The land uses that we have depend solely upon precipitation and even now we are coping with extreme conditions. We keep planning on the average year, but we are to the point now that we can't define average.

If I had the ability to receive the weather I asked for, chances are I still wouldn't be happy or satisfied. It seems that what is good for one aspect of our business is harmful to another aspect of the ranching industry, but I have always been taught that in Nevada you take precipitation any time you get it and be thankful for it.

In conclusion we in the ranching business try to cope and adapt to any situation. It would be ideal if sometime in the near future we could have a more realistic idea of what weather patterns are coming on any given year. Hopefully, we're at the beginning of being able to at least predict what might be going to happen.

Thank you!

[Editorial note: Mr. Saterthwaite is President of the Nevada Cattlemen's Association.]

SKIING INDUSTRY

*Ted Seeholzer, Owner-operator
Beaver Mountain Ski Area
Logan, Utah*

[Mr. Seeholzer became ill just before the Workshop and was not able to attend. Without any advanced notice, Rick Colling, operator of the Snowy Range Ski Area near Laramie, Wyoming volunteered to participate in the panel and discuss his operations.

While expressing regrets over not being able to participate in the Workshop, Mr. Seeholzer offered the following observations about the possible effects of climate change on his operations.]

At about 7,000 ft. at the base and about 9,000 ft. at the top, Beaver Mountain Ski Area is at a somewhat lower elevation (e.g. about 1,000 ft.) than most of the large ski areas in Utah and Colorado. It is the lower-elevation areas that would be at the greatest risk from rising temperatures.

Beaver Mountain needs about a 100-105 day ski season to operate profitably. A typical profit margin is about 6.5-7.0%, and a 2° temperature increase could reduce his revenue by 20%.

Snow making would not appear to be the answer because it takes cold temperatures (e.g. in the teens) to make high-quality snow (i.e. 4-6% water).

Seeholzer commented that Utah skiers, accustomed to the light, low-moisture Utah snow ("Utah powder") will not ski on the kind of snow that eastern skiers frequent. He stated that skiers this year have been complaining about the quality of the snow.



Terry O'Connor

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MINING/ENERGY

*Terry O'Connor
Vice President for External Affairs
Arco Coal Company
Denver, Colorado*

As the global climate-change debate continues to mount, both in the United States and through various United Nations' organized groups, it is becoming increasingly apparent that the fossil-fuel industry in general, and the coal industry in particular, has become the targeted industry which would be dramatically and adversely impacted, depending upon the specific direction which the public-policy debate takes. Why is this so?

Coal represents the most carbon-intensive of all the fossil fuels - approximately 28% greater than oil, 79% greater than natural gas, and of course much higher in carbon content than non-fossil fuels such as nuclear, hydroelectric, and other renewable energy sources. A related point to remember, though, is that our U.S. economy is integrally tied to electrification, and over 57% of all electricity generated in this country comes from coal-fired power plants. In the Rocky Mountain West the electrical generation percentage is much higher, representing well in excess of 90% in many states. Thus, a dramatic decrease in coal utilization in the Rocky Mountain West could and would have profound economic effects on our citizens.

Major changes in our region's energy mix will not come easily and will certainly not be without pain. When one looks at all domestic energy sources in the United States, coal represents almost 95% of all present, economically recoverable fossil-fuel reserves. Furthermore, as utilities scan the energy smorgasbord, it is obvious why coal represents such an overwhelming majority of electrical generation in the Rocky Mountain West: simply put, coal is the lowest-cost available fuel. When comparing coal to natural gas, the delivered price of coal into power plants on an energy-equivalency basis is generally one half that of gas. Furthermore, while gas is relatively available, at least in the short-to-intermediate term for home heating and other present uses, there is simply not enough available gas to sustain a massive utility conversion from coal.

Similarly, unless this country embarks upon a radically different policy of encouraging massive additional developments of nuclear-fired power plants (rather unlikely in light of Three Mile Island and other controversies - - real or perceived), no other energy source is available today. Hydroelectric power (generally the least expensive, electrical-generation option, where it is available) represents 11 percent of U.S. generation. Most of that is confined to the Pacific Northwest states of Washington, Oregon, and Idaho. Other renewables such as wind and solar get lost in the rounding. Even with massive, additional governmental subsidies, non-hydro renewables are projected to represent less than 4% of electrical generation by 2010.

Thus, how do we reduce coal usage by 40%-60% by 2010, absent monumental technological breakthroughs (which almost never come in giant steps but occur incrementally over time)? American consumers' electric-usage habits would have to be radically changed over the next 12 years. Such change could come either by rationing (which was the effective means of energy-use reductions during the Arab embargoes of the 1970's) or by radically increasing the cost of coal-fired electrical generation for all consumers as a means of stimulating fuel-switching/conservation through the marketplace. This could be accomplished by a number of mechanisms, including direct

or indirect energy or carbon taxes, emission-trading programs or other national or international government programs. None of these has yet been identified, either by Washington or the Intergovernmental Panel on Climate Change (IPCC), the U.N. panel of international jurisdiction over the global climate-change issue.

These and other matters will be discussed in greater detail to describe the effects of climate change policy on the U.S. in general, and the western United States in specific.



Dale E. Towell

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CLIMATE CHANGE AND WILDLIFE: WHAT CAN WE EXPECT?

*Dale E. Towell
Planning Division
Idaho Department of Fish and Game
Boise, Idaho*

Wildlife can be broadly defined as all non-domesticated mammals, birds, reptiles, amphibians, and fish. Collectively, these animals not only enrich our lives, but they:

- (1) Provide the basis for fishing, hunting, and other forms of outdoor-related recreation. Wildlife-associated recreation attracted over 3.5 million hunters to this region in 1996, an average of 48 percent of our population (USFWS 1997).
- (2) Contribute to both economic well-being of many rural communities and businesses, (and to some kinds of regional agricultural losses). In 1996, the income to this 8-state region was well over \$6 billion. Seventy-seven percent of that total (\$4.7 billion) was business attracted from out-of-state (USFWS 1997).
- (3) Contribute in myriad ways to the proper functioning of ecosystems and the human environment: plant succession, seed dispersal, pollination, etc.

Clearly, any potential decline or loss of this resource has serious repercussions for the economic and social well-being of the Great Basin and Rocky Mountain area. This is especially true in the area we are here to discuss. Significant decline in endemic wildlife, for example, may trigger such national legislation as the Endangered Species Act, which would result in limitations on a wide range of human activities including logging, grazing, mineral extraction - - even road-building. Even if declines are less, but habitat quality is adversely affected, many activities may be limited or curtailed. Effects on water quantity and quality are especially worrisome in a region whose politics have been dominated since settlement times on the allocation of scarce and limited water resources, critical habitat for many endemic fish and amphibians.

The Fossil Record

The fossil record shows that this is not the first major climatic warming event in this area in recent geologic history. Fossil evidence suggests that temperatures were even warmer than presently predicted about 6,000 years BP (before present) during an altithermal period (Graham 1992, Grayson 1993). This has important implications, since wildlife typically responds in one of two ways to changes in environment: either narrowly-adapted species quickly decline, or broadly-adapted species adjust to changed conditions and persist under the new climatic regime. The fact that most wildlife species in the Great Basin have survived climatic changes greater than those presently anticipated may mean that many of the present surviving species were, in effect, 'pre-selected' to survive anticipated changes.

There is another, more subtle, indication from the fossil record, and that is that changes in habitat use are more closely related to the extremes of temperature and rainfall than to the averages (Graham 1992). Thus the differences between the wettest and driest season, and the hottest and coldest temperatures may ultimately determine the capability of many plants and animals to occupy any given area.

Requirements of Wildlife

Wildlife abundance is an expression of habitat quality. Animal numbers are regulated by availability of water, food, shelter, and space. It is important to remember that we are here discussing the entire regionwide availability of major ecotypes – Southern, Middle, and Northern Rocky Mountains, Nevada-Utah Mountains, and Intermountain Semi-Desert (Bailey 1995), and nearly 15% of the nation's land area. Stated differently, we are discussing the future of entire ecosystems, and the plants and animals that comprise those ecosystems.

Climate-related changes that might have an impact on wildlife include:

- (1) Those that may affect animal water supplies - - availability and water quality. This includes annual snowpack accumulation, timing, and amount of precipitation, run-off, and chemical content.
- (2) Changes that affect the timing of plant development will affect the availability of food and shelter for many species of wildlife.
- (3) Changes in climate may affect and alter plant distribution of hundreds of species of plants, and, depending on the type of animal, the insects and other organisms that rely on plant abundance but which are themselves food for other animals.
- (4) Changes in climate can have dramatic effects on the amount of space available to many kinds of animals. Because animals rely on specific kinds of habitat - - that is, plants and temperature regimes and moisture - - and because the landscape has been cut apart by development of roads and cities and other man-made changes - - most kinds of animals are not free to simply move somewhere else. Changes that make their immediate habitat less desirable will simply mean that there is less habitat and that means smaller populations.

One certainty is that habitats will change, whether climate changes or not. Habitats are affected by geological processes, natural patterns of plant succession, and human-induced alterations in the environment. The climate-change scenarios provided (no change, increased temperature, and increased temperature with variations in annual precipitation in either summer or winter) are all superimposed on this framework of change, and they will 'drive' those changes in certain, fairly predictable directions which will have impacts on wildlife.

The 'no change' scenario has the least impact, but it is not benign. Under this scenario changes in habitat, many caused by human development, will result in declining animal populations in those habitats that are both limited in extent and desirable for future human development. Without planning and careful management, wildlife habitat is becoming, and will continue to become, progressively more fragmented, and populations will decrease unless specific management actions (which can be designed based on past history and a predictable future) are taken to prevent this from happening.

The effects of the no-change scenario changes radically under Scenario 2, a regime of increased temperature, with no change in precipitation. Increased winter temperatures of 7°F would result in dramatically reduced snowpack accumulation. Summer temperature increases of 4°F would result in more rapid run-off. This would increase the difference in flows between summer and winter, and as a consequence of temperature increase and reduced water volume during summer, it would increase the extremes in annual water temperature as well. Many species of fish and amphibians are greatly influenced by

water temperature, since they are 'thermal conformers' (Ray et al. 1992) unable to maintain a body temperature much different from their surroundings. Most have a much narrower tolerance of temperature increases than decreases (since increased body temperatures allow the chemical processes that regulate digestion, metabolism and energy expenditure to operate more actively at higher temperatures).

Some cold-water species would be unable to adapt to even small increases in water temperature; others would be unable to tolerate a new range of seasonal water-temperature extremes. Some of those that can tolerate water temperature *per se* will be affected by the decreases in oxygen and other dissolved gasses associated with increased temperature.

Some types of plants - - such as certain algae - - would flourish under increased water temperature, and proliferation of these species in the form of alga 'blooms' could further upset the balance of dissolved gases in the water, stressing fish and other animals, and some even produce byproducts poisonous to fish. The so-called 'cold water biota' could have a very rough time. There is another, associated problem - - earlier run-off from snowmelt would reduce the amount of annual groundwater infusion, and temperature increases would result in increased evapotranspiration rates. This 'double-whammy' could lead to seasonal drying of shallow lakes and wetlands, stranding or eliminating some populations of fish, amphibians, and other animals.

Scenario 3, temperature increases accompanied by a 15% decrease in winter precipitation and a 15% increase in summer precipitation, would compound the problems of temperature increases alone. Winter snowpack would not only be reduced, but that reduction would be accompanied by high-elevation, rain on snow events that would strip snowpack out of the mountains even more rapidly, widening seasonal variations and exacerbating water-temperature impacts.

Scenario 4, temperature increases associated with a 15% increase in winter precipitation and a 15% decrease in summer precipitation, appears to be more benign than Scenario 2 or 3. Snowpack should increase, and some of that increase would offset the impact of the higher temperatures.

However, there are other critical concerns for wildlife in all temperature-change scenarios. Fossil evidence and computer models both clearly show that changes in temperature do not only result in shifting existing plants communities along latitudinal or altitudinal gradients. Instead, plant and animal species respond in different ways to the new regimes of temperature, water, food, and space. Two plants that presently live side by side can react in very different ways, one expanding its range while the other fails to reproduce. The fact is, many existing plant communities would change in composition, into something entirely new. The animal communities that rely on them would change as well, based on the primary productivity of plants or the animals that benefit or suffer from those changes. Synergistic effects, many of which cannot be predicted, would rebound through ecosystems, affecting animal populations in unforeseen ways.

A very serious consideration relates to the migrants - - animals that reproduce in one area, over-winter in another, and range widely between seasons. Songbirds or shorebirds are good examples. These species expend a great deal of energy traveling to 'secure' habitats for reproduction. They have no way of knowing, in advance, if those habitats have been altered, and most arrive in weakened body condition, dependent on abundant food supplies for survival as well as reproduction. Changes in climate could affect the

quantity, character, and availability of food these species would find on their breeding grounds (Myers and Lester 1992). If key reproductive habitats change significantly, adults might be unable to survive and reproduce; if new predators could invade formerly secure nesting habitats, their offspring might not survive. Timing of arrival on the nesting ground is often critical, related to plant growth and food abundance. But while plant growth and food abundance are usually closely related to ambient temperature, timing of migration is more typically related to photo-period (day length). These kinds of changes might also favor competitors or predators, further increasing risks to migrants.

In addition to problems of timing of plant development, food supplies, and potential predation on nesting grounds, a significant potential exists for timing of migration to become increasingly out of tune with plant and animal cycles. And this would affect not only the timing of arrival on the reproductive area - - many migrations are closely attuned to food abundance at waypoints, providing the energy for migration to occur (Myers and Lester 1992). Significant failure of food availability during migration itself could lead to tremendous mortality among adult migrants. This is a landscape-level problem of vast proportions.

General Conclusions

What generalities can be drawn? First, under any temperature-increase scenario, isolated populations of animals would face increased risks. For example, there have been several studies of wildlife associated with Nevada-Utah mountain ranges, and especially those species found in alpine communities. Following discussions by Grayson (1987), both Murphy and Weiss (1992) and McDonald and Brown (1992) examined implications of climate change in the Great Basin. Both sets of investigators focused on animal populations existing on isolated mountain ranges. Murphy and Weiss (1992) focused their attention on boreal mammal, bird, and butterfly species on ranges in east-central Nevada, as characteristic of the kinds of isolated populations most likely to be affected by climate change, and assumed that boreal habitat would ascend 500 m in elevation with a temperature rise of 3° C. They then mapped the habitat that would remain after warming, and utilized species/area curves to determine the impact on species abundance. They concluded that reductions and fragmentation of boreal habitat would range from 66% to 90%, while the number of species lost would average 44% of the presently-occurring mammals (excluding the mobile bats and large game species), and 15% of the presently-occurring birds.

A different study (McDonald and Brown 1992) built on that work, and concluded that boreal habitat losses would range from 35% to 96%, and losses among small mammals would range from 9% to 62%. White-tailed jackrabbits, Belding ground squirrels, and jumping mice were believed at greatest risk, although only bushy-tailed woodrats and Uinta chipmunks were believed secure among the 14 species examined.

Second, narrowly-adapted species with very specific habitat requirements would face increased risks. Cold-water fish are especially vulnerable. The best information to date for assessing impacts of climate change in the Rocky Mountains has been presented by Romme and Turner (1991) and Bartlein et al. (1997). These authors examined a range of climate-change scenarios and their potential impacts on vegetation and associated wildlife. They concluded that under all scenarios montane and boreal habitats would be reduced in area and fragmented (Romme and Turner 1991). Mature and older-age vegetation communities, forested and otherwise, were likely to become fragmented, as some of the plant species in existing communities became stressed while others

responded favorably to differing conditions. Bartlein et al. (1997) emphasized that resultant change was counter-intuitive, with some species expanding their ranges while others decreased; put differently, the kinds of changes expected would result in new assemblages of plant communities rather than simple gradient changes of existing associations. Obviously, changes in plant communities affect wildlife habitat, and such changes would result in isolating some wildlife species and reducing their distribution.

Third, migratory animals would face numerous challenges, and those challenges might occur at many different portions of their migration route as well as on their traditional reproduction and wintering areas.

Finally, wildlife habitats would change in unpredictable ways, as effects of temperature and precipitation changes resonate through ecosystems, affecting food resources and food chains in sometimes unexpected ways. Topographic relief typical of the Rocky Mountains would provide a buffer for many mobile species, allowing them to move to more favorable habitats as changes occurred, and reducing risks of species losses if travel corridors remained available.

What Should We Do?

There are some measures that can— and should— be undertaken now to minimize adverse impacts of climate change. Perhaps the most important is to continue to take steps to protect water quality and flows in rivers and streams. Decades of western water law which dictate that the only beneficial use of water is to remove it from rivers and apply it to the ground for irrigation must be tempered with provisions for minimum stream flows in the rivers. A flowing river, accompanied by streamside riparian vegetation, can both prolong the run-off period and minimize water-temperature fluctuations. This benefits both wildlife and agriculture.

Wildlife management agencies need to work more closely with state and county planners on landscape-level planning to ensure that there are connections in the natural world - - corridors that enable animals to get from one habitat to another.

Stressed animal populations with shrinking habitat bases will decline. Those declines will likely be most evident for animal species at both extremes on the distribution scale - - animals with small habitats, unable to disperse effectively (like cold-water fish) and extremely widespread species able to disperse very widely (migrants). Mobile, adaptable local species will be those most likely to find suitable habitats in the new climate regime. Some of those species that did decline would be likely to decline widely and dramatically, triggering protections of such laws as the Endangered Species Act which would, in turn, affect management of activities on both the public and private lands.

Some generalities seem to emerge:

- (1) Isolated populations with very specific habitat requirements appear to be at greatest risk. Within this group of species, cold-water-adapted aquatic species (fish and amphibians) would be likely to be the first affected. Some of these isolated populations are already at the end of their adaptive limitations and would likely face extinction.
- (2) Narrowly-adapted endemic species also face grave risks, as their habitats would change, in unpredictable ways, as a result of the individual species responses of plants adjusting to new climates. Biotic associations would emerge that are different from those existing now, benefiting some species while dooming others.

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- (3) Migratory birds, in particular, face grave risks associated with migration pattern and changes in their breeding and wintering areas.
 - (4) Many mammalian species are highly mobile and, being endothermic, highly adaptable to a wide range of climatic variation.

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PLENARY SESSION:
Scientists' Reports

Monday Afternoon, February 16, 1998

Jill Baron, Chair



Jim MacMahon

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Kelly Redmond

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CLIMATE-CHANGE ISSUES IN THE MOUNTAINOUS AND INTERMONTANE WEST

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For the purpose of this discussion, this region is taken to encompass the Rocky Mountains from Canada to Mexico, the Great Basin to its westernmost divides, and the northern extension of the Great Basin through eastern Washington, and to a lesser extent the high deserts of eastern Oregon.

Degree of Fine-scale Structure

Overall, a large portion of the West is characterized by a high degree of fine-scale structure. Vertical relief of 3,000 to 5,000 feet is common, and in some cases this scale approaches 10,000 feet. Major mountain ridges typically have widths of 25-100 miles, but many important features have horizontal dimensions of 5-10 miles, and large differences in elevation can occur over small fractions of a mile. Climatic processes respond to these topographic forcings, and very large differences in long-term climate can occur over horizontal distances of 1-5 miles, or even less in some cases.

The shape of the annual cycle changes drastically with elevation in many places. For example, in southwestern Montana, winter is the time of year with minimum precipitation in the valleys, and with maximum precipitation in nearby mountains. In early spring, the relative contribution to valley precipitation is maximum, while nearby mountain precipitation is decreasing toward its relative summer minimum. As a general rule, the importance (i.e., the relative contribution to the annual total) of winter precipitation increases with altitude throughout the West. However, the rate at which the shape of the annual precipitation cycle changes with altitude is itself a factor which varies spatially from one part of the West to another.

Existing systems, human and natural, “know” about these variations and usually take them into account. What typically matters most are climate conditions in the immediate local environment of an affected organism. The extreme topographic diversity greatly complicates attempts to make generalizations about how climatic behavior might vary, and about how human and natural systems would respond to changes in the long-term climate, or else reduces the value of such generalizations, in many cases probably to meaningless levels. Elevational effects abound in the region and are important.

Another complicating factor for detection of change is that much of the West receives limited precipitation. Valleys everywhere receive less than their neighboring mountains, and as a rule, at a given elevation precipitation decreases from north to south. Drier climates usually exhibit more relative precipitation variability in time than wet climates; their records are “noisier.” This makes detection of trends and of other types of variability all the more difficult. In this area precipitation varies from approximately 2" (southwestern Great Basin) up to about 110" (Glacier National Park).

The presence of frequent inversions, particularly in winter, means that mountain and valley temperature records, even close by, are often poorly correlated. For example, over several decades, annual temperatures at two high-quality sites in Oregon, 29 miles apart, one in a river valley and the other on a mountaintop, only have a correlation of 0.57.

From the standpoint of numerical simulation of climate, this fine-scale structure is not “grid-point friendly.” The equations which the atmosphere and its related “spheres” must follow involve taking differences in space and in time. The diversity of elevation adds greatly to the complexity of this process. The tendency toward spatial “lumping” in numerical simulations can obscure or eliminate important behavior.

In order for predictions of how climate might vary or change to be credible, these models should first demonstrate that they can reproduce the seasonal and elevational differences of the present-day climate, which are important to present-day sectors, both human and natural. To be of use, they also need to be able to produce the requisite level of detail.

Climatic Linkages Across Space and Time

In the West, the resource bases (watersheds, timber, minerals, agricultural production, electrical power sources) for population centers are often long distances away from the point of consumption. Streamflow originates in regions and times that are often far away, out of sight and frequently out of mind, from winter storms many months ago, usually in unvisited high-mountain basins. About three quarters of western streamflow arises from the melting of winter snows. Many rivers, once they leave their source regions, flow through long reaches without significant augmentation from tributaries, or even suffer losses. In the Great Basin, this loss proceeds to complete extinction in all cases.

Because of these factors, drought characteristics in the West are very different from those in the East. Today’s or last week’s weather, or recent weather and climate in the local environment, may have little bearing on the status of water supplies.

Increasing connectivity between regions, even countries, makes climate behavior elsewhere relevant. Storms and weather activity in other parts of the country affect the supply of hydropower, and also affect the demand for electricity. Some warm-climate utilities buy cool-region hydropower, at increased cost, during episodes when fossil-fuel power would produce unwanted emissions. In the deregulated energy sector, “power trading” will prevail, driven as much by weather and climate factors that affect both supply and demand, and thus markets, as by other human habits and needs.

Climate Is Very Unevenly Sampled

As a general rule, in the West we know more about low-elevation climates. These areas were settled first, have had a continuous human presence, and thus often have the longest records. Because they are warmer and more accessible, climate elements are easier to measure. There are also many more low-altitude sites than high-altitude sites.

Many mountain ranges are completely unsampled, even today. Although it has about 160 mountain ranges according to geographers, only a small percentage of Nevada’s mountains have even one long-term climate record.

In order to understand whether large-scale climate variations produce different rates of variation with altitude within a small area, we need dense networks of long-term stations spanning all local elevation ranges. Such networks are also needed for calibration of statistical techniques to estimate climates on similar non-gauged mountain ranges (the majority). They are also needed to help construct the parameterizations used by numerical climate simulations, and to assess whether today’s climate is being correctly simulated or not. There are only a few locations that have such networks.

Most of the West's precipitation falls as snow. This is especially true for the portion of the precipitation that ends up as part of the water supplies that the region depends upon. Precipitation which falls as snow is much more difficult to measure, and often poses a strong logistical challenge. Long-term records from snowy locations, made in the consistent way that climatological analysis requires, are even more rare.

Fractured and Slightly Coordinated Monitoring

Monitoring is an essential prerequisite for sound resource management. Several major federal networks are present in the West. These include the National Weather Service cooperative network, the USDA Natural Resources Conservation Service SNOTEL (Snowpack Telemetry) network, the USDI/USDA Remote Automatic Weather Station (RAWS) network run mostly by the Bureau of Land Management and the Forest Service, plus a number of other smaller or sub-regional networks. The West is unique in the U.S. in having these region-wide networks, a reflection of the large federal presence, with about half of the land under the stewardship of the federal government.

The networks were put in place in support of specific agency-dependent missions. At their original deployment, there was thus essentially no coordination between network managers. Recently, as resources have tightened, there has been greater desire and willingness to coordinate. Regional entities such as the Western Regional Climate Center, which maintains operational versions of each of these databases, have been working to facilitate such integration. Long-term commitments to continued and consistent environmental monitoring are needed from all resource management agencies.

The cooperative network has a far longer history than any other network, and serves as the backbone of the nation's climate-observation structure. (It may seem surprising, but the U.S. has no formal climate-monitoring system. The cooperative network comes closest to fulfilling this vital role.) It is essentially the only source of long-term data, is more dense than any other network, is by far the cheapest (on a per-station basis), and is the most widely used climate data base in the country. This network has taken on an added importance in recent years as a result of disruptions and a general decline in usefulness and quality of the first-order airport network, especially for precipitation. In the West, there is approximately one cooperative station every 25 miles. There is very great concern within the climatological community about the national commitment to the NWS cooperative network, widely regarded by those who supply its output to a broad and diffuse constituency as a neglected national treasure.

Much of the emphasis in discussions of global climate change has focused on temperature: Will the earth warm? By how much? But it is becoming increasingly evident that hydrological quantities are looming as perhaps the most important elements. Although it has its own problems, representative measurements of temperature are easier to obtain. We continue to need long-term, consistent measurements of precipitation quantities: amount, timing, phase/type (rain or snow), intensity, frequency, and the behavior of extremes.

Above all, a long-term perspective is very much needed to adequately monitor for climate change.

A Few Comments on Climate Variability and Climate Change

Climate has always fluctuated and always will. Up to the relatively recent past, these fluctuations have been regarded as "natural." Two problems of interest in the West (and

everywhere) are: (1) Are there long-term changes occurring in climates of the region (the “detection” problem)? And (2) if there are such changes, can they be attributed to a “natural” or “artificial” cause? Would they have happened anyway without humankind’s presence (the “attribution” problem)?

It would hardly be surprising if climate change brought different consequences to different months, locations and altitudes, in this topographically diverse region. Preliminary studies in the Alps, for instance, show that warming should be greater at higher altitudes. Many models predict that the global evaporation-precipitation cycle will speed up, with higher precipitation and larger numbers of extreme events over the earth, but the spatial pattern of increases and decreases remains unresolved. Most enhanced greenhouse simulations predict a West with both wetting and drying subregions, in both winter and summer.

Global temperatures, based on surface measurements, do seem to indicate warming in recent years. Global borehole data, an entirely independent set of measurements, also indicate warming. Satellite measurements, also independent, based on 1979-1997, show almost no trend. U.S. temperatures, a dataset perhaps less subject to artificial biases, also seem to show almost no temperature trend. For the U.S., temperature warming evidence thus seems ambiguous. U.S. precipitation measurements, on the other hand, show an increase of about 10% over the past century, based on the aforementioned cooperative data. Evidence also shows that extreme precipitation events have increased over the past century in the U.S.

Some Regional Climates are “Marginal” Already

Climates in much of the Rocky Mountain-Great Basin region are close to ecological boundaries, both in hot arid lands that are near absolute limits for all life, and in elevated alpine regions. In dry areas, small absolute shifts in climate are large relative shifts. In the West, climate shifts translate to both latitudinal and altitudinal movement. With its hundreds of isolated mountain ranges, many of the precepts of “island biogeography” apply, where mountaintops are essentially islands of isolated biological communities which evolve in different directions. Since area decreases as elevation increases, more competition for less area would occur if species were forced upward by warming.

Climatic Constraints on Human Activities

The West contains a variety of paradoxes and odd juxtapositions. For all its wide-open spaces, the West is the most urbanized area in the U.S. (percentage living in cities). It is also the fastest growing. The resource base supporting population centers extends well beyond city limits. It is quite clear that the present situation is not sustainable (i.e., in long-term equilibrium, where resources are consumed no faster than they are replaced). The region (indeed, almost nowhere on earth) has yet to collectively address the issue of what would constitute a reasonable limitation on the magnitude of the human presence amidst its magnificent environment. The region has always loomed large in the American psyche as a wellspring of the spirit of rugged individualism and unfettered personal freedom. A graceful resolution of the conflict accompanying these opposing historical trajectories would be desirable, as an acknowledgement that there are limits to everything. Fluctuations in the physical environment impose one set of limits on human behavior. Acquiring knowledge of the properties of climate variability, both natural and otherwise, and then incorporating that knowledge into the societal decision-making process, would be of great value in allowing for a “margin of error.”

Water availability has acted as a perpetual bound on economic activity in the region, although great creativity has been exercised to extend those bounds. The mental imagery of severe and demanding climates in the beautiful but often austere landscape has also helped limit human intrusion into remote locations. Now, population pressure, technological innovation, and cultural changes are allowing growth into regions formerly left alone, areas with more climate-related hazards, such as fire, and heavier snows and snowloads.

People are drawn to the West by its wide-open spaces and vistas. The region has an outdoors-oriented population. The highly transparent air that is still present in parts of the region is extremely susceptible to visibility degradation, whether from local or regional, or now even global, aerosols. In its many valleys, and with its extremely dry air and frequent snow cover, radiative conditions favor the formation of pollution-trapping inversions with high frequency, in many places on nearly every clear night. Climate changes, and changes in the radiatively active gas content, could alter this picture in now-unknown ways.

The West as "Evidence Locker"

With its dry climate (low absolute and relative humidity, and low precipitation), especially in the Great Basin, evidence of past climates is preserved here far better than other places. This seemingly barren landscape harbors an extremely valuable and unique repository of information about past climates, often lying undisturbed for thousands of years, sometimes in plain sight. We badly need to understand the long-term context, the representativeness, of our 20th Century climate, the only climate we have measured directly. With or without global climate change, what are the likelihoods of extended periods of warm or cool, wet or dry? What forces have led to climate variations over the past 400-500 years? The past millenium?

We also need to learn much more about the possible presence, and causes, of "regimes" of climate, that is, episodes which last a few decades to a few centuries. These last long enough that we can be lulled into thinking that they represent "the" climate, when in fact they are just one facet. The recently discovered "Pacific Decadal Oscillation" is a good example; do others exist?

Useful and unique evidence is at risk from increasing human expansion into desert and dry environments. A need exists to insure that potentially valuable information is not unknowingly destroyed before we have a chance to hear its story.

This past evidence needs to be interpreted in light of what we know about the physics of climate, a marriage of the disciplines of climate dynamics and paleoclimatology. A more integrated linkage between these fields is needed, to learn more about how climate has varied from year to year, for the past several centuries. Awesome climate events have occurred in the West since 1500; we need to know more about them, and about how rapidly regional climate can shift "on its own" from one pattern to another.

Inexperience in the Use of Uncertain Information

To most of the public, the concept of climate change is largely abstract and academic, with consequences too uncertain to know how to react, and with little perceived relevance to daily life. (However, surveys of attitudes are nonetheless showing that the issue is not being simply dismissed out of hand.)

It is self-evident that forecast information will never be certain. Just because forecasts are not perfect does not mean they are useless. Increased understanding is needed of how to more effectively use uncertain information. How do we find the middle ground of not “under-using” nor “over-using” that which we know imperfectly?

In a related vein, it seems that we do not effectively make use of what is now known about various aspects of climate variability. Why is this? A more holistic view is needed, of all the steps and processes that occur between the first uncovering of a fact, or a body of facts, and its eventual application. Many in the scientific and technical arena only concern themselves with the first set of steps, and do not seek to understand the remaining processes with the same zeal.

Furthermore, information about predicted and never-before-observed climate changes will always be less certain and less accepted than information about past variability that is known to have occurred. But if we have not been able to use that which we regard as “known,” then what hope is there for using that which we regard as much more uncertain?

The recent dramatic appearance of El Nino in 1997-98, and the associated seasonal climate forecasts, which came out well in advance of the predicted effects, would seem to furnish an excellent tool for learning about the global climate-change issue, because: (1) the variation is known to have actually occurred (and many times), (2) the uncertainty seems quantifiable, (3) the forecasts appear to have some reliability, and (4) El Nino as a phenomenon is in between “weather” time scales and long-term “climate” time scales. Follow-up studies should be undertaken to find out whether - - and how - - learning occurred during this event about how to use uncertain information.

This is a Complicated System

In a highly complex system like the earth’s climate system, interacting with an enormous number of at least equally complicated ecological systems, each with innumerable degrees of freedom, and a large number of potential modes of activity, there are ample opportunities for small, seemingly insignificant, factors to combine in unexpected ways, and produce surprise.

“Subtle does not mean unimportant.”

(Prof. Mike Wallace, Seattle, July 14, 1997)

Additional Information via the World Wide Web

A number of graphics and textual products (including station-specific information for about 1500 National Weather Service cooperative stations) elaborating the background climate of the western United States, both historical and recent, may be viewed at: <http://www.wrcc.sage.dri.edu>.

ASSESSMENT OF CLIMATE-CHANGE IMPACTS ON THE WATER RESOURCES OF THE WESTERN UNITED STATES

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Abstract

A regional assessment of potential climate-change impacts on the water resources of the western United States was performed using future climate scenarios generated by global climate models run with CO₂ concentrations at double current levels. The impact of these potential future climates was assessed using hydrologic and water-resource models. Quantitative results were produced not to be viewed as predictions, but to reveal the sensitivity of the hydrologic resources, aquatic ecosystems, and water institutions to potential, future climate change.

Under two global climate models, runoff impacts vary across the western United States. Individual river basins show a wide range of impacts on annual runoff with increases of 157% to decreases of 14%. Individual states show changes from current runoff that range from increases of 146% to decreases of 15%. Both scenarios suggest that most river basins will experience an increase in the peak flow and snowmelt-dominated river basins will see a shift to earlier peak flows.

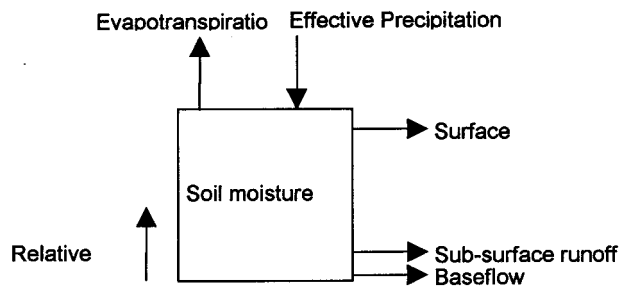
Introduction

This report provides an assessment of climate-change impacts on the river runoff, a central property to managing the water resources of the western United States. The current analysis addresses the sensitivity of the hydrologic resources, aquatic ecosystems, and water institutions to a future climate change. A variety of modeling approaches was used to obtain the regional analysis presented herein. The goal of this summary document is to provide decision-makers with an understanding of the types of hydrologic impacts that climate change may pose on the management of water and environmental resources of the western United States.

Impacts of Climate Change on River Basin Runoff of the West

Few regional-scale investigations of climate-change impacts on runoff in the western states have been undertaken. Significant research has been done on the impacts of climate change on river-basin runoff (Kaczmarek, et al., 1995; Arnell, 1995). Miller (1997) presents an excellent summary of the main published studies on climate-change impacts on river runoff in the western United States. The work reported on by Miller (1997) has focused on only a few basins in western states and does not provide a consistent (same climate-change scenario) region-wide impact analysis. It is not possible to synthesize these detailed case studies into a regional analysis because there was no consistent climate-change scenario simulated by all the studies. To perform a comprehensive regional analysis at the detailed scale of these analyses would require significant time, resources, and data. As an alternative approach, other researchers have undertaken assessments of regional climate-change impacts on runoff using less sophisticated modeling techniques. Schaake (1990) performed a regional analysis of the southeastern United States to provide insights into the sensitivity of the region's runoff to changes in

Box 1. Overview of the WATBAL Water Balance Model



Model Equations

$$S_{\max} \frac{dz}{dt} = (P_{\text{eff}}(t)(1 - \beta)) - R_{\text{uns}}(z, t) - R_{\text{sat}}(z, t) - E(PET, z, t) - R_b \quad (1)$$

$$R_{\text{sat}} = \alpha z^\gamma \quad (2)$$

$$R_{\text{uns}} = \begin{cases} z^\epsilon (P_{\text{eff}} - R_b), & P_{\text{eff}} > R_b \\ 0, & P_{\text{eff}} \leq R_b \end{cases} \quad (3)$$

where S_{\max} ≡ maximum storage capacity
 z ≡ relative storage ($0 \leq z \leq 1$)
 P_{eff} ≡ effective precipitation
 R_{uns} ≡ runoff in the unsaturated zone
 R_{sat} ≡ saturated zone runoff
 E ≡ evaporation
 R_b ≡ baseflow.

Model Parameters

There are three parameters for each grid: S_{\max} , α and ϵ .

Model Inputs

Precipitation and Snow Monthly precipitation comes from the gridded climate databases as mm of water. An important component of the hydrologic cycle for some basins is snowmelt. WatBalGIS has a snow balance model and releases water from the snow using an "adjusted" effective precipitation with a temperature index snowmelt

climate variables. He used a non-linear monthly water balance with fixed parameters for the entire region. Yates (1997) extended the monthly non-linear regional concept of Schaake to account for spatial variability in parameters of the non-linear, water-balance model. Yates (1997) was able to relate the three parameters of the WATBAL (Yates, 1996) water-balance model (See Box 1) to land use/cover on a 0.5° latitude by 0.5° longitude grid. This work has resulted in a GIS-based version of the WATBAL. The system WATBAL-GIS enables a rapid examination of the potential consequences of climate change on runoff on a range of spatial scales up to continental, with data inputs obtained directly from gridded climate databases and gridded climate-model results.

Yates (1997) has demonstrated that both regional-scale hydrologic models provide a high level of accuracy in modeling monthly runoff. Given the uncertainty and large spatial scales of climate models (2° by 3° grids), 0.5° by 0.5° gridded, regional hydrologic models provide more than enough precision for modeling the impact of future, regional climate scenarios on a river-basin scale.

Methodology

A consistent and regional analysis of climate-change impacts on the hydrologic resources of the western United States was conducted using WATBAL-GIS. The hydrologic analysis, performed on a 0.5° by 0.5° spatial scale, covered the continental United States west of the 90th meridian including 22 western states and 10 major river basins. The WATBAL-GIS system was run on a monthly time scale for a single year using average monthly climate data obtained from the 0.5° by 0.5° gridded database of monthly, average climate variables used in the VEMAP Project (NCAR, 1996). Before climate-

change impacts were simulated, the WATBAL-GIS system was validated using 19 medium-sized river basins that spanned the region. Monthly average runoff from the USGS streamflow database was compared to WATBAL-GIS-modeled runoff for the 19 basins. An average monthly correlation between observed and modeled runoff was of 0.78 for all 19 basins, with a correlation range of 0.92 to 0.64. This correlation of model output to observed runoff indicates that the WATBAL-GIS model adequately depicted the major hydrologic processes at both the regional and river-basin scale.

The WATBAL-GIS system was then run with the same parameters but under alternative climate-change scenarios. The climate-change scenarios were generated by taking the output of climate models, General Circulation Models (GCMs), and determining the average monthly increases in temperature and changes in precipitation that the model suggests for a doubling of CO₂ concentration in the atmosphere. GCM results are not predictions, but are scenarios or possible future climates that are spatially consistent. GCMs have become a standard for developing regional climate-change scenarios of regional impact assessments.

Two widely accepted GCM outputs were used as scenarios for this analysis, the Goddard Institute for Space Science (GISS) and Geophysical Fluid Dynamics Laboratory (GFDL) model outputs. The GISS scenario suggests an increase of mean annual temperature of 2.5°C globally, and 4.7°C over the western United States, and a 10% increase in global precipitation and an 8% increase in precipitation over the western United States. The GFDL scenario suggests an increase of mean annual temperature of 3.0°C globally and 4.2°C over the western United States, and a 15% increase in global precipitation and a 30% increase in precipitation over the western United States. The monthly changes in climate over the western United States were applied to current climate data and simulated in WATBAL-GIS. The climate-change runoff was compared to simulated, current-day runoff to assess the impacts of the potential climate change.

Analysis

Spatial Results. Figures 8 and 9 provide a spatial display of the WATBAL-GIS results, showing the ratio of GCM to current modeled annual runoff with the major river basins delineated. Figures 10 and 11 show the same results with the western states delineated. Table 1 is a summary of the results presented in Figures 8 and 9 for the major river basins. Table 2 is a summary of the results presented in Figures 10 and 11 for the states. The values presented in Tables 1 and 2 were determined by summing the runoff from each grid cell in a basin or state for each scenario and for the current climate, and finding the ratio of the GCM runoff to the current runoff for each basin or state.

The GISS scenario (4.7°C increase in annual temperature and 8% increase in precipitation) suggests four river basins with decreases of up to 15% and six basins with increases of up to 23% (Table 1). Twelve states show decreases in runoff of up to 16% and ten states show increases of up to 27% (Table 2). Due to the gridded representation of the western United States, and states and river-basin boundaries, aggregated results for states and river basins do not all match exactly.

Summing over the western United States shows a 12% increase in runoff. The Northern Pacific coast is shown to have a great increase of runoff, while the Southwest and the Central Plains states show drying. If the two basins of the Northern Pacific coast are excluded, there would be a net decrease in runoff of 2% over the remainder of the western basins.

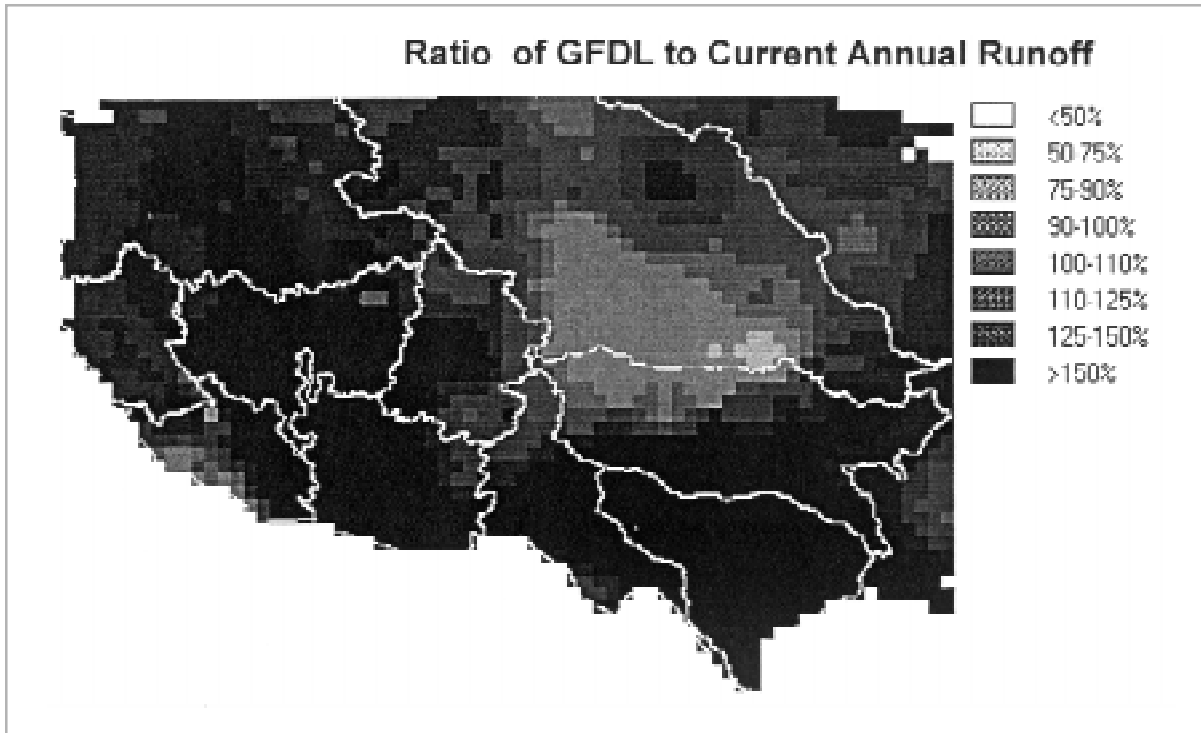


Figure 8. Ratio of GFDL-modeled runoff to current modeled runoff for major river basins.

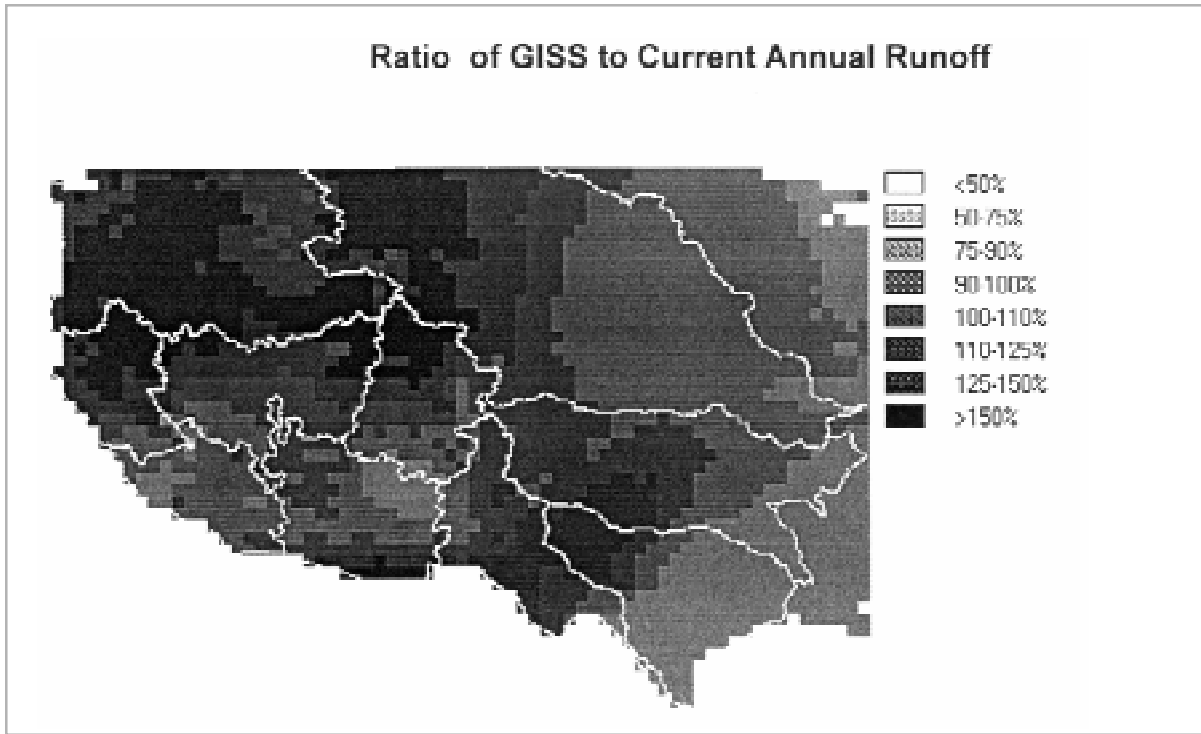


Figure 9. Ratio of GISS-modeled runoff to current modeled runoff for major river basins.

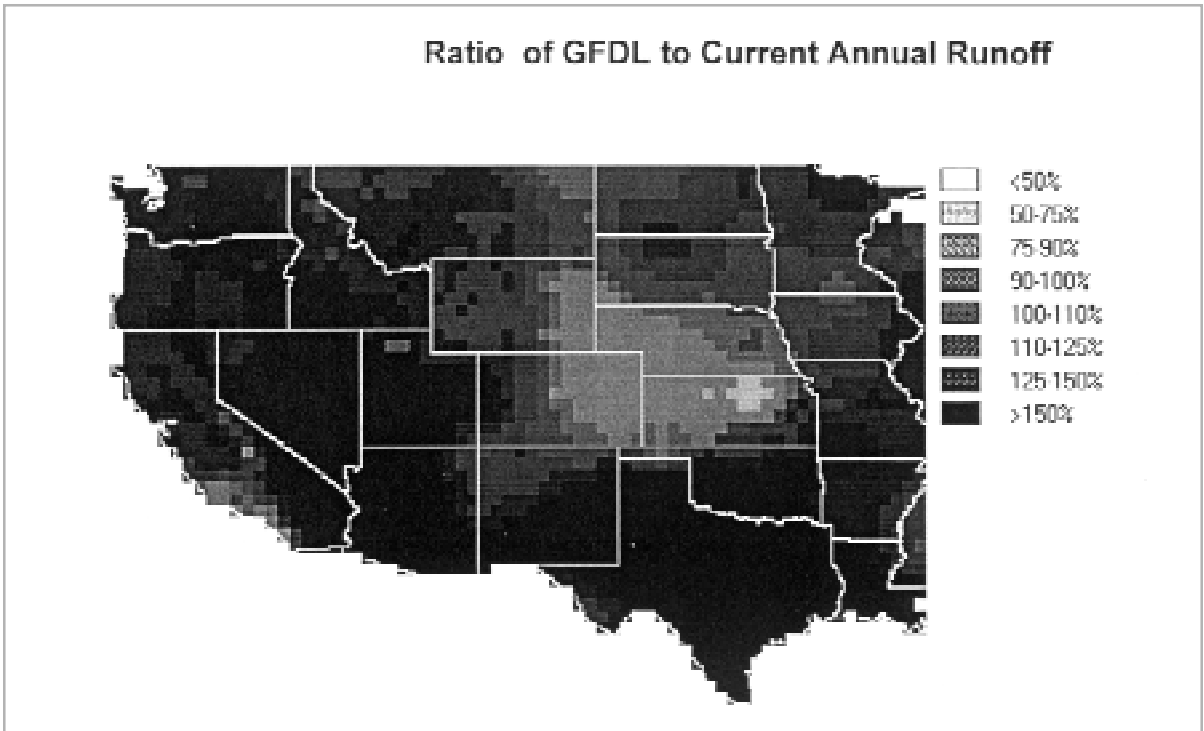


Figure 10. Ratio of GFDL modeled runoff to current modeled runoff for western states.

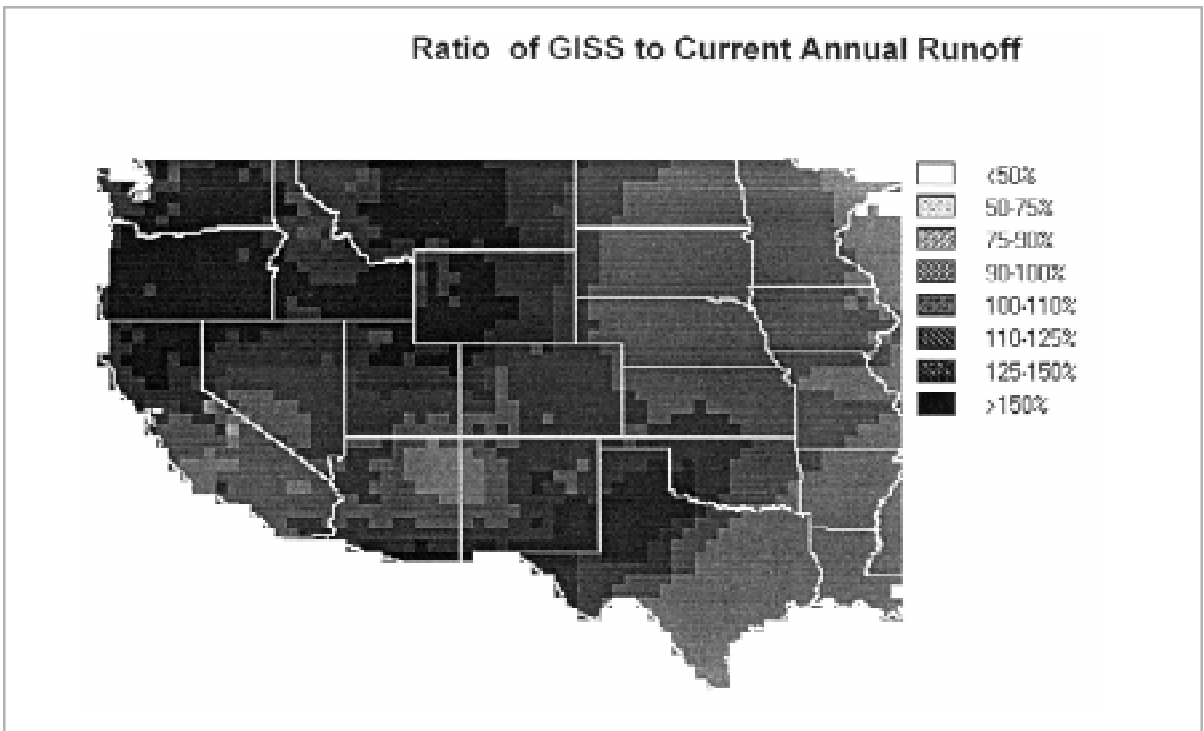


Figure 11. Ratio of GISS modeled runoff to current modeled runoff for western states.

Table 1

Ratio of Climate Change Modeled Annual Runoff to Current Modeled Annual Runoff for Major River Basins

Basin/Region	Scenario	
	GISS	GFDL
Arkansas -Red	0.91	1.59
California- North	1.22	1.37
California- South	0.87	1.15
Columbia	1.23	1.39
Grand Basin	1.10	1.66
Lower Colorado	0.98	2.46
Missouri	1.05	1.17
Rio Grande	1.01	1.35
Texas	0.85	2.65
Upper Colorado	1.08	1.30
All Basins	1.12	1.45

Table 2

Ratio of Climate Change Modeled Annual Runoff to Current Modeled Annual Runoff for Western States

STATE	Scenario	
	GISS	GFDL
Arizona	0.97	2.54
Arkansas	0.87	1.39
California	1.18	1.34
Colorado	1.04	1.17
Idaho	1.16	1.37
Iowa	0.92	1.14
Kansas	0.97	1.09
Louisiana	0.84	1.83
Minnesota	0.91	1.16
Mississippi	0.91	1.44
Montana	1.19	1.29
Nebraska	0.95	0.92
Nevada	1.13	2.06
New Mexico	1.03	1.41
North Dakota	0.98	1.14
Oklahoma	0.95	1.73
Oregon	1.27	1.40
South Dakota	0.94	1.07
Texas	0.86	2.57
Utah	1.20	1.64
Washington	1.24	1.42
Wyoming	1.19	1.20
All States	1.09	1.44

The GFDL scenario (4.2°C increase in annual temperature and 30% increase in precipitation) is cooler and wetter than the GISS scenario. No river basins show decreases in runoff, but rather increases of up to 166% (Table 1). Only one state (Nebraska) shows a decrease (8%) and 21 states show increases of up to 157% (Table 2). The Great Plains show a slight drying with the rest of the region showing major increases in runoff, especially the rivers of Texas and the Lower Colorado. The GFDL results, averaged over the western United States, suggest a 45% increase in regional runoff.

These results suggest three important implications of climate-change impacts on the water resources of the western United States.

- (1) Flooding and not drought may be a more serious consequence of climate change.
- (2) The impacts are going to vary widely across the West depending on the nature of hydroclimatology, and
- (3) The difference between the results for the two GCM scenarios are based more on differences in precipitation than temperature.

Precipitation is the least accurate variable simulated by GCMs, so these analyses cannot be viewed as predictions, but as possible climate futures that are regionally consistent based on the assumptions of the GCMs. Despite the variability of the GCMs, the spatial analysis of results suggests that the northern and central plains states, traditionally the nation's bread basket, have the greatest likelihood of seeing a net decline in runoff compared to current conditions.

Temporal Results. While the spatial results of climate-change impacts on annual average runoff are an important criterion for vulnerability to climate change, the temporal change or the impacts on the

seasonal distribution of runoff is equally, if not more, important for water-resource management in the western United States. This is particularly important under the Prior Appropriation Doctrine of water allocation in the West where water rights are specified in terms of time and location. Current water-diversion patterns are based largely on the demand for water for irrigated crops. For irrigated crops, a shift in the timing of runoff relative to the growing season could have huge impacts on mechanisms to store and distribute water. Finally, with the potential for increases in flows, flood control and protection are designed based on peak or flood flows which is a seasonal process.

Figure 12 is a plot of the average monthly distribution of runoff for the entire western United States. It shows that for both GCM scenarios there is an increase in the peak runoff (potential flooding) and that the peak runoff occurs in March as compared to May under current climate conditions. The shifting of the peak flow 2 months earlier is due to an earlier snowmelt from the increase in temperatures. Seventy percent of western runoff is from snowmelt, so the timing of the peak runoff is a function of monthly temperatures. This result suggests that current, western water institutions are potentially vulnerable to changes in the timing of runoff. Water rights are issued for amounts of flow over specified time periods. If the streamflow comes earlier with little change in the growing season, there will be less water for diversions and junior water- rights holders will be harmed even if the annual flow in the river is not changed.

Figure 12 provides temporal runoff results for the West as a whole. Table 3 and Figures 13 and 14 present temporal summaries of climate-change impacts on the month of peak flow for the ten major basins of the study. The basins are ordered in west-to-east orientation. Western-states basins have more snowmelt contributions than central plains states. These results show that the western-states basins for both GCM scenarios have a shift of the peak flow of 1 to 2 months earlier in the year as indicated by the negative values on Table 3 and Figures 13 and 14. This is caused by earlier snowmelt as the central plains states basins show the peak moving zero to 2 months later in the year for the GISS scenario, and the peak shifting 2 to 5 months later in the GFDL scenario. The change in the timing of the peak flow is reason for concern as water allocations are based on both quantity and timing of flows. Are western water institutions flexible enough to deal with these potential changes?

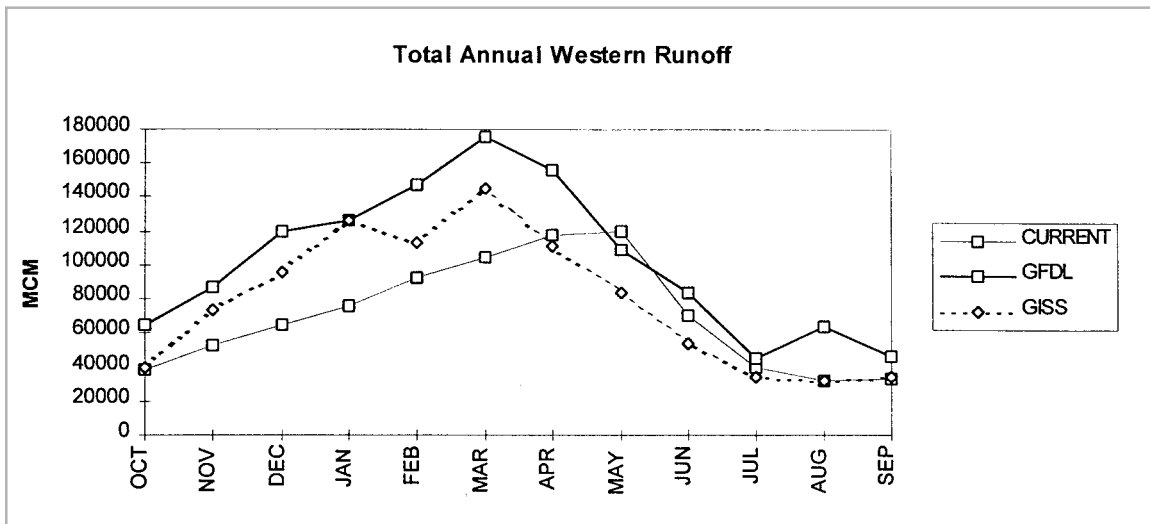


Figure 12. Monthly distribution of total, western-United States runoff.

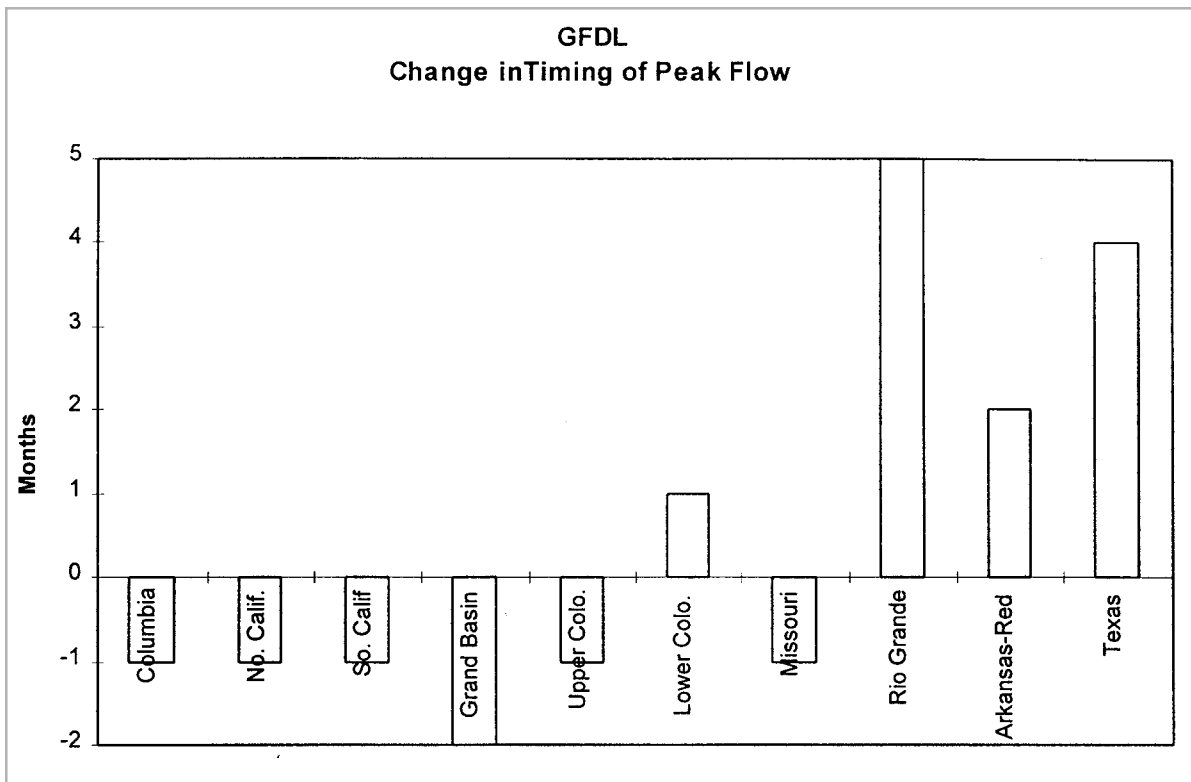


Figure 13. Climate change impacts on peak runoff month—GFDL.

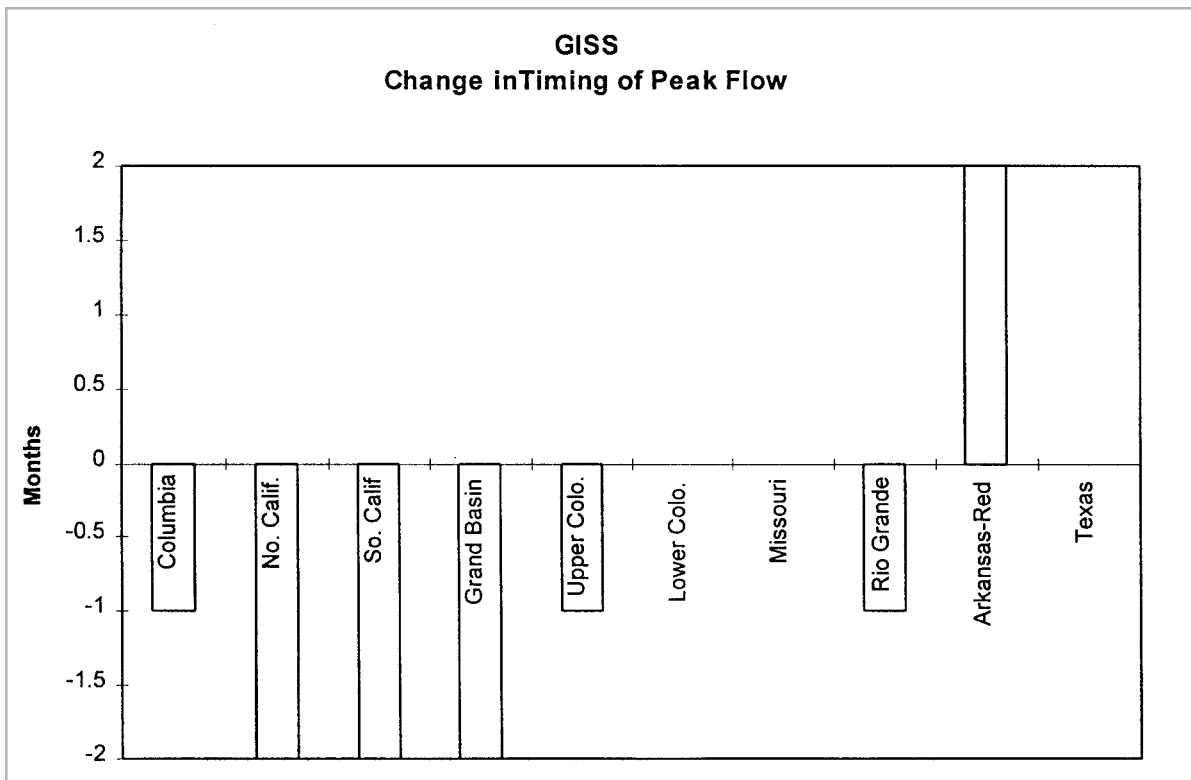


Figure 14. Climate change impacts on peak runoff month—GISS.

Table 3

Climate Change Impacts on Temporal Distribution of Runoff

Basin	GFDL			GISS		
	<i>Change Months to Peak</i>	<i>Ratio of Max to Current</i>	<i>Ratio of Min to Current</i>	<i>Change Months to Peak</i>	<i>Ratio of Max to Current</i>	<i>Ratio of Min to Current</i>
Columbia	-1	1.47	1.04	-1	1.33	0.89
No. Calif.	-1	1.46	1.10	-2	1.30	0.78
So. Calif.	-1	1.37	0.99	-2	1.06	0.58
Grand Basin	-2	1.31	1.81	-2	0.82	1.03
Upper Colo.	-1	0.99	1.49	-1	0.79	1.35
Lower Colo.	1	2.73	1.70	0	0.96	0.87
Missouri	-1	1.21	1.14	0	0.83	1.21
Rio Grande	5	0.93	1.37	-1	0.80	0.91
Arkansas-Red	2	1.53	1.59	2	0.91	0.96
Texas	4	4.19	1.98	0	0.84	0.89

Extreme Events. Regionally and especially in the western-states basins, the peak flow shifts to earlier in the year. The impact on water management however, also depends greatly on how the magnitude of the peak and low flows change with time. Table 3 and Figures 15 and 16 present summaries of climate-change impacts on the peak and low flows for the ten major basins of the study. The GFDL scenario suggests that eight out of the ten basins will have an increase in the peak flow of a significant amount (Table 3, Figure 16). However, consistent with the regional spatial analysis, the GISS scenarios show only three out of ten basins with increased peak flows and these are all located along the Pacific Coast (Figure 15), while the basins of the Rocky Mountains and the Central Plains all show a decrease in the peak flow. These GCM results would suggest that flooding in the Pacific Northwest basins might be a potential consequence of climate change and should be more carefully examined.

Equally important to water management are low flows, especially for aquatic ecosystems and water quality. The GFDL scenario shows nine basins with relative increases in low flows and one basin remaining the same (Figure 16). However, the GISS results show the three Pacific coast basins, the only ones to show an increase in peak flow under this scenario, to have significant decreases in low flow, with four other basins showing decreases, and only three showing increases (Table 3, Figure 15).

These GCM scenarios hint at what some in the climate-change-impacts community have speculated, that not only will the timing of annual, average runoff change, but extreme events will become more extreme with higher peaks and lower minimum flows.

Implications for Management

Western water management is dominated by large reservoirs which store runoff within-year and over-year, and change the timing of flows to meet demands that do not match the streamflow pattern. In many cases, the stored water is transferred out of the river basin to meet demands far away. A very important aspect of reservoir design is the variability of streamflow. Should variability increase due to changes in extreme events,

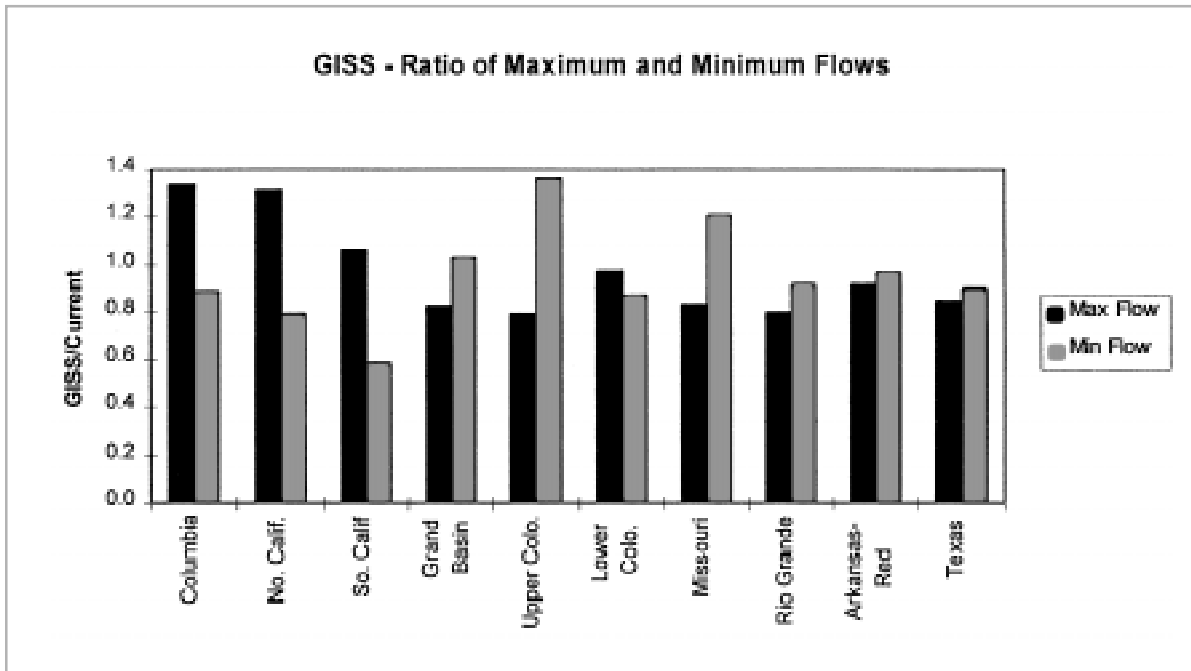


Figure 15. Climate change impacts on peak runoff month—GISS.

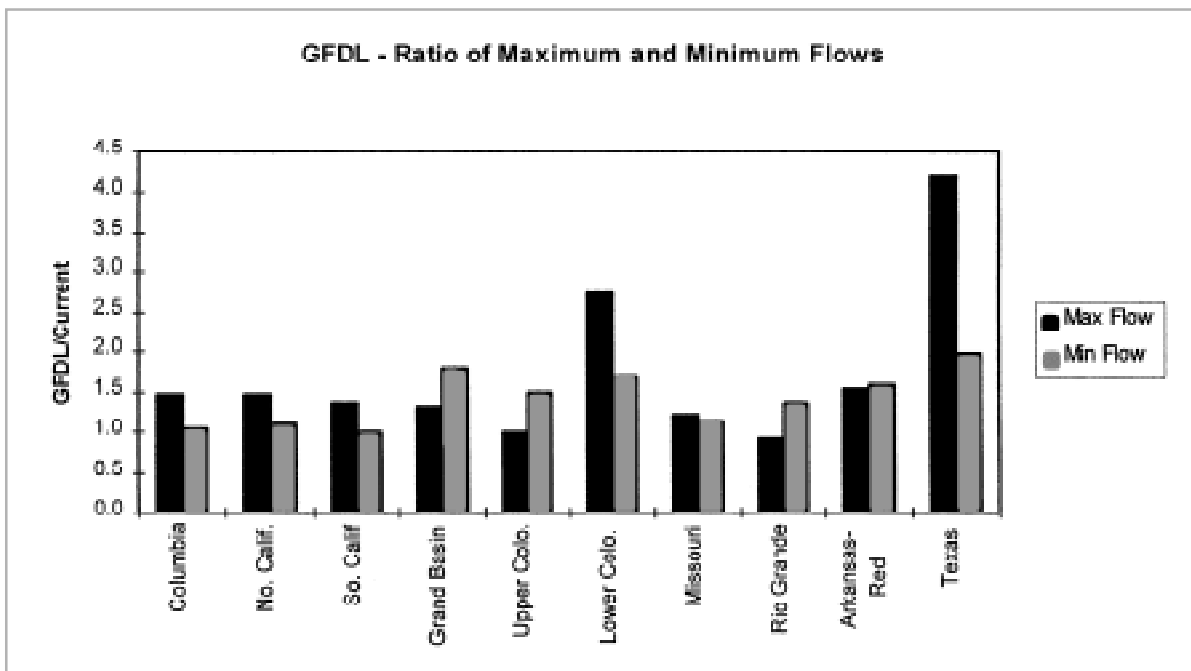


Figure 16. Climate change impacts on maximum and minimum flows—GISS.

the current water-resources infrastructure would not meet design criteria. Adaptations would have to be made. Water allocation in the West is extremely sensitive to the temporal distribution of streamflow. Enormous stress will be placed on existing water institutions at local, state, and federal levels should there be climate- change impacts on the timing of water supply or water demand. The flexibility of institutions to change along with the changing patterns of runoff needs to be explored.

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Ken Strzepek

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Martyn M. Caldwell

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THE FERTILIZING EFFECTS OF CARBON DIOXIDE

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Increasing quantities of CO₂ in the atmosphere contribute to the “greenhouse effect” and global warming. However, CO₂ is also used by green plants to grow. Thus, under many circumstances increasing CO₂ might cause greater plant growth if CO₂ is otherwise the limiting resource for plant growth. How much increased growth should we expect in a future world of twice the present-day CO₂? Will all plants be similarly affected? Will there be other changes in vegetation we should expect?

Extensive research on this topic has been underway in the last several years. In these studies, plants are grown in growth cabinets or outdoors in large cylinders or even in the open surrounded by special computer-controlled standpipes emitting CO₂ into air around the plants. In all these studies, the plant growth and performance is compared with plants growing under normal “ambient” CO₂ and an elevated CO₂ level - - usually twice the ambient level. From this body of research, some generalizations and educated guesses can be drawn about plant response in an elevated-CO₂ world that is fast approaching.

Some rather consistent findings include:

- (1) Plants that are otherwise well supplied with water and nitrogen, and experiencing favorable temperatures and sufficient light, will benefit from added CO₂ much more than plants growing under less favorable conditions. If, for example, nitrogen or water is limiting, elevated CO₂ will produce little effect. The benefits can include more growth, increased fruit production, and more root growth.
- (2) Even under favorable growing conditions, plant species will vary in their responsiveness to elevated CO₂.
- (3) For the same leaf area, plants will generally lose less water since the pores on the leaves (called stomates) will tend to close to some degree in elevated CO₂. Thus, under many conditions, it will generally take less water to grow the same amount of plant material under elevated CO₂ if growing conditions are otherwise suitable.
- (4) Whether less soil moisture is consumed, however, depends on the timing of plant growth and whether more leaf area is produced under the elevated CO₂.
- (5) Some plants already possess internal CO₂-concentrating “pumps” and therefore will likely not respond as much to increasing CO₂ in the air. These include most warm-season grasses and their agricultural relatives such as sugarcane, maize, sorghum, etc. Many succulents and weedy broadleaf plants also possess these pumps and will be less responsive to the increased CO₂.
- (6) Outside of agriculture, most natural vegetation includes mixtures of several species. Since different species of plants respond to different degrees of CO₂ enrichment, the balance of competition between plant species will likely be

affected. For example, in mixtures of warm-season grasses and normal cool-season grasses, the warm-season grasses might lose ground since the cool-season grasses profit more from the added CO₂. The result would be changes in the composition of plant communities.

- (7) Plant tissues will have lower nitrogen (and protein) quantities, more carbohydrates, and alterations in other chemical constituents under elevated CO₂. Such changes have implications for the feed quality of forage crops and the degree to which insects consume plant tissues. However, the direction of change in insect consumption is difficult to predict. It will vary among plant and insect species and growing conditions.

These generalizations concern primarily the responses of plants to elevated CO₂. But, in nature, vegetation and soil need to be considered together when considering the response of whole ecosystems to greater CO₂. There will be many indirect effects of elevated CO₂ on soils, soil nutrients, and loss of CO₂ from soil, termed soil respiration. These can be very important effects at the ecosystem level and in some areas the effects on soil CO₂ fluxes can overwhelm changes in the vegetation CO₂ exchange. For example, in the Arctic, elevated CO₂ and the warming associated with global change may cause the whole system to be more of a source of CO₂ emission rather than a net consumer of CO₂ on an annual basis, according to some studies. Thus, the whole system CO₂ balance must be taken into account when considering how elevated CO₂ may influence the manner in which global change affects overall CO₂ balances.

In summary, elevated CO₂ will probably have a growth-promoting effect on many plants in the coming years, depending on their growth conditions. It may affect the balance of competition among plant species in many forests, grasslands, etc.; and cause unpredictable changes in the ways insect pests affect vegetation. Apart from the effects on plants themselves, other indirect effects, especially on soils, need to be considered.



Ronald P. Neilson

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POTENTIAL EFFECTS OF GLOBAL WARMING ON NATURAL VEGETATION AT GLOBAL, NATIONAL, AND REGIONAL LEVELS

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Global vegetation modeling for assessments of global warming impacts has progressed from empirical, correlational modeling, such as Holdridge (1947) to increasingly process-based equilibrium modeling of potential natural vegetation (e.g., VEMAP Members 1995) to the first generation of Dynamic Global Vegetation Models (DGVM), which are only now emerging (Woodward et al. 1995; Foley et al. 1996; Neilson & Running 1996). The global equilibrium vegetation models include two separate model classes, biogeography (vegetation distribution) and biogeochemistry (growth and nutrient cycling) models. The two classes of global models were recently intercompared and loosely coupled for an assessment of both model realism and the potential impacts of global warming on U.S. ecosystems (VEMAP Members 1995).

The Vegetation/Ecosystem Modeling and Analysis Project (VEMAP) compared three biogeography models, including MAPSS (Neilson 1995) and three biogeochemistry models (VEMAP Members 1995). The VEMAP process determined that all the models have roughly equal skill in simulating the current environment, but do exhibit some divergences under alternative climates.

The MAPSS model (Mapped Atmosphere-Plant-Soil System) is the only biogeography model originating in North America and the only one applied at a relatively high 10 km resolution (Neilson 1995). The results that I will present here are generally consistent with the other VEMAP biogeography models, but contain significantly more detailed spatial information. The newer DGVMs couple the capabilities of both the biogeography and biogeochemistry models, but were too new to have been broadly tested for assessment use at the time of this presentation.

The MAPSS model simulates the competition for light and water between overstory woody vegetation and understory grasses. Thus, it is capable of simulating the full continuum of vegetation types from desert, through shrub-steppe, savannas and forests. Although we commonly aggregate the vegetation into 7-10 types (Figure 17), there are currently 45 unique vegetation types simulated by MAPSS (Figure 18).

Part of the climate input for the western-U.S. portion of these maps includes a polar-front gradient running west-east along the Idaho-Nevada border, and a subtropical jetstream gradient extending from northern Baja California into Wyoming. This produces a north-south precipitation gradient of polar-front winter precipitation declining from north-south, and a south-north decline of subtropical, monsoonal summer moisture. With warming, the polar front could shift northward or weaken, and bring more summer rains into the Rockies and Intermountain West.

Several possible future climate scenarios for the time of doubled CO₂ concentration (ca. 2050-2100) have been constructed (summarized in Neilson and Drapek, 1998). Simulations by the MPSS model of vegetation change under these future scenarios has

MAPSS Simulated Vegetation Distribution - Current

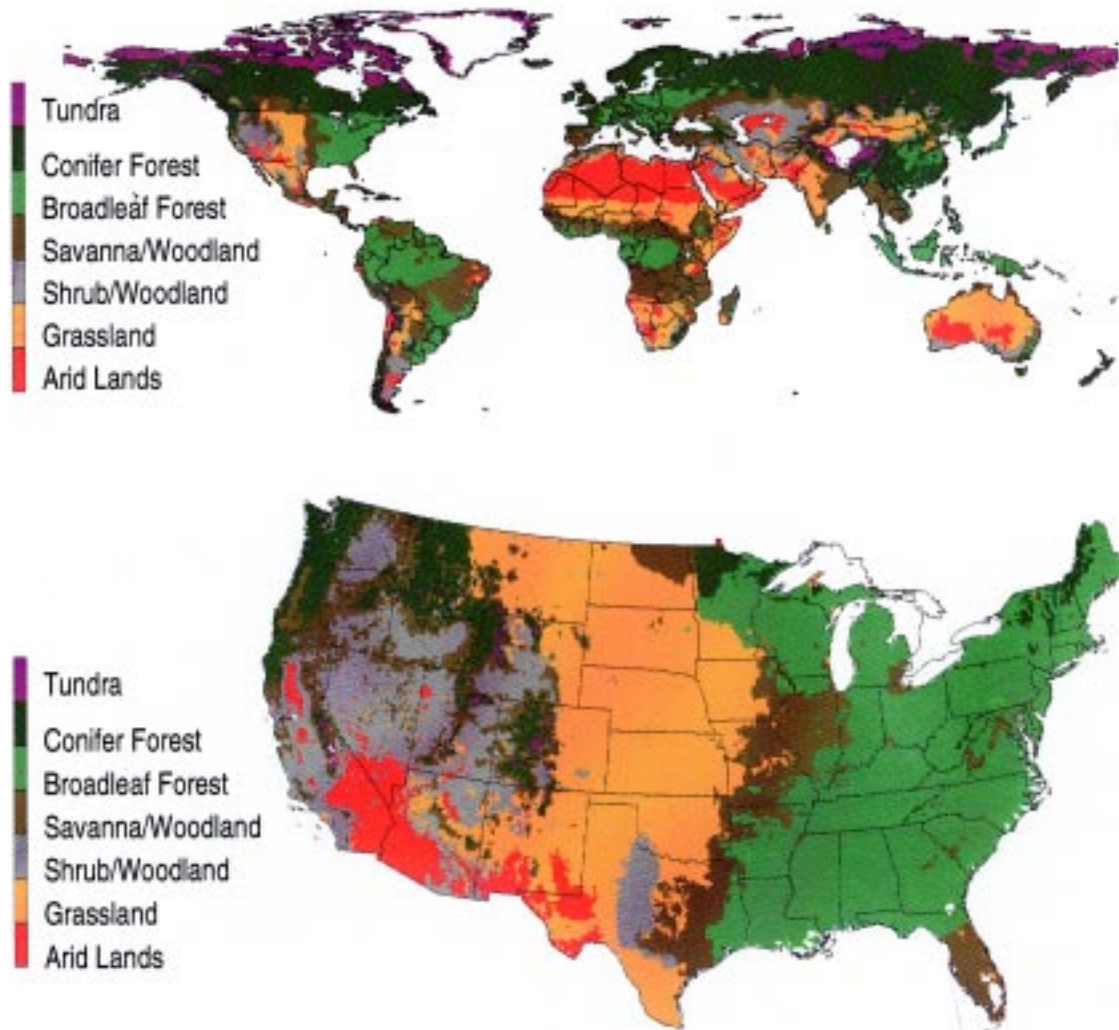


Figure 17. Global and U.S. vegetation distribution under current climatic conditions simulated with the MAPSS model with seven aggregated vegetation types.

MAPSS Simulated Vegetation Distribution - Current

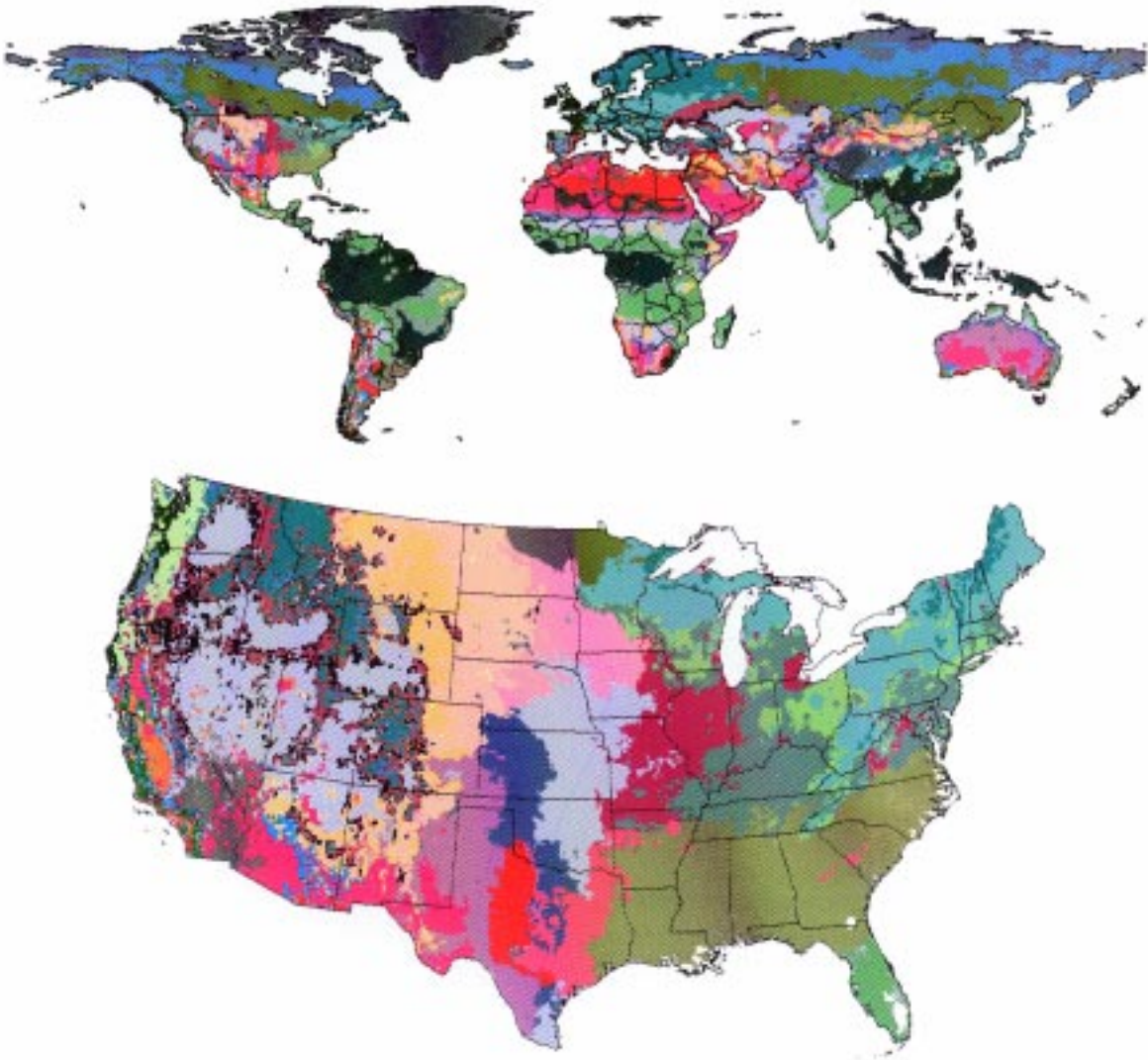


Figure 18. Global and U.S. vegetation distribution under current climatic conditions simulated with the MAPSS model, and with fine-scale subdivision of vegetation types.

Key to MAPSS Vegetation Types

	Deciduous Broadleaf Forest (Oak / Hickory)
	Warm Conifer / Hardwood Forest (Oak / Pine)
	Cool Conifer / Hardwood Forest (Pine / Fir / Hardwood)
	Tropical Evergreen Broadleaf Forest
	Taiga (Boreal Forest)
	Warm Conifer/Hardwood Forest
	Seasonal Tropical Forest
	Dry Tropical Savanna
	Cool Hardwood Forest (Beech / Maple)
	Evergreen Needle Maritime Forest (Douglas Fir)
	Evergreen Needle Continental Forest (Douglas Fir)
	Deciduous Broadleaf Tree Savanna
	Warm Mixed Tree Savanna (Oak Savanna)
	Cool Mixed Tree Savanna
	Warm Mixed Tree Savanna (Oak Savanna)
	Evergreen Needle Maritime Tree Savanna (Pine Savanna)
	Evergreen Needle Continental Tree Savanna (Pine Savanna)
	Pinyon / Juniper Savanna (less grass)
	Pinyon / Juniper Savanna (more grass)
	Juniper Savanna (maritime)
	Open Shrubland
	Tropical Shrub Savanna
	Mixed Cool Shrub Savanna
	Sage / Steppe
	Subtropical Mixed Shrub Savanna (Mesquite / Oak Woodland)
	Dry Subtropical Shrubland
	Chaparral
	Tall C3 Grassland
	Mid C3 Grassland
	Short C3 Grassland
	Tall C3 / C4 Grassland
	Mid C3 / C4 Grassland
	Short C3 / C4 Grassland
	Tall C4 Grassland
	Mid C4 Grassland
	Short C4 Grassland
	Semi-desert C3 Grassland
	Semi-desert C3 / C4 Grassland
	Semi-desert C4 Grassland
	Temperate Desert
	Subtropical Desert
	Tropical Desert
	Extreme Desert
	Taiga/Tundra
	Tundra
	Ice

produced the following possible impacts, which are further described in Neilson and Drapek (1998).

At a global scale:

- (1) Tundra declines, boreal and temperate forests shift northward.
- (2) There is a large increase in tropical forests under low warming levels, sharp tropical-forest decline under hotter scenarios.
- (3) There is increased vegetative biomass in tropical deserts.

At the North American scale:

- (1) Both broadleaf and northwest conifer forests shift northward.
- (2) Northwest conifers increase in Alaska, potentially to a large extent.
- (3) Forests are at risk in southern areas of the Northwest and Southeast under hotter scenarios. With less warming, forests could expand to the south in the northwest forests and into marginal regions in the Southeast.

It is of interest to note the relative biome shifts projected by the MAPSS simulations under three different possible future scenarios (Figure 19) produced by different climate models (OSU, Oregon State University; GFDL, Geophysical Fluid Dynamics Lab; UKMO, United Kingdom Meteorological Office). These models produce different levels of possible warming under doubled CO₂ concentration, with the OSU model producing the least warming and the UKMO model the most warming. Under a small amount of warming (OSU), there is minimal change in vegetation distribution (Figures 17 and 18).

Greater warming, as with the GFDL scenario (Figure 19), would produce the following changes:

- (1) Alpine tundra would virtually disappear.
- (2) Lower-elevation forest ecotones (a) would shift down in the Sierra Nevadas, Cascades, and coast ranges; (b) rise in the Blue Mountains of eastern Oregon; (c) stay about the same or rise slightly in the Rockies and Colorado Plateau.
- (3) Grasslands would increase in the Great Basin and southwestern deserts, as would the woodlands.
- (4) Southwest desert species would shift north.
- (5) A large number of southwestern communities - chapparral, oak-mountain mahogany, mesquite-oak woodlands, various types of grasslands - are currently constrained by a thermal boundary at the rim between the Great Basin and the Southwest. These would move dramatically into the Great Basin as the thermal constraint tops the rim.

The large warming scenario of the UKMO predicts profound shifts in vegetation distribution over the U.S. (Figure 19):

- (1) The Prairie Peninsula would shift north displacing Great Lakes forests.
- (2) Southeast forests would gradually become savannas and grasslands.

MAPSS Simulated Vegetation Distribution - 2 x CO₂

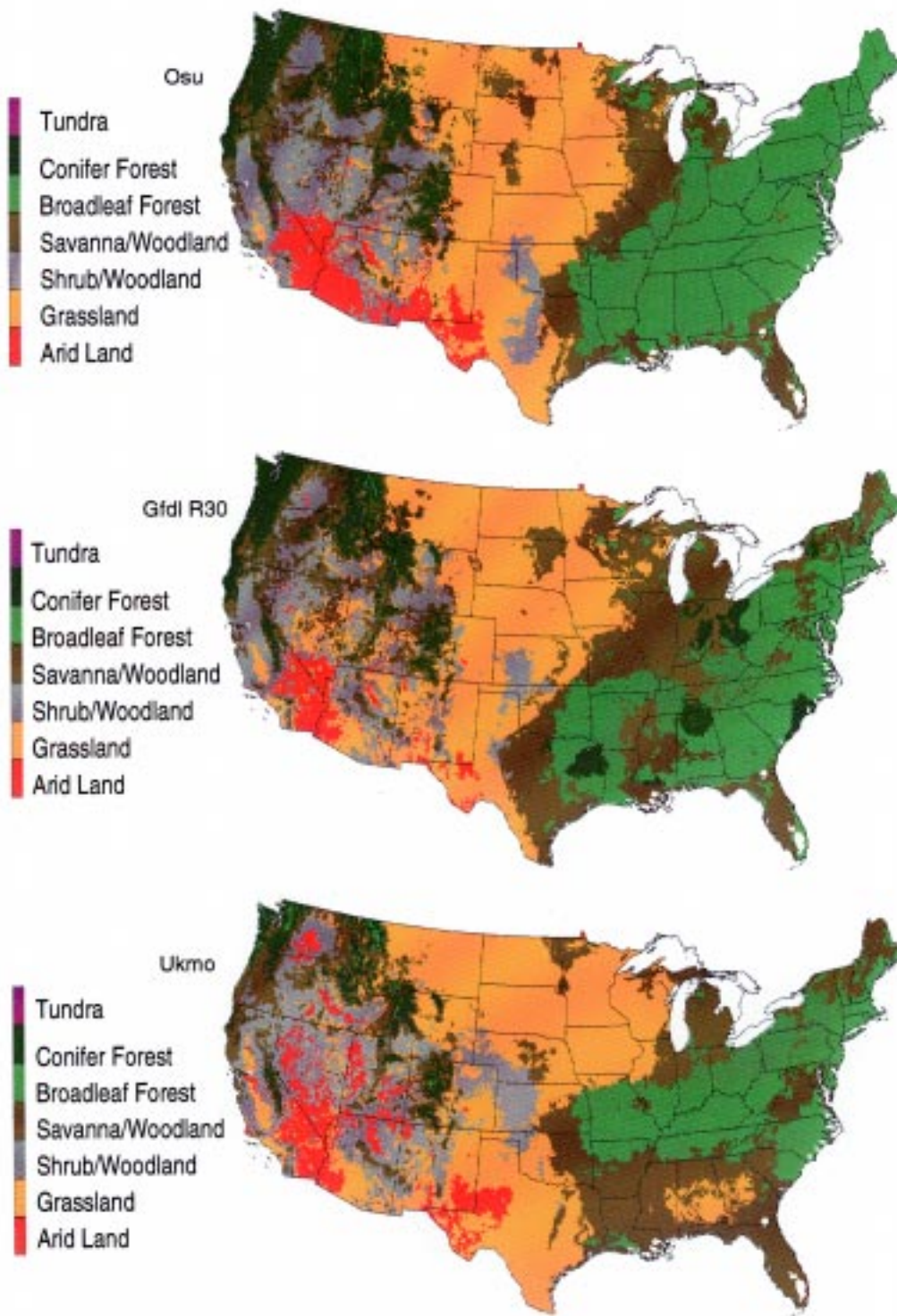


Figure 19. U.S. vegetation distribution under 2xCO₂ simulated with the OSU, GFDL, and UKMO models.

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- (3) Southwestern desert species would shift northward through the Great Basin as far as eastern Washington. It is conceivable that saguaros could be grown in eastern Washington.
 - (4) Central Texas mesquite-oak woodlands would shift north into Kansas, Nebraska, and eastern Colorado.
 - (5) Broadleaf tree species would increase in mountainous areas.
 - (6) Grasses would increase in the Great Basin.
 - (7) Woodlands would increase in the mountain areas of the Great Basin.
 - (8) Sagebrush would decrease, displaced by grasslands and woodlands from the south.

I have also simulated vegetation-density changes, once again using the different temperature-increase scenarios of the OSU, GFDL, and UKMO modeling efforts (see Figure 20). There would be a large increase in vegetation density under slight warming (the OSU scenario) in the West and parts of eastern U.S. that is partly enhanced by the direct fertilization effect on plant growth by the increased CO₂ concentration which would render the vegetation more drought tolerant. What the effect would be on the composition of plant communities cannot be predicted, but the reality of the fertilization effect has been demonstrated in growth-chamber and small field experiments.

Part of the pattern shown in Figure 20 appears to follow the increase in rainfall along the major storm tracks, particularly the polar front and the subtropical jetstream. The Bermuda High also appears to cycle increased moisture up from the Caribbean.

With the hotter temperatures of the GFDL and UKMO scenarios, evaporative demand overwhelms the increased water availability of enhanced precipitation, and vegetation density is reduced through drought stress over most of the West and Rocky Mountains. Areas in the West showing increases in vegetation density are the southwest deserts and the central valley of California.

Conclusion

Regardless of whether the average climate gets wetter or drier in the future, possible changes in the year-to-year variability of weather could produce equally profound impacts. Wet periods build fuels in the woodlands, forests, and shrub-grasslands. Wet followed by dry produces increased flammability, and more and larger fires. However, if the mean trend is toward drier conditions, fires would also break out with increased severity.

Vegetation change could be complex through time. Early effects could show an increase in vegetation growth, in part due to increased drought resistance from higher CO₂ concentrations. With increasing warmth, elevated evaporative demand could overwhelm the increased drought resistance causing forest and vegetation dieback. The scenario would be similar to that occurring in interior forest now. The current dieback is due to fire suppression and buildup of fuels. Similarly, under global warming, forests could dry out, insect infestations might increase (we know that trees under drought stress are more susceptible to insect attack), and forest dieback could occur. Fires would then become more frequent and severe.

2 x CO₂ Potential Vegetation Density Change - MAPSS Simulations

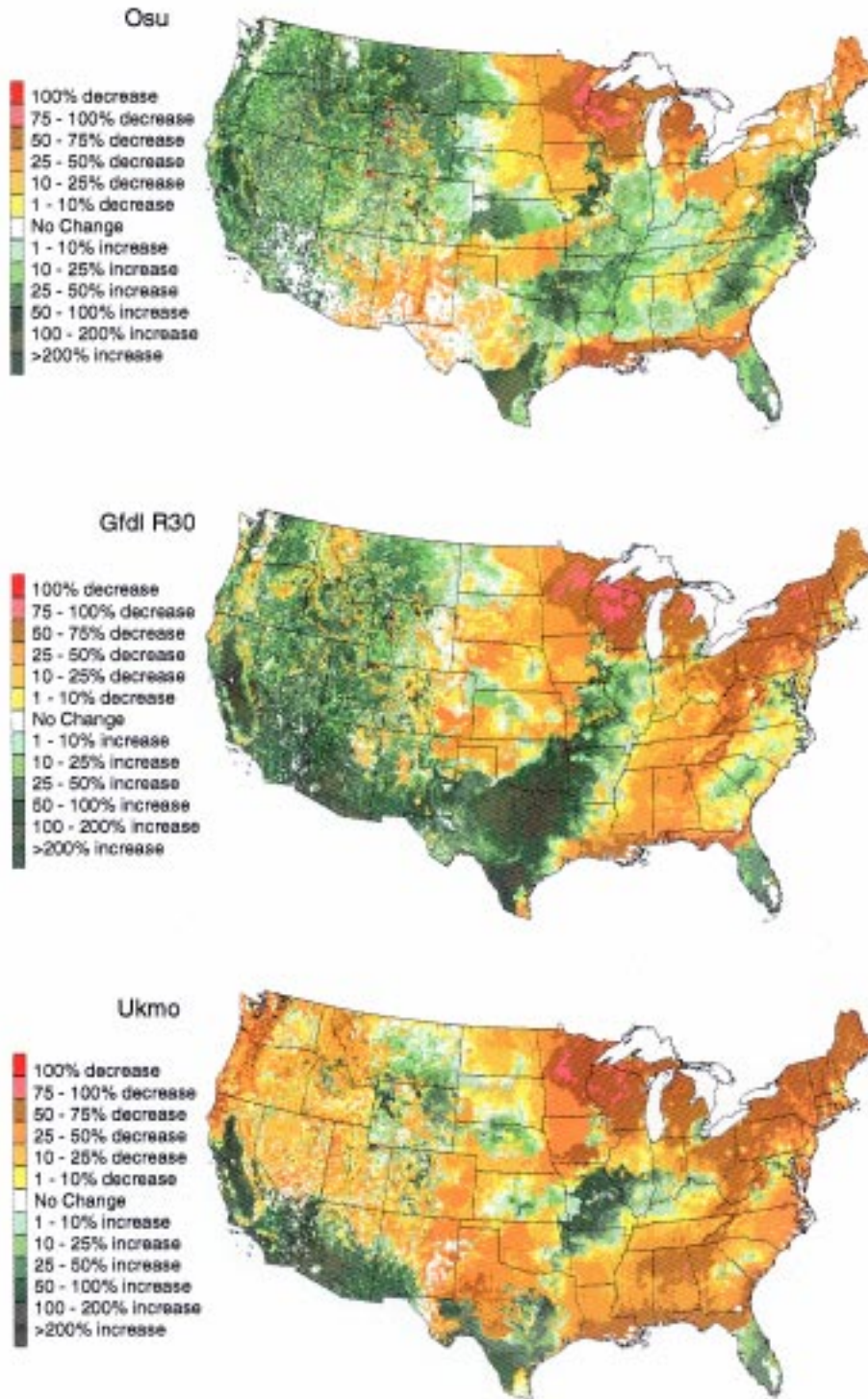


Figure 20. Changes in U.S. vegetation distribution under 2 x CO₂ simulated with the OSU, GFDL, and UKMO models.

Grasslands could increase in the Great Basin, as would woody vegetation in the mountainous regions. Species diversity would increase considerably in the Great Basin as southwestern species moved north into the region.

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William A. Reiners

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ECOLOGICAL EFFECTS OF PROJECTED CHANGES ON ROCKY MOUNTAIN ECOSYSTEMS: GLOBAL CLIMATE CHANGE IN THE ROCKY MOUNTAIN-GREAT BASIN REGION

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Definition and Description of the Rocky Mountain Region

(1) Geographic Definition of the Rocky Mountain Region:

The Rocky Mountain region is normally defined as the central North American cordillera extending from northern New Mexico to northern British Columbia (Figure 21). It is bounded on the east by the Great Plains, and on the west, from south to north, by the Colorado Plateau, Great Basin, Columbia Plateau, and at the Canadian northernmost extent, by the convergent coastal ranges. The Rocky Mountains can be subdivided latitudinally in various ways. Peet (1988) provides a subdivision between the northern and southern Rockies, and differentiates the main cordillera from the mountains of southern New Mexico and Arizona as part of the Madrean Region (Figure 21). Not all geographers divide the Rockies in the same manner.

(2) Area and elevation:

Regional assessments of potential climate change are mostly done on areas of limited relief. In such cases, spatial variation simply can be treated two-dimensionally. With mountainous regions, the essential variations associated with elevation must be taken into account along with variation in latitude and longitude. This is particularly true with the Rockies which feature an elevational extent of approximately 900 to well over 4000 m. In fact, it could be argued that differences along the elevational gradient anywhere along the 1500 km latitudinal extent in the U.S. are greater than the differences between the latitudinal extremes of this cordillera. Thus, a treatment of this topic must include some description of ecosystem variation along elevational gradients.



Figure 21. Map of western United States from Espenshade (1990) showing subdivisions of the Rocky Mountain region as delimited by Peet (1988). Reprinted with permission of Rand McNally Co.

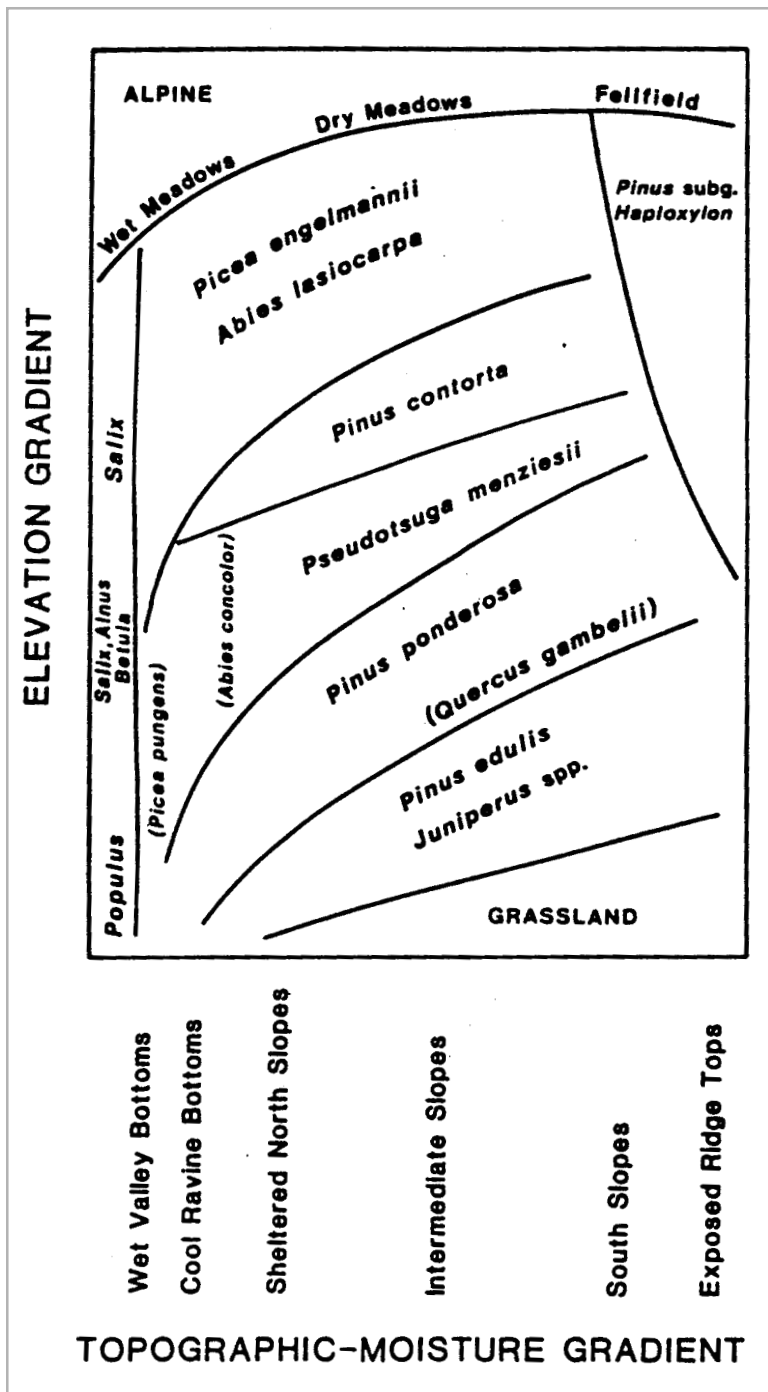


Figure 22. Major vegetation zones of the central Rocky Mountains represented as a gradient mosaic diagram (Peet 1988). Reprinted with permission of Cambridge University Press.

It is convenient to describe the changes in ecosystem structure along elevation and topographic gradients in terms of the dominant vegetation. Peet (1988) provides a unified means for visualizing patterns as elevational zones. Figure 22 is one of Peet's topographic-moisture gradients for the central Rocky Mountains. This is a two-dimensional representation of vegetation units that are mainly horizontally zoned with respect to elevation but show inclinations from horizontal with respect to slope aspect and particular topographic positions such as canyons and ridge tops. In general, vegetation zonation extends from grasslands or shrublands in the foothills, through a series of forest types, to treeline and the alpine zone.

While the general pattern of elevational zonation is more or less the same along the latitudinal extent of the Rocky Mountains, the details of the zones as defined by vegetation dominants, and the elevations at which they occur differ with latitude. Variations in topographic-moisture gradients from the Santa Catalina Mountains of Arizona (technically not part of the Rockies) to Jasper National Park, Alberta are illustrated in Figure 23. Besides illustrating changes in the floristic composition of these vegetational zones, there is also an increase in the slope-aspect effect from south to north due to declining solar angles with increasing latitude. The change in elevational position of vegetational zones is best illustrated by a graph of changing

upper treeline along the latitudinal gradient (Figure 24). Between the Sangre de Cristo of New Mexico to Glacier National Park, Montana, upper treeline descends from about 3600 m to about 2300 m. Other zonal boundaries decline concordantly with latitude. One potential effect of climate change is to change the elevational, aspect, and latitudinal patterns of these vegetational zones. Conceivably, zonal vegetation types may shift in

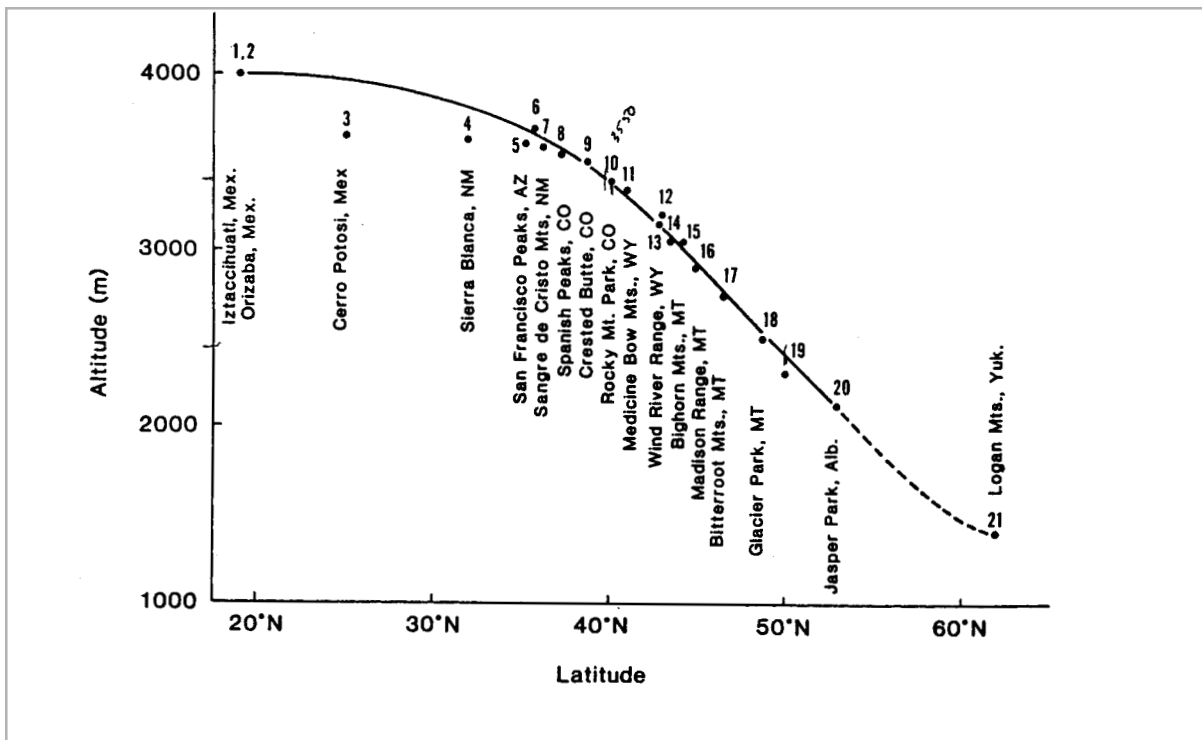


Figure 24. Decline in upper treeline along the latitudinal extent of the Rocky Mountains (Peet 1988). Reprinted with permission of Cambridge University Press.

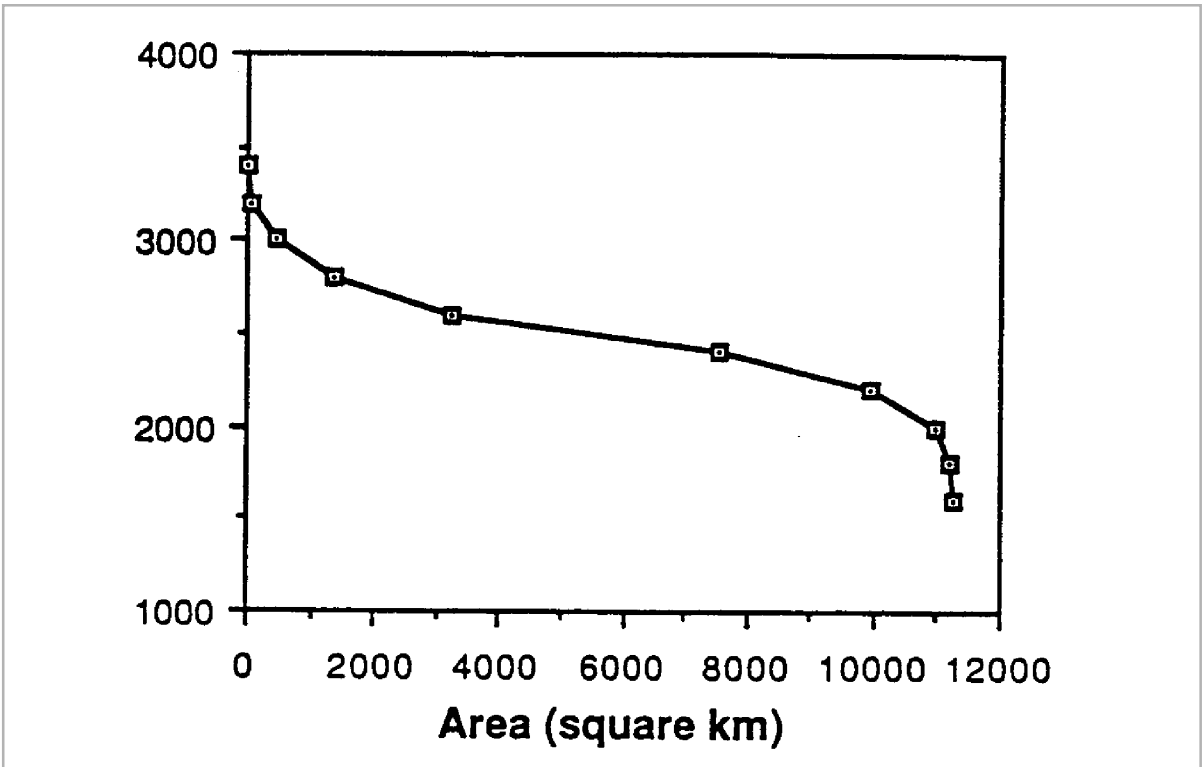


Figure 25. Hypsometric curve for the Greater Yellowstone Ecosystem area (Romme and Turner 1991). Reprinted by permission of Blackwell Science, Inc.

space, become reorganized into new assemblages, or disappear entirely. This will be discussed later. Since vegetation is a major determinant of “habitat,” this means that animal habitats are also vulnerable to shifting. Shifts in environmental variables plus biotic assemblages mean that ecosystem functions may become spatially altered as well.

An important characteristic of mountainous terrain as compared with areas of low relief is that the land area decreases drastically with increasing elevation (Figure 25). This has important implications for high-elevation biota if vegetational zones should move upward on the mountains in response to climate warming. In such an eventuality, high-elevation ecosystems will be reduced in area or eliminated entirely.

Climatic Patterns in the Rocky Mountain Region

(1) Elevational patterns:

It is well known that temperature decreases with increasing elevation. Less well realized is how precipitation may also change. Precipitation can vary with elevation in complex ways not only in amount, but in seasonal distribution. Seasonality of precipitation is extremely important in many ways. Patterns of climatic variation with elevation underlie the differences in ecosystem structure outlined above. These changes are illustrated in Figure 26 for three locations representing an elevational gradient along the eastern slope of the Medicine Bow Mountains at 41.5° north latitude. In the three climate diagrams arranged on the left of the series, temperatures decline as expected, but precipitation increases in a nonlinear way with elevation, and even more important, the seasonality of precipitation changes from a slight summer maximum to a bimodal winter maximum. This means that the dominant form of precipitation occurs as snow in the upper elevations. This has tremendous ecological and hydrological implications not to be detailed here. Suffice it to say that snow pack accumulations and snow melt will be sensitive to changes in amount or seasonality in the Rocky Mountains. As an example, the discharge of a third-order stream along this same gradient is also illustrated in Figure 26. Clearly, the hydrograph is controlled by snowpack melt in May, June, and July. The seasonal hydrograph dictates the fluvial geomorphology, riparian biology and irrigation-water management in the Rocky Mountain region. Obviously, shifts in the hydrograph due to climate change may have effects on these processes.

One other important detail is illustrated in Figure 26. The fourth climate diagram on the right end is for the Saratoga location at the base of the western slope of this range. The seasonal pattern of precipitation is scarcely discernible, yet it is slightly more biased toward late spring and winter precipitation compared with the Laramie location. This small change in precipitation seasonality causes an enormous change in lowland vegetation as the basins to the east of this range are dominated by grasslands, while the basins on the west side of the range are dominated by sagebrush steppe (Figure 27). Through analysis of vegetation data like those represented in Figure 27 together with climate data, we have determined that where summer precipitation (May-October) is greater than 282 mm, there is greater than 75% probability the site will be occupied by mixed-grass prairie (Driese et al. 1997). Conversely, where summer precipitation falls below 222 mm, there is a greater than 75% probability of occupation by Wyoming big sagebrush. Clearly, the balance between these contrasting vegetation types is in a relatively delicate balance in Wyoming and could easily be disrupted by a shift in seasonality of the water balance.

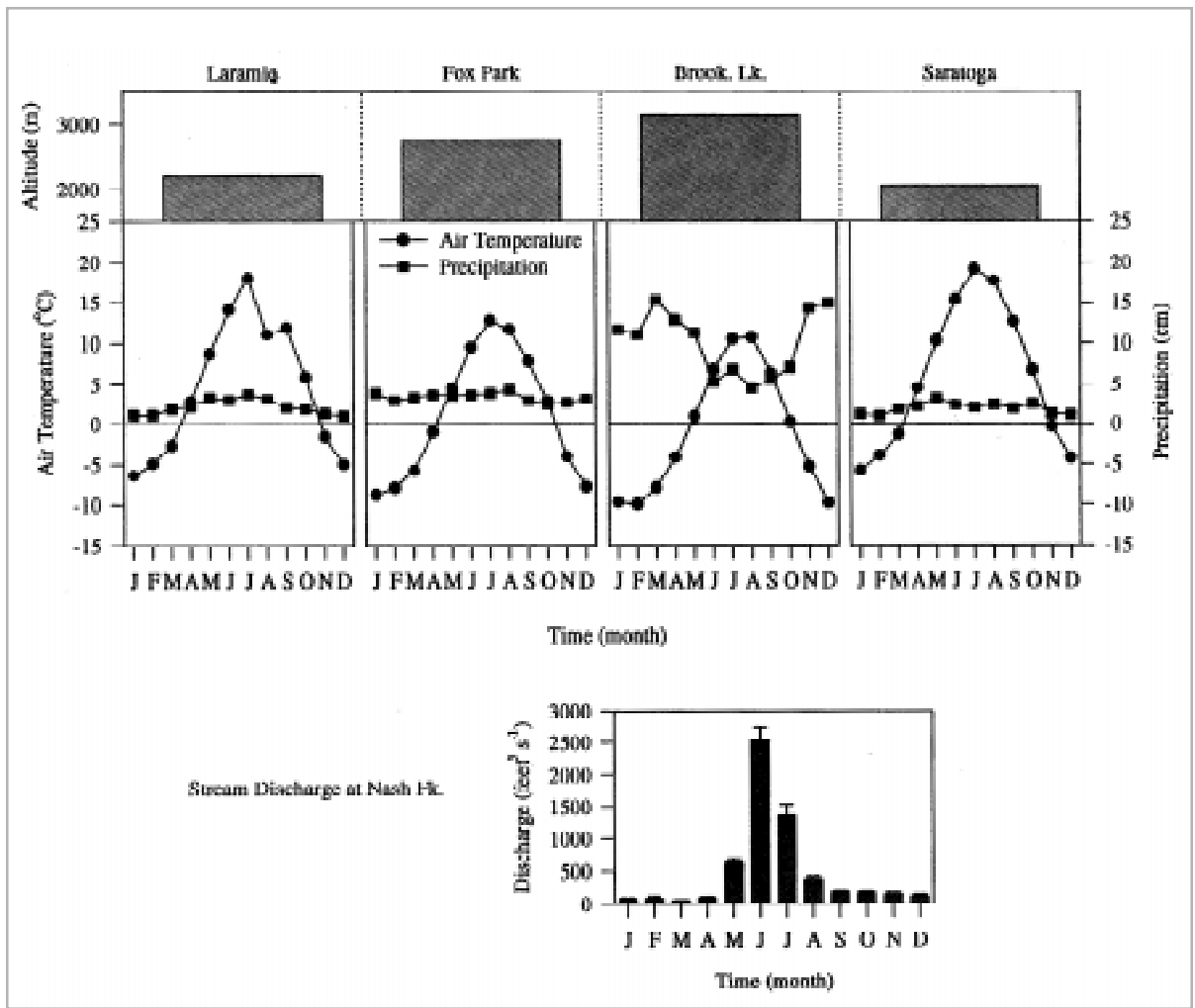


Figure 26. Climate diagrams for four locations in the Medicine Bow Mountains, Wyoming and vicinity. Upper panel, from left to right: Laramie (elev. 2215m), Fox Park (elev. 2760m), Brooklyn Lake (elev. 3158m), Saratoga (elev. 2068m). The first three locations occur along an elevational gradient on the eastern slope of this range; Saratoga lies at the base of the western slope. Lower panel: A hydrograph for Nash Fork, a third-order stream on the eastern slope of the Medicine Bow Mountains, Wyoming.

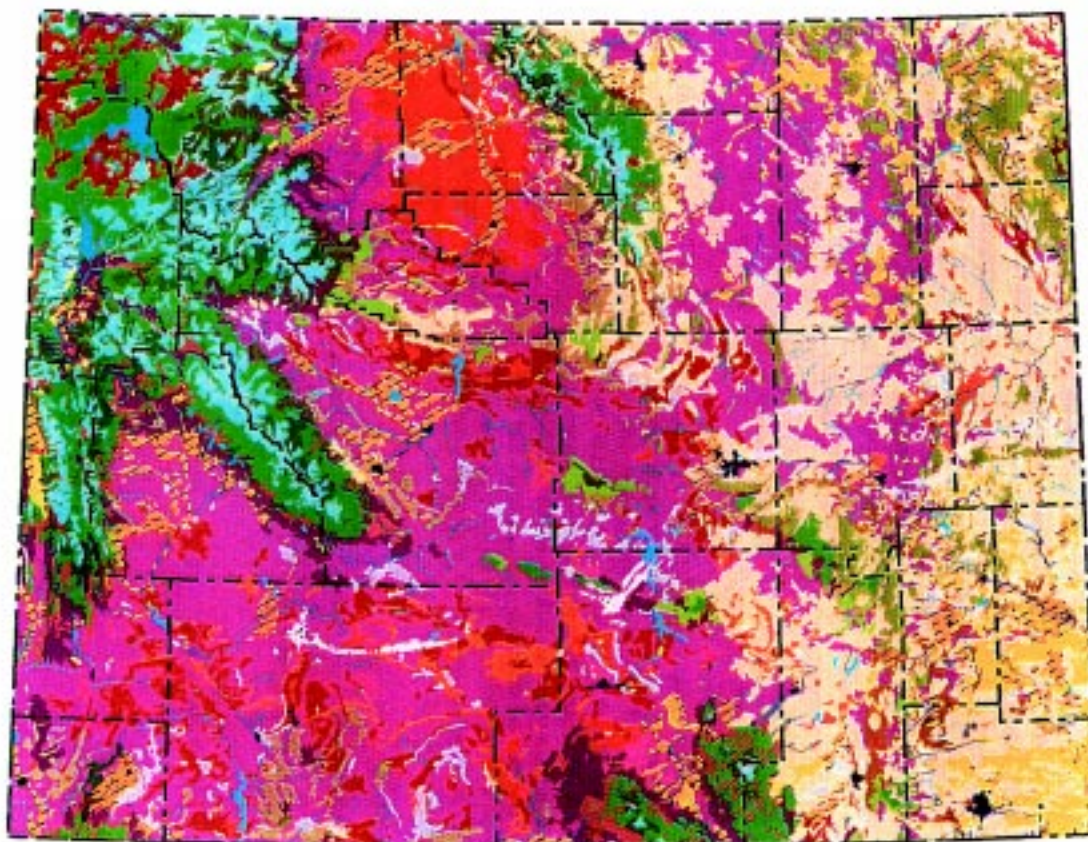
(2) Historical changes in climate in the Rocky Mountain region:

Climate has changed radically throughout the Pleistocene in the Rocky Mountains as witnessed by glacial and periglacial features found throughout the region and by fossil evidence (Thompson 1988). Changes throughout the Holocene are less marked. Is there any evidence for climatic changes in the region over the last century, the period of known global increases in greenhouse-gas concentrations?

A recent product of the VEMAP group is the production of a digital 100-year climate record for the lower 48 U.S. states (Kittel et al. 1997). Kittel and Royle (1998) have used this database to do a regional analysis of climate trends in the Rocky Mountains. Their simulations project 100-year trends for annual average, monthly maximum and monthly minimum temperatures, and seasonal precipitation in the northern, central, and southern Rockies. Their results show no significant trends for maximum temperatures, but there is an upward trend in the minima for all three sectors, with regressions for the northern and

Wyoming, USA Land Cover

1cm = approximately 42.5 km, Projection UTM



Grassland Types

- Short grass prairie
- Mixed grass prairie
- Foothills grassland
- Subalpine meadow
- Alpine tundra

Shrub Types

- Xeric shrub
- Mesic shrub
- Bitterbrush
- Mt. big sagebrush
- Wy. big sagebrush
- Basin big sagebrush
- Black sagebrush
- Salt desert shrub
- Saltbush
- Greasewood

Forest Types

- Aspen
- Bur Oak
- Spruce/fir
- Douglas fir
- Lodgepole pine
- Whitebark pine
- Limber pine
- Ponderosa pine
- Juniper woodland
- Burned conifer

Riparian and Wetland Types

- Open water
- Forest riparian
- Shrub riparian
- Grass and forb wetland
- Grass and forb riparian

Anthropogenic Types

- Human settlement
- Dryland agric.
- Irrigated agric.
- Logged conifer
- Mining operations

Figure 27. Land cover for Wyoming, U.S.A. (Driese et al. 1997). Note shift from grassland on the east slope of the Medicine Bow Mountains to sagebrush steppe on the west slope.

Temperature Changes

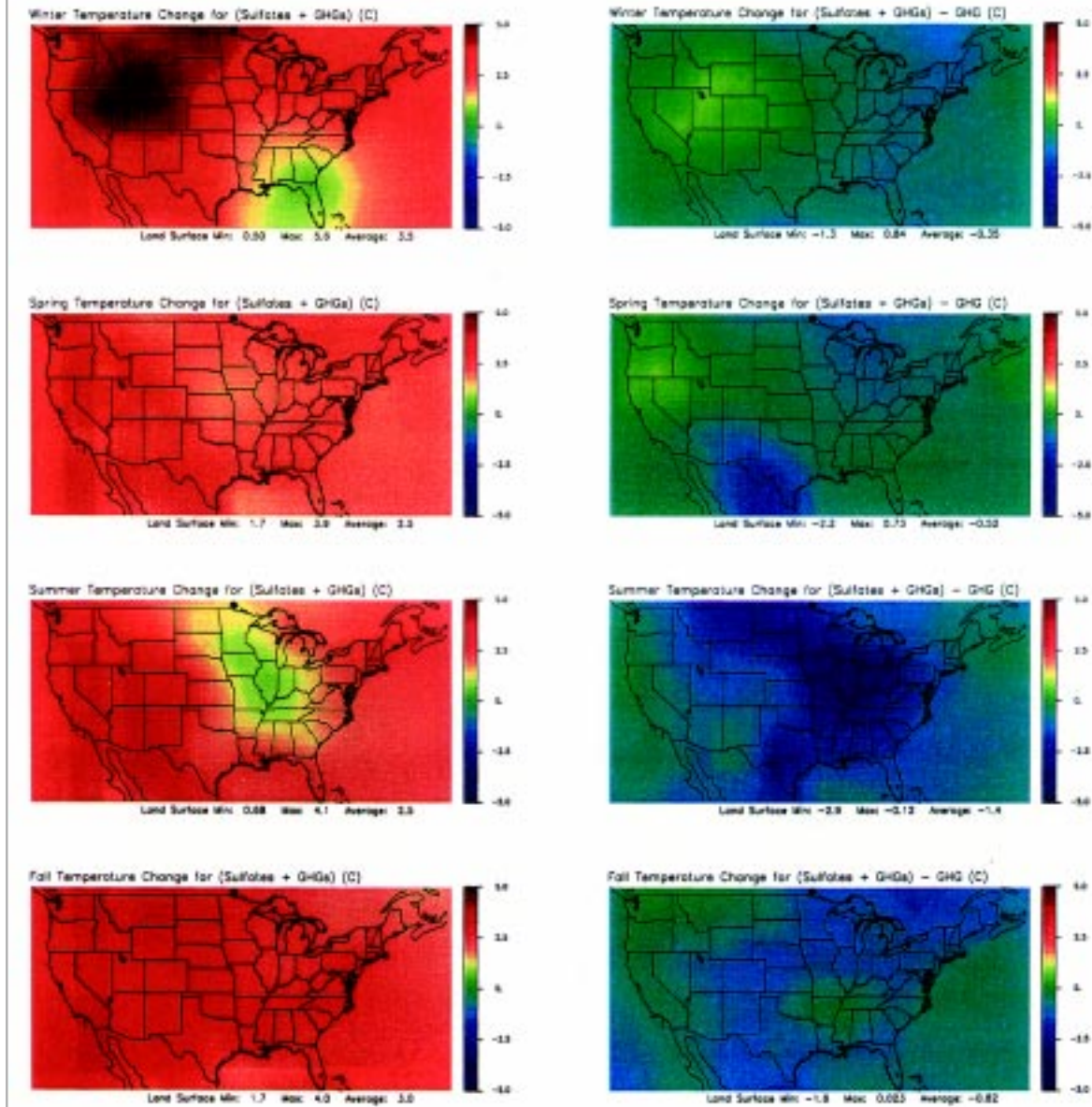


Figure 28. Left: Projected temperature changes over the next century as given by the Hadley Centre based on greenhouse gases and sulfate aerosols for each season. Right: The net effect of sulfate aerosols alone for the same periods (Smith et al. 1997).

Precipitation Changes

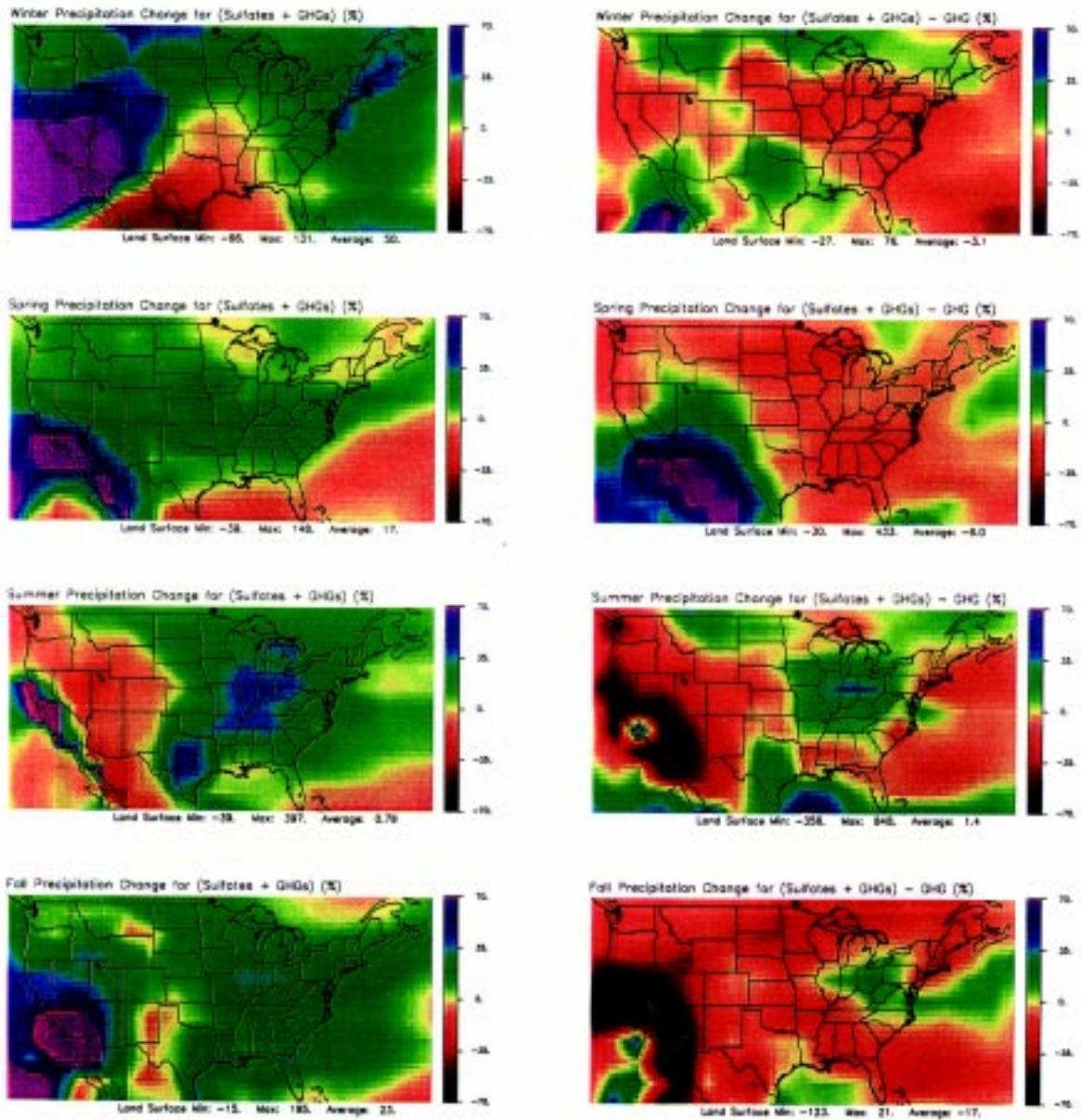


Figure 29. Left: Projected precipitation changes over the next century as given by the Hadley Centre based on greenhouse gases and sulfate aerosols for each season. Right: The net effect of sulfate aerosols alone for the same periods (Smith et al. 1997).

central sectors being highly significant. The increase in minimum but not maximum temperatures is consistent with the widely accepted expectation that the greatest temperature changes will occur in the winter and nighttime rather than in summer and daytime.

These investigators' summer precipitation data over the last 100 years show upward trends that are significant in the central and northern sectors of the Rockies. We must accept that precipitation is not well modeled in general circulation models, so these results are virtually the only information we have on possible changes in seasonal precipitation. Summer rain is welcome but the snowpack is critical to maintenance of mountain ecosystems as we know them as well. Perhaps more data will be forthcoming as the VEMAP data are analyzed further.

(3) Prognoses for future changes in the Rocky Mountain region:

Possibly the best regionalized climate-change predictions available at the present time are presented in a recent NCAR report based on the Hadley Centre Model (Smith et al. 1997). Although spatial resolution is no better than any other GCM (2.5° latitude 3.75 longitude grid size) and terrain is overgeneralized, these predictions are unusually valuable because they incorporate the modeled effects of sulfate aerosols along with greenhouse gases. As can be seen in Figure 28, the western half of the U.S. is predicted to respond more to warming than the eastern half, mainly because of the cooling effect of sulfate aerosols in the East. Particularly in the winter time, the Rocky Mountain region shows the

highest amount of warming over any other part of the country.

Smith et al. (1997) also model precipitation changes (Figure 29). Precipitation projections are considered to be much less reliable than are temperature projections. Nevertheless, according to these outputs, winter precipitation is projected to be higher in the winter in this region, but lower in the summer.

No global-scale GCM really takes topography properly into account. The spatial scale of GCMs "smear" topography of the western U.S. into one general highland. Mesoscale models such as those generated by Pielke et al. (1996) or analyses by analogy with historical deviations from the norm (Levenson 1997) may better inform us about possible trends in precipitation change in the Rocky Mountain region. One generalization of which climate modelers

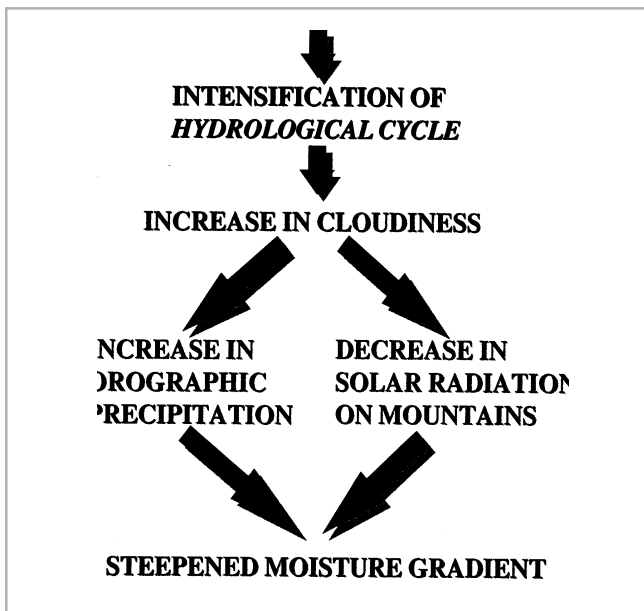


Figure 30. Postulated effects on mountain climate of intensifying the global hydrologic cycle.

are reasonably confident, is that global warming will lead to an intensification of the global hydrological cycle. A manifestation of that will be an increase in cloudiness. It is possible that an increase in general cloudiness may lead to an increase in orographic precipitation as well as a decrease in solar radiation in the mountains. This will lead, in turn, to a cooling at high elevations and a steepening of the moisture gradient between high and low elevations in the Rocky Mountain region (Figure 30).

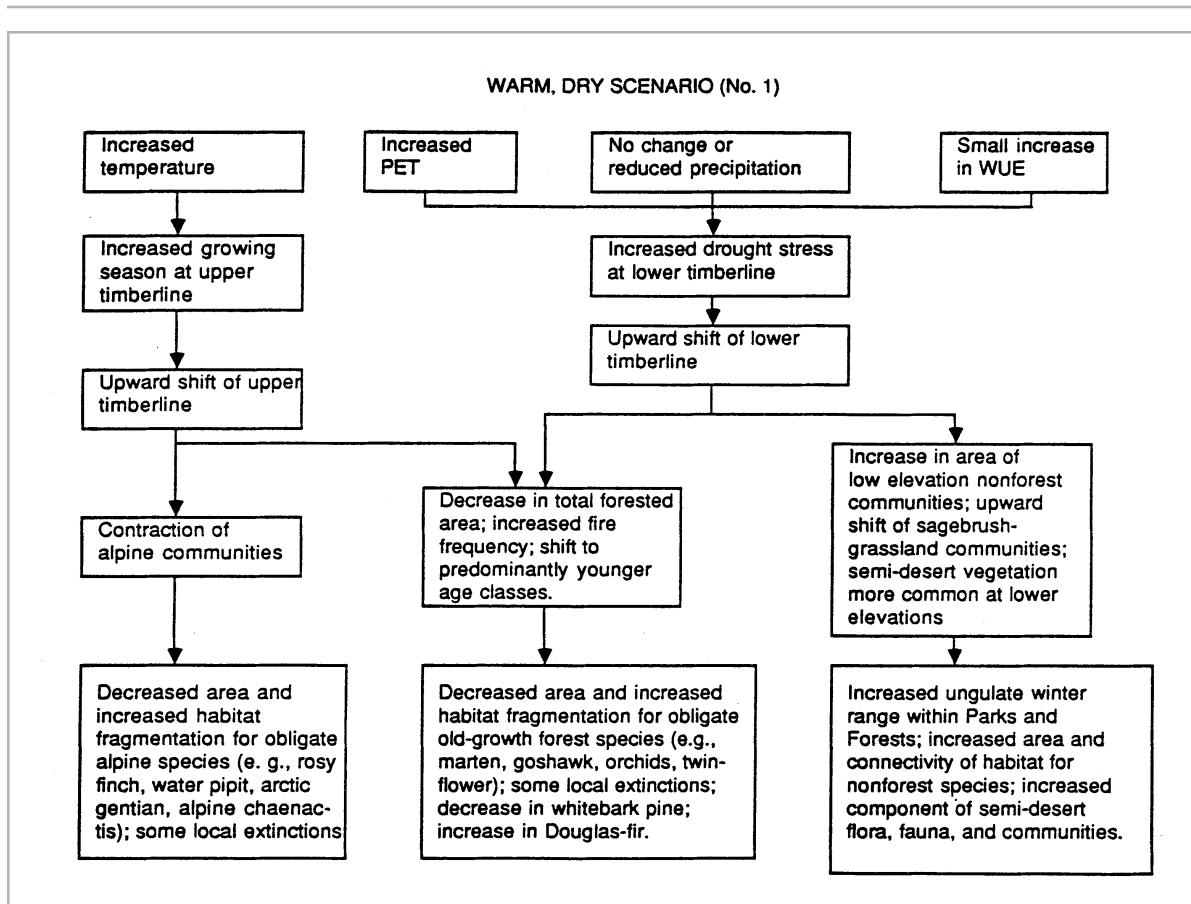


Figure 31. Potential effects on the Greater Yellowstone Ecosystem of a climate that is warmer and drier than the present climate, no provision made for changes in water-use efficiency due to higher CO₂ (Romme and Turner 1991). Reprinted by permission of Blackwell Science, Inc.

Ecological Effects of Climate Change in the Rocky Mountains

(1) Terrestrial ecosystems:

Climate change of the magnitude projected by the Hadley Centre Model would doubtless have extensive effects on the regional patterns of vegetation and attendant habitat and ecosystem functions. Such changes could be modeled by combinations of mesoscale climate, vegetation, and ecosystem models (Kittel et al. 1991, Pielke et al. 1996) as well as some experimentation (Harte and Shaw 1995, Harte et al. 1995), but it is probably premature to exert too much effort in that direction until the GCMs, in which the mesoscale climate models must be imbedded, are improved.

There are a number of respects, however, in which we can consider possible changes for specified scenarios. Romme and Turner (1991, 1992) have done this very effectively for the Greater Yellowstone Ecosystem (GYE) which lies at the northwestern edge of the southern Rockies (Peet 1988). Just taking a consensus of GCM projections at the time, they provided potential outcomes for three possible scenarios: warmer and dryer without compensating increases in water-use efficiency (WUE), warmer and dryer with increased WUE due to higher CO₂ levels, and warmer and wetter without changed WUE. Scenario 1 is given in Figure 31. Possible outcomes include contraction of alpine zones, decreases in the total forested area with attendant fragmentation and extinction of forest species,

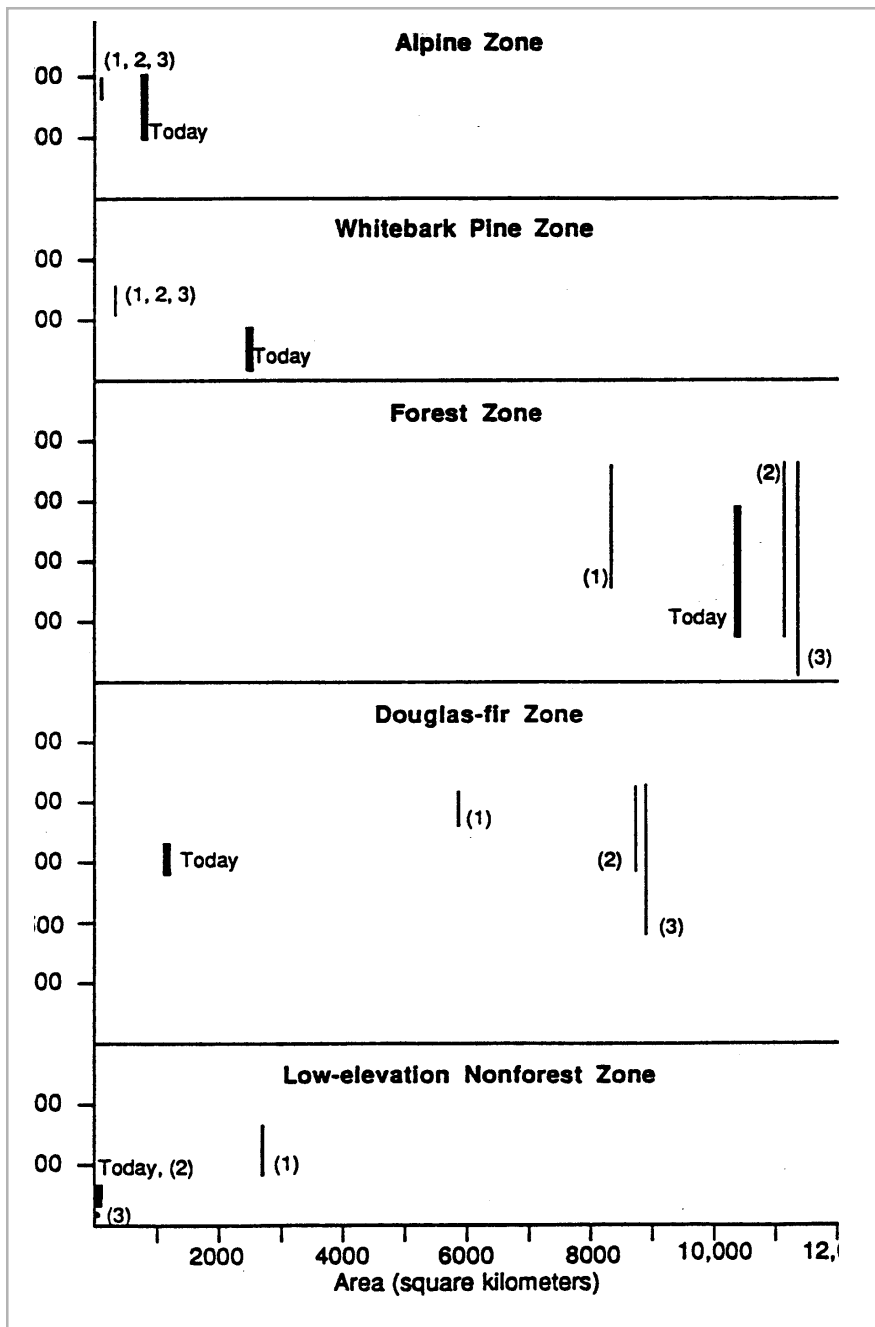


Figure 32. Summary of range shifts for zones within the Greater Yellowstone Ecosystem based on three scenarios: (1) climate that is warmer and drier than the present climate without water-use efficiency changes due to higher CO₂; (2) a climate that is warmer and drier than the present climate but with compensating water-use efficiency changes due to higher CO₂; and (3) a climate that is warmer and wetter than the present climate and without compensating water-use efficiency changes due to higher CO₂ (Romme and Turner 1991). Reprinted by permission of Blackwell Science, Inc.

increased fire frequency, shift in tree demography to younger age classes, increases in non-forested environments, and increases in summer range for ungulates. Outcomes for the other scenarios are variations on these.

A summary of the projected shifts in elevational ranges and spatial areas for different zones in the GYE are diagrammed in Figure 32. In all three scenarios, zonation rises in elevation and the alpine and whitebark pine zones diminish in areal extent. As these zones are critical habitats for some species, this represents a loss in biodiversity and population health. Upper limits of the forest and Douglas-fir zones rise in all cases, but the total elevational ranges expand or contract differently with the various scenarios.

There are many implications of such zonal movement. One aspect is the change in critical habitat that would result for some species. Results of the Wyoming Gap Analysis program indicate that most vertebrate diversity lies at low elevations, particularly in riparian

zones (Merrill et al. 1996). These areas fall outside the mountainous regions being discussed here. However, there are some species, both plant and animal, whose habitats are strictly at high elevation. The clustering of many mammal and bird species at low elevation can be seen in Figure 33, but clearly there are many whose major habitat occurs

above 2200 m elevation (a general foothill elevation for Wyoming). These species would be jeopardized with the kind of zonal shifts projected by Romme and Turner.

Another important aspect to consider is the possible alteration of fire frequencies, extents, and magnitudes in an altered climate (Knight 1994). Fire is a paramount factor in the ecology of the Rocky Mountains and much is known about fire and weather in this region (Johnson and Larson 1991, Johnson and Wowchuck 1993). When GCM projections become more reliable, it will be valuable to evaluate how projections would alter expected fire return times across the cordillera. Forest pathologists should be consulted on how even subtle changes in weather patterns may influence the dynamics of insect and disease outbreaks.

(2) Aquatic ecosystems:

Aquatic ecosystems and their associated littoral and riparian zones are important far beyond their areal extent in the semiarid and arid west.

Due to their glacial history, the Rocky Mountains feature many lakes. And, due to their topography and greater precipitation, they feature many low-order streams. The ecological fate of these aquatic ecosystems has received little attention. Hostetler and Georgi (1995) have simulated changes in the temperatures and energy budgets of Pyramid Lake and Yellowstone Lake with a mesoscale model. It is not surprising that with climate warming, the lake temperatures and thermal dynamics would shift. We can imagine that, with warming and attendant changes in the water budget of the mountains, lake levels, temperatures, and stratification regimes would be expected to change. The streams would be altered in terms of their characteristic hydrographs and total volumes

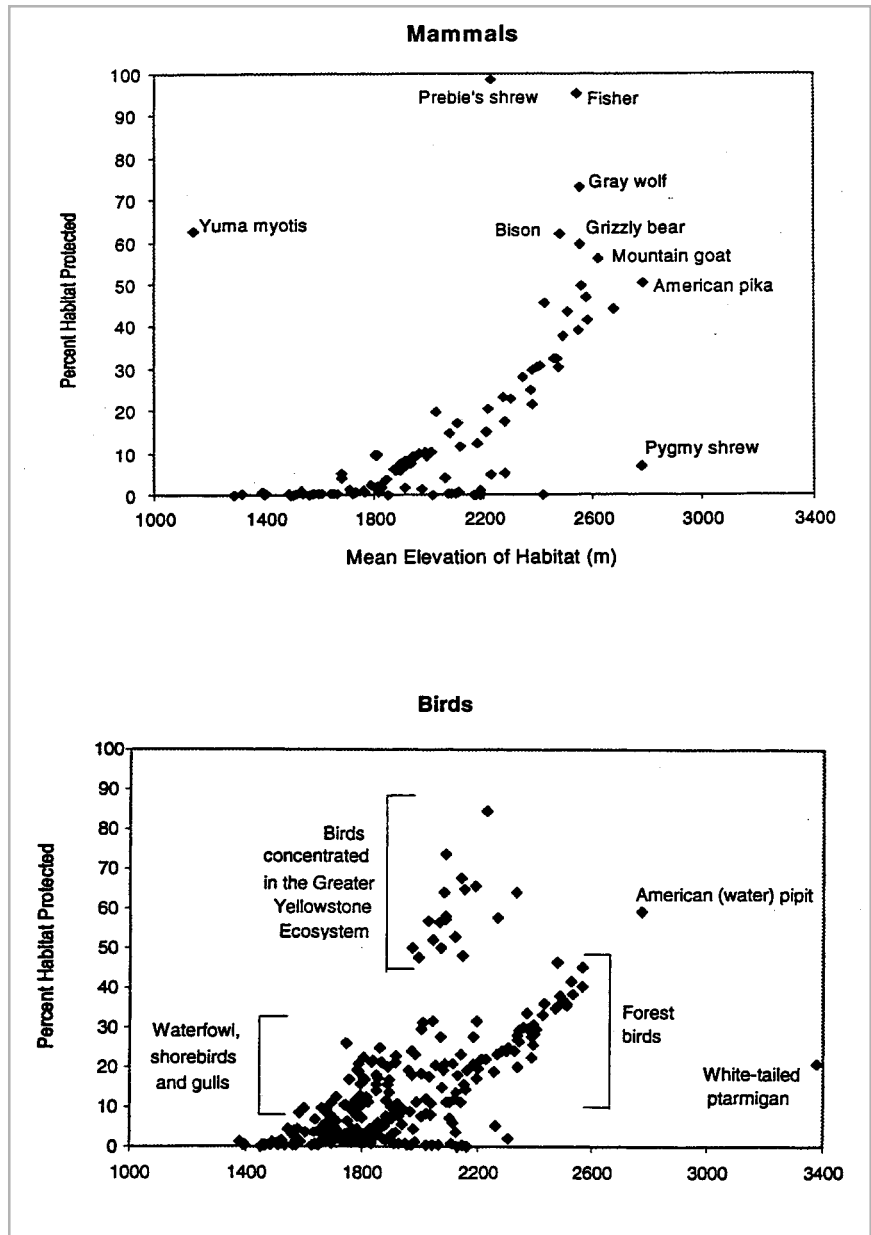


Figure 33. Percentage of mammalian (upper) and avian (lower) species habitats in Wyoming, managed to protect existence of the species, plotted against elevation (Merrill et al. 1996).

of flow. These properties are central to hydrological, geomorphological and biological properties of these streams. Aquatic systems may be the most sensitive of all ecosystems in the Rocky Mountains.

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ECOLOGICAL EFFECTS OF PROJECTED CHANGES ON GREAT BASIN ECOSYSTEMS

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The Great Basin and Its Physical Environment

Physiographically and geographically, the Great Basin is commonly thought of as that region lying between the north-south Wasatch Mountains of central Utah and the Sierra Nevada Mountains along the Nevada-California border. In this perspective it roughly encompasses the western half of Utah and all of Nevada from about 100 km north of Las Vegas northward.

But adjoining areas have similar elevations and climate, and are therefore ecologically similar. Thus, the Great Basin ecology is often considered to include a portion of the southwest corner of Wyoming, Idaho south of the Snake River, the Columbia River Plateau of eastern Oregon, and a portion of southeastern Washington.

Lying in the rainshadow east of the Sierra Nevada and Cascade Mountains, the climate ranges from semi-arid to arid, with precipitation generally declining from north to south. Mean, annual precipitation at Salt Lake City and Reno of 40 and 25 cm, respectively, declines to 10 cm at Las Vegas. Most of this occurs between fall and spring, although the region's southeast extreme is on the northern edge of the Southwest's summer monsoon and receives a small amount of July-September moisture.

In addition to lying 10-12° latitude farther north than the southern "hot" deserts (Chihuahuan, Sonoran, and Mojave) of the U.S., the Great Basin "cold-desert" elevations are significantly higher, ranging mostly from around 1,200-1,700 m. The Great Salt Lake level fluctuates around 1,280 m. This combination of latitude and altitude produces a cool climate in which much of the precipitation occurring in winter falls and accumulates as snow. Spring thaw saturates soil moisture for a short period of plant growth and soil-microbial activity, after which the hot, largely rainfall-free summer dries soil moisture and slows biotic processes.

Topographically, the region is corrugated with small north-south mountain ranges producing the Basin and Range physiographic province. Nevada alone has 160 ranges. There is a positive correlation between elevation and precipitation so that the mountain ranges capture much of the moisture, especially as winter snow. Run-off from the resulting snowpacks supports the streams.

Except for a few in northern Nevada and southern Idaho that flow into the Snake River drainage, the streams - - including major rivers like the Truckee, Humboldt, Bear, and Sevier - - drain internally within the region into marshes and ephemeral salt ponds termed "playas"; or they drain into major lakes such as Pyramid, Walker, Ruby, and Sevier Lakes, Carson Sink, and Great Salt Lake. Thus they never reach the coasts. Most of them are impounded, and provide water for irrigation, urban and recreational use, a limited amount of hydropower, and profoundly altered aquatic ecosystems.

Run-off from the smaller mountain ranges and hills, and from lowland snowmelt in spring, collects in the playas and evaporates under the high summer temperatures. The result over time is salinity build-up in the playas to the extent of surface NaCl flakes, and an upslope gradient of declining soil salinity.

In addition to the elevational salinity gradient, there is also an upslope decline in temperatures, and increase in soil textural diversity and precipitation.

The Biota

As in the Rocky Mountains, the Great Basin elevational gradient in physical environments also produces an elevational gradient in vegetation. These altitudinal changes produce a high level of beta diversity, each of the mountain ranges and surrounding basins in the aggregate having a diverse collection of species, habitats, and landscape structures. But the vegetation alpha diversity at any given site and elevation is low by continental standards. In the basins, the vegetation is frequently expressed in 2-5 perennial species, and on some sites verges on monotypes. As in the southern deserts, diversity rises with increasing elevation, associated with the upslope increase in soil textural diversity and precipitation.

The low-elevation, basin vegetation is commonly divided into two zones. One is the lower salt-desert shrub zone containing salt-tolerant (halophytic) species like greasewood (*Sarcobatus vermiculatus*) and saltbush (*Atriplex falcata*); and the widespread shadscale (*Atriplex confertifolia*), grey molly (*Kochia americana*), and winterfat (*Ceratoides lanata*). This zone occupies about 40% of the lower-elevation, Great Basin Desert type. Greasewood and shadscale are low, woody shrubs. The other species are “half shrubs” (suffrutescents) that die back at the end of each year and regrow from the root crown the following year.

The second zone, at slightly higher elevations between the salt-desert shrub and the woodland zones of the mountains, is the sagebrush-grass zone, occupying over half of the Great Basin Desert. The zone is slightly more diverse than the salt-desert shrub, containing several species of sage (*Artemisia*), associated shrubs, and an understory of perennial bunchgrasses and forbs.

The balance between sagebrush and herbaceous perennials in the region appears to be a function of precipitation and latitude (i.e. possibly temperature and/or growing season). At the lower end of the precipitation scale in the region (i.e. 20-30 cm, 8-12”) sagebrush predominates and herbaceous perennials are a minor component. But from 41 cm (16”) upwards, perennial bunchgrasses are an increasing component, grading eventually into the Palouse Prairie of eastern Oregon and Washington.

Unlike the southern, “hot” deserts, the Great Basin Desert does not have a significant, native, annual-plant flora. In some areas, native annuals are virtually nonexistent. But there is a conspicuous, introduced annual flora that is largely a disturbance vegetation. Intact, largely undisturbed, perennial vegetation, even with only 1 or 2 species, blocks expression of most of the nonnative annuals. But with disturbance or removal of the perennials, and in above-average precipitation years, the annuals grow in profusion (Figure 34).

The low-diversity basin vegetation of the region supports a more diverse fauna. A given valley may have 10-15 species of rodents, 2-4 lagomorphs, and 1,000 species of arthropods. And this array may support a predatory superstructure of 10-15 species of

raptors, 5-8 species of carnivorous mammals, and a low species diversity of insectivorous birds.

At increasing elevations, the Basin's mountain ranges have a series of wooded or forested zones ranging from the pinyon-juniper (*Pinus monophyla* and *Juniperus osteosperma*) zone above sagebrush-grass, up through ponderosa pine and/or Douglas fir (*Pinus ponderosa*, (*Pseudotsuga menziesii*), to subalpine fir and Engelmann spruce (*Abies lasiocarpa* and *Picea Engelmani*). The animal life changes through these zones, showing affinities for the continental boreal forest in the higher ones.

Because of the internal drainage and frequently ephemeral nature of the streams, there is little capacity for gene flow among the aquatic species. As a result, there is a considerable number of endemic species and subspecies in the streams and lakes, a number of which are now threatened or endangered. The few wetlands of the region, scattered through a largely arid to semi-arid environment, are strong attractions for dense concentrations of migratory, aquatic birds.

Possible Climate-Change Effects

In arid and semi-arid areas, like the Great Basin, the concerns about possible climate-change effects focus more on possible changes in precipitation than on temperature. The global forecasts predict increased precipitation for the world as a whole as a result of warming. But how any given region is affected depends on the dynamics of the local meteorology.

Precipitation in the Basin arrives from two sources. The major one is the southward shift of the subpolar storm track in winter to and below the U.S.-Canadian border. This produces the predominantly winter precipitation of the region, in declining amounts from north to south; and its movement back across the international border produces the predominantly dry summer season. The second source is the southwestern monsoon, the edges of which reach the southern Great Basin in small amounts and provide a limited amount of summer moisture.

This is the average pattern, but it undergoes a great deal of year-to-year variation induced by the ENSO cycle. In El Niño years, the subtropical storm track, normally positioned over northern Mexico, shifts northward approximately along the Mexican-U.S. border bringing winter precipitation to the U.S. Southwest, and slightly augmenting winter precipitation in the southern Great Basin. At the same time the subpolar track shifts northward reducing winter precipitation in the northern Great Basin, and producing subnormal winter precipitation in the Pacific Northwest.

How the Great Basin biota will respond to global warming will depend importantly on how these moisture patterns are affected. One possibility being considered by climatologists - - and I emphasize that this is highly speculative at this point - - is a permanent northward shift of the subpolar storm track. Since the region is a primarily winter-precipitation area, this would have a net drying effect with reduced snowpacks and stream run-off, and negative effects on wetlands and stream biotas. The endemic Threatened and Endangered stream species would be at risk.

Another possibility under consideration is a northward extension of the monsoons, bringing more summer moisture at least to the southern half of the region. Whether or not this would result in a more mesic summer environment would depend on whether the rainfall increase were sufficient to override the higher evapotranspiration resulting

from the higher temperatures. If that occurred, it would give the Sonoran Desert plant species to the south a competitive advantage over the Great Basin species adapted to winter moisture, and facilitate displacement of the latter. That would occur even more readily if there were a decline in winter moisture. The net result could be an infusion of Sonoran Desert species, as predicted by Neilson in his paper, and in particular an increase in warm-season, perennial grasses, all at the expense of the present Great Basin shrubs and perennial herbaceous species.

These changes would almost certainly occur gradually, and their reality might depend on whether they could occur in the face of more rapid, precipitation-linked changes in the Great Basin biota presently underway. Sagebrush and shadscale, the most widespread shrubby species across the Great Basin, are very fire sensitive, suggesting that they did



Figure 34. Adjoining sagebrush and cheatgrass vegetation types in Curlew Valley, northwestern Utah. In this eastern Great Basin area, intact, native perennial vegetation can block growth of nonnative, annual weeds. When the perennials are destroyed by fire or other severe disturbance, as probably occurred on this site, the exotic annuals flourish and constitute a semi-permanent ecological conversion.

not evolve with fire. At the more mesic end of the sagebrush-grass steppe, the understory of perennial grasses and forbs provides a fuel source for fire. When it occurs, the shrubs are eliminated and the vegetation is converted to grassland, provided there is an understory of perennial grasses.

At the more arid end of the sagebrush-grass steppe, there is little understory by virtue of the scarcity of herbaceous perennials and the depauperate native-annual flora. As a result, the interplant spaces are characteristically and extensively bare ground (cf. Figure 34). Hence there is little fuel for fire, and one must suspect from this, and from the sagebrush sensitivity to fire, that it was uncommon in prehistory.

The exotic annuals introduced by Europeans now change the pattern. A healthy, largely undisturbed shrub stand - in many cases only a single species - can prevent expression of the annuals

even though there is a ubiquitous seed source (cf. Figure 34). But if the shrubs are significantly disturbed as with grazing, or removed as with fire, a flush of annual growth dominates the site (Figure 34). The process is accentuated by above-average precipitation (Anderson and Inouye 1988, Young 1994). In higher precipitation years, some annuals can grow in only moderately disturbed shrub stands, and more species of the exotics grow in profusion.

The annuals provide a fuel source, and lightning or anthropogenic fires burn off the shrubs and convert the vegetation to pure stands of annuals that flourish in all but the driest years. There is some debate among plant ecologists over whether the native perennials can reoccupy and succeed the annuals. But the debate may be largely theoretical since the annuals, once they dominate a site, provide an annual fuel source that is susceptible to periodic fire. Periodic fires thus de facto, permanently alter the biota (D'Antonio and Vitousek 1992).

Moreover, the process is a positive-feedback one. The more the Great Basin is burned off, the greater the area with fuel and the likelihood that lightning strikes or errant cigarette butts will start fires (Knapp 1996). As a result the annual number of fires in the Great Basin is rising exponentially (Figure 35). Over the period 1983-88, an average of 0.3% of the area of Nevada and western Utah burned each year. In 1985, an above-average precipitation year, 1.0% of that area burned.

Ecologically, the changes constitute the impoverishment of the entire biota. Rodents and lagomorphs of the region depend on the native vegetation for food and habitat. These prey species virtually disappear when the shrubby vegetation is burned off and converted to monotypes of exotic

annuals (Larrison and Johnson 1973, Groves and Steenhoff 1988), and with them the predator communities which they support (Clark 1972, Wagner and Stoddart 1972, Egoscue 1975, Smith and Murphy 1979, Smith et al. 1981).

Climate-change effects are likely to interact with these changes. A decline in winter precipitation could slow the changes, an increase could accelerate them since the annuals are primarily winter annuals which germinate in fall with the onset of seasonal rains. Whether or not the southern vegetation would move into the region could depend on how far the "annualization" had proceeded and whether the southern species could succeed the stands of exotics.

The precipitation-fire-vegetation complex also has more far-reaching implications for the global carbon balance. Desert soils the world over are underlain by calcium-carbonate crusts termed "caliche" in North America. These deposits are calculated to hold a major fraction of the carbon content of the world's soils. And they can serve either as a source or sink of atmospheric CO₂.

Utah State University soil chemists Janis Boettinger, Lynn Dudley, Jeanette Norton, and microbial ecologist John Stark, in yet unpublished work, have concluded that much, if not most, of the caliche in the Great Basin Desert is formed by root exudates from the perennial plants. Laboratory CO₂ fertilization studies have shown that the process is accentuated by added CO₂. Hence, rising atmospheric CO₂ levels could produce a sink effect as long as the perennial vegetation remained intact. But destruction of that vegetation, as with burning, would leave a large, dead root mass to decompose. That decomposition could reduce soil pH, erode the caliche, and release CO₂. The result would be addition of CO₂ to the already rising atmospheric levels. Which direction the processes would take could depend on the effects of changing precipitation patterns on fire frequency and extent.

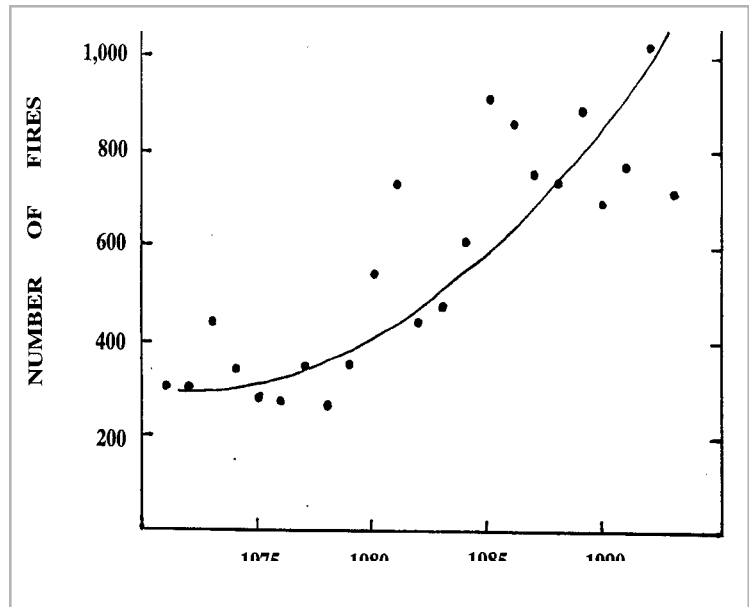


Figure 35. Annual number of range fires recorded by the U.S. Bureau of Land Management over all of Nevada, and the Salt Lake, Richfield, and Cedar City Districts of Utah.

Finally, changes in the precipitation-fire-vegetation complex could affect soil hydrology and stability patterns. The Great Basin Desert perennial vegetation has root:shoot ratios ranging from 3:1 to 5:1, providing an extensive soil-holding function. The annuals which replace the perennials after fire have smaller, fibrous superficial root systems that die by summer when they have completed their life cycles. For half of the year there is no live, active root system. What effect this has on soil stability has not yet been researched. And once again, whatever the extent of that effect will be in the future will depend on how climate changes affect the prevalence of fires.

The discussion to this point has concentrated on potential precipitation changes. Rising temperatures could also have significant ecological effects. The traditional prognosis is for upward transition of altitudinal zones in the mountain ranges, with the subalpine and alpine zones at the summits being forced out. Growing seasons would likely be longer. And predictions on the futures of snowpacks vary, but at the least would be expected to experience elevational rise of their lower edges, form later in the fall, and run off earlier in the spring with possible diminution of aquatic systems.

An earlier growing season in the mountains could make it possible for ranchers to move their livestock into the higher-elevation ranges, while a later fall could allow them to bring their animals out later. The result could be a longer summer grazing season. At the same time a longer growing season coupled with increased moisture from higher precipitation levels could make it possible to harvest one or more additional hay cuttings and reduce hay costs. The net effect of all the changes could markedly benefit the ranching industry, all the more so if southern grasses moved north to become a larger component of the desert vegetation.

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BREAKOUT SESSIONS
for
Resource-Based Sectors

Tuesday, February 17, 1998



Jill Baron

ANTICIPATED CONSEQUENCES OF CLIMATE CHANGE ON BIOLOGICAL RESOURCES

Jeff Klopatek, Chair
Erica Fleishman, Co-chair
Richard Hauer, Recorder

Framework and Current Conditions

Biological resources were defined as native biota, vegetation and animals, of the region. We also considered the community interactions, ecosystem functions (services), and landscape feedback processes that are dependent on the biological resources as essential elements of any discussion of biological resources. While climate-change impacts may be evident first at the individual species level, biological resources must be evaluated in an ecosystem framework, by looking at the structure, processes, and interactions that are necessary to maintain that system. The combined effects of elevation, soils, moisture and latitude translated to the nutrient, temperature and moisture regimes of the vegetation result in a complex pattern of biological resources. The whole region is marked by an uneven distribution of resources, some covering vast, continuous expanses such as the Great Basin sagebrush, and others existing in isolated patches as in the case of alpine lakes and subalpine meadows. In order to quantify the effects of climate change on the region's biological resources, it was decided to subdivide the region into five areas: Northern (MT, ID, and parts of WY), Central (S. WY, UT, CO), and Southern (AZ, NM) Rocky Mountains, and the Great Basin deserts and mountains.

(1) Existing climate in the region:

The present-day climate in the region is marked by extreme spatial and temporal variability. This variability is influenced by both the latitudinal location and the topographical position of the site in question. Precipitation (and especially effective moisture) increases with elevation, while temperature decreases with elevation and latitude. Most vegetation is dependent on winter precipitation and subsequent snow melt for survival, although, in the southern portion of the region, summer monsoonal precipitation is important. As a result, most animal species (up to 70 percent depending on the region) are dependent on riparian zones for food, water or habitat. Present and recent climate has resulted in distinct hydroperiods that influence the aquatic biota and equally distinct rainy and dry periods that determine the terrestrial vegetation structure. Temperature increases are not as important as the moisture changes at low elevations. However, temperature increases its importance as one moves into higher elevations where it determines length of growing season and the rate of snow melt.

(2) Climate-biological resource interactions:

This region possesses a tremendous amount of physiographic variability and biological diversity. The topographic position and local climate variability will interact greatly with future climate-change effects on ecosystem structure and function. It is a given that this region is already on a trajectory of change, both from natural and anthropogenic agents. Change is not new to this region, but the rate and direction are. Much of this change can be attributed to human

disturbances in the mid- to late 1800's. Because of the extreme seasonal and annual aridity of this region many species and communities are on the edge of maintaining their existence or microhabitats (perennial springs, wetlands, relict stands of vegetation), where others are expanding (sagebrush, pinyon-juniper woodlands). It should be mentioned that much of this area is primed (because of disturbances listed below) for the invasion of noxious weed species - - cheat grass (*Bromus tectorum*), knapweed (*Centaurea sp.*), pepper weed (*Lepidium sp.*), salt cedar (*Tamarisk sp.*), etc. - - which can have cascading effects on change of the ecosystem.

Existing seasonal patterns in precipitation events have controlled the distribution of species and communities in the region as in the case of the Great Basin Desert Shrublands, Palouse Prairies. Many species have adapted to different seasonal sources of water as in the case of C-3 and C-4 grasses, while some of the woody species are opportunistic using both sources. Hydrological patterns have selected for endemic species as well as whole wetland communities. Tree species are often limited by minimum temperatures and length of growing season. Thus, the interactions of climate and biological resources are complex and not just a function of mean annual precipitation and temperature.

Current Stresses to Biological Resources Under Present and Climate-change Scenarios

Table 1 is a matrix of present-day climate-related stressors, their current relative effects (in column 1 rated from high to low), and their predicted amplification (+, 0, -) in the different regions due to the three climate-change scenarios. It appears from the matrix of climate-related stresses and the four scenarios presented that Scenario 4, with increased temperature, increased winter precipitation, and decreased summer precipitation, will result in the greatest impact on the biological resources of the region. Many species exist in isolated populations in refugia or locations with different microclimates. Examples:

- (1) Hydrologic cycle and stream flow in the Northern Rockies: Climate change that results in hydrological changes will have a major impact on riparian and wetland ecosystems. Under Scenario 4, peak flows will move to March instead of May. Changing the hydrograph pattern can have severe consequences for stream biota (especially salmonids), including blow outs and down cutting (during the spring), loss of spawning beds, and loss of riparian vegetation. Decreased hydrological input would result in increased summer-time variability in terms of flow, depth, and increase in elemental concentrations and temperature.
- (2) Increase in frequency, intensity and size of forest fires: Increased winter precipitation with a decrease in summer for many of the region's forest and rangelands would result in an increase in fuels from the growth of annual (C-3) weeds and a priming for extensive and intensive fires during the summer. This may lead to changes in habitat, invasive species, and changes in ecosystem structure and function, which may feed back to permanent habitat changes. Conversely, an increase in summer precipitation would lead to more fires (lightning caused), smaller in size, and with less intensity.
- (3) Shift in vegetative species in terrestrial communities: Many vegetation communities in the Great Basin have evolved to take advantage of temporally and spatially limited soil-water supplies. Nowhere is this more evident than the sagebrush steppe, dominated by big sagebrush and perennial grasses. Much of

Table 1

Matrix showing existing climate-related stresses in the Great Basin-Rocky Mountain Region and the anticipated effects of the four scenarios: 1) no change, 2) 4 and 7 degree F increase in temperature with no precipitation change, 3) same as 2 with a 15% increase in winter precipitation, 4) same as 2 with a 15% increase in summer precipitation. Altered Disturbance Regimes—fires, floods, insect pest outbreaks. Land-Use Conversion—permanent or semi-permanent, natural to agriculture, urban sprawl, dams, etc. Intensive Use—grazing, clear cutting, recreation. Climatic variability existing variability as a natural stress. Habitat Loss—road building, type change. Invasive species both plant and animal. Contaminants—airborne (N) and waterborne.

	Northern Rockies				Central Rockies				Southern Rockies				Great Basin Mountains				Great Basin Desert			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Altered Disturbance Regimes	high	+	-	+	high	+	+	+	high	+	0	+	high	+	0	+	high	+	+	+
Land Use Conversion	high	+	0	0	high	0	+	0	med	0	0	+	high/med	0	0	0	high	0	0	+
Intensive Use	high	0	0	+	med	+	0	0	med	+	0	+	high	0	0	0	high	+	+	=
Climatic Variability	med	+	+	+	med	+	+	+	high	+	+	+	high	+	+	+	high	+	+	+
Habitat Loss	high	0	0	+	high	+	-	0	high/med	+	0	+	high	+	+	0	high	0	+	0
Invasive Species	high	+	+	-	high/low	+	+	+	high	+	+	+	med/high	+	+	0	high	-	+	+
Contaminants	low	0	+	0	med	+	+	-	med	0	0	-	high/low	0	0	0	low/high	0	+	0

low, medium, high = current relative stresses to the ecosystem regionally

Expected direction of change given the four scenarios: + increase, 0 no change, - decrease.

the area still occupied by this vegetation type has been changed to one dominated by cheatgrass, that has entered as a result of disturbance (grazing), out-competes the perennial grasses for soil moisture, and is encouraged by fire as its seeds readily re-sprout. It is anticipated that if winter precipitation increases and summer decreases, with rising temperatures, permanent habitat changes will occur that favor lower-productivity ecosystems similar to that above in many areas of the region.

- (4) Impact on migratory and endemic animal species: Migratory animals, specifically bird species may be severely affected by increased inter-annual climate variability, but also by longer-term changes. This is because migration is controlled by photoperiod and migrants have limited capabilities to locate food sources if resource production declines or changes timing due to temperature changes. Success of the migrants is based on reproductive success, which is

based on food-resource availability. Thus, there is little that can be managed for. A decline in food resources would have grave consequences on endemic species, especially if habitat or resource availability changes result from invasive species.

In summary, the forests and rangelands of this region exist amid a highly variable environment. Many are a product of disturbance, with old-growth forests and pristine areas few in number and size. Despite the disturbance, and in some cases because of it, much of the region appears to have been in the aggrading state for the past hundred years, especially since the advent of grazing and fire-suppression policies. In other words the region has been a net sink for carbon storage. It is viewed that under the four given scenarios the region will change from a carbon sink to a source. It is assumed that regardless of the change in climate, levels of CO₂ will significantly increase. It is also realized that studies have shown direct CO₂ fertilization effects, and specifically to some of the weedy species (e.g., cheatgrass). However, because of the great uncertainty regarding fertilization effects, both in magnitude and longevity, it was decided not to include this as a positive or negative influence on the biological resources.

Information Uncertainty and Data Needs

The diversity of the region requires predictions from mesoscale-level models, since GCM spatial resolutions are too coarse to be of use. Confidence limits must be placed on the predictions. The prediction of trends in annual and seasonal variability, again with confidence limits, is of major importance in this region. Better baseline data are required to address future consequences of climate change, including species distribution and ecosystem responses, climatological data (especially the variability), and means for data exchange. There is a need for better spatial and temporal data, including feedbacks resulting from ecosystem and landscape change (e.g., local climate change, hydrological modifications). Data, including historical and trend, should be provided to all interested parties over a fully accessible network over the Internet.

Cohesive Interdisciplinary Monitoring Effort

A cohesive interdisciplinary and interagency monitoring effort is necessary to address the multiscale problems listed above. A sound monitoring plan is required to provide the data listed above. Monitoring should include: (1) the climatic forcing functions of solar radiation, temperature and precipitation; (2) physical response variables, in particular hydrological flows, as well as other factors such as depth of snow pack, soil temperature and moisture, etc.; and, (3) biological response variables which should consist of a set of ecological indicators that can be used to document ecosystem change in response to a changing climate or other stresses. All monitoring needs to be operated with consistent methods and techniques so that the data are comparable across sites and regions.

POTENTIAL CONSEQUENCES OF CLIMATE CHANGE ON CULTIVATED AGRICULTURE

*Barbara Curti, Chair
Don Bustos, Co-chair
Tracey Beal, Recorder*

I'd like to extend my appreciation to those who attended the cultivated-agriculture-sector breakout session and to Tracey, our recorder.

We listed the major cultivated crops grown within the Rocky Mountain Great Basin area as:

- (1) fruits and vegetables (potatoes, onions, cherries, peaches, and apples)
- (2) field crops (alfalfa, grains, sugar beets, and beans; both irrigated and non-irrigated)
- (3) specialty crops (mint and nuts)
- (4) forage crops

These commodities react differently to variable climate changes. Considering the 4 questions and the 4 climate-change scenarios, we conclude the following:

- (1) Fact: cultivated crops require and are affected by climate changes.
- (2) Current climate-related stresses are:
 - rapid temperature changes, e.g. hail
 - hotter than normal summer days, especially drought
 - occasional colder or warmer winters, and late spring frost
 - biological pests.

Anyone who has farmed longer than 1 year will have experienced just about all of the above. That is the dynamic nature of agriculture. It is adaptable, agile and certainly never content.

Under the 7^o Increase In Winter Temperature and 4^o Increase in Summer Temperature, No Change in Precipitation Scenario

- (1) Fruits and vegetables will bud earlier and there will be increased risk of frost damage. The humidity created by increased precipitation may cause disease problems or susceptible crops like:
- (2) Tomatoes or root/leaf impacts on potatoes or sugar beets.
- (3) Precipitation would vary; snow would melt earlier. For our irrigation-dependent agricultural crops, extra storage capacity for water would be necessary. Because winter freeze keeps insects and some weeds in check, milder winters may cause an increase in the use of pesticides and herbicides. In all probability this would cause changes in cultivation.

-
- (4) With less snow cover, certain crops (wheat) would have a reduction in the occurrence of snow mold, allowing for more no-till methods of cultivation to take place.
 - (5) On forage crops, a longer growing season would enhance crop yields.
 - (6) Increased temperature will intensify the focus of the debate on water, not just more storage for agriculture but for urban areas also. We will need to mitigate efforts of heavy water runoff at certain times causing us to revisit the current public paradigm on water storage. We may also be redefining the current water-allocation systems. Water would be delivered in different amounts and at different times.

A 15% Variation in Precipitation with 4^o to 7^o Temperature Changes

This would not cause enough variability to make a big difference. The methods of farming our crops and inputs may, and probably will, change; that is a normal occurrence now. Crop mix and crop rotation could change irrigation seasons by making them longer, with more capacity for crop production. Reduced availability of water for agriculture may also result in more salt build-up in the soils of the Great Basin thus rendering the land unproductive.

American Agriculture is Capable of Change

We can and will adapt to any climate changes if:

- (1) A political climate is maintained that fosters private-sector innovation (absent excessive regulations and imposition of additional costs).
- (2) Cost-effective agricultural research is maintained and enhanced to assist farmers and ranchers which will help them adapt through: genetic manipulation of crop varieties to meet temperature and precipitation changes as well as increased capability to absorb CO₂.
- (3) There is emphasis on enhanced cooperative research by agricultural experiment stations and extension and private-sector research.

Other Areas of Importance on Mitigating the Risks

- (1) Improved long- and short-term weather forecasting in order to have lead time to develop new crop varieties.
- (2) Better water management, weed and insect control.
- (3) New risk-management tools as risks increase, more comprehensive insurance programs, and biotechnology.
- (4) Educational efforts to enhance public knowledge and understanding of agricultural needs.

In general, agricultural policy needs to lay support and make agriculture resilient and diverse. And it needs to support agriculture in a broad way because agriculture is diverse and all sizes and sectors are important.

CONSEQUENCES OF CLIMATE CHANGE ON THE LIVESTOCK INDUSTRY

Bruce Roundy, Chair
Douglas Reiter, Recorder

Abstract

Western livestock operations are highly dependent on scarce water and forage resources. Climate-pattern changes could severely impact not only the livestock industry but also other natural resources such as wildlife habitat. Four areas of concern are identified: (1) Livestock/Resource Management; (2) Animal Health; (3) Available Resources; and (4) Economics. Another question relates to the adaptability and flexibility of both private- and public-land management policy. There are also concerns as to the reliability, accuracy, and impartial reporting of research information about climatic changes. Given truthful information and flexibility to adjust to changing conditions, all interested stakeholders should be able to adapt successfully.

Participants and Process

The focus of this group's discussion centered around potential effects that a Great Basin/Rocky Mountain regional climate change would have on livestock-industry operations. Participants were representative of a variety of diverse sectors including large-scale cattle and sheep ranch operations, small-scale goat ranching, environmental activists, elementary and university educators, hydrologist, city government, National Aeronautics and Space Administration (NASA), Bureau of Land Management (BLM), and the U.S. Geological Survey. States containing their base of operations included Colorado, Utah, New Mexico, Nevada, and Wyoming with the NASA representatives coming from Washington D.C. The number of participants was approximately 13.

Participants were asked to confine their discussion to four general questions: (1) What are the main climate-related stresses on your operations under the present climate patterns? (2) How will these stresses be affected (for better or worse) by the predicted changes in the climate pattern? (3) How would you adjust your operations to cope with these effects if they come about? (4) What additional information do you need to be able to plan more confidently for the predicted changes? Questions 2 and 3 (discussed together in the following sections) dealt with four possible climate-change scenarios which were (a) no change in current climate (this scenario was mostly discussed under consideration of question 1 above); (b) an increase in average winter temperature by 7° F and average summer temperature of 4° F with no change in precipitation; (c) same temperature increases as b and with a 15% decrease in winter precipitation and 15% increase in summer precipitation; and (d) same temperature increases as b and with a 15% increase in winter precipitation and 15% decrease in summer precipitation. Participation was somewhat free-flowing with comments and concerns expressed in an open and somewhat unstructured workshop atmosphere.

Current Climate-related Stresses on Livestock Operations

Although there were some differences on aspects regarding livestock operations in the West (e.g. disagreement on amount of meat produced in the 11 western states that finds its way to the marketplace), participants identified four broad areas of concern that

challenge successful operations both under current climatic conditions and possibly in the future if those conditions were to change. These areas include livestock/resource management, animal health, available resources, and economics. It should be noted that these concerns are not exclusive and may include aspects of other areas of concern.

(1) Livestock/Resource Management:

Compounded by the fact that aspects of western livestock operations include resources contained on public lands, the scale and conflicting concerns of the different decision makers involved creates challenges to maintaining successful business operations while still adhering to public law and administrative policy. These differences contribute to appeals and protests due to tensions among public-resource management agencies, permittees, and other interested stakeholders. Because of the unpredictability of weather conditions and plant growth, uncertainty in the arid west, livestock operations and land-management agencies must “manage for extremes.”

The question was raised as to whether the public-land management system is adaptable to unforeseen changes in policy focus due to shifting social and physical conditions. Even though management plans cannot necessarily allow for every contingency, hopefully they can allow for flexibility in adjusting for changing conditions. Due to the fact that social values do change, land-management focus changes over time. Although it was generally thought that BLM policy was more flexible than that of the U.S. Forest Service, it was brought up that perhaps there is too much flexibility in public-land management decisions.

(2) Animal Health:

Although somewhat limited, there was some discussion on animal health as it relates to land-use practices. It was stated that it is in best interest of ranchers that cattle (or other livestock) gain weight not only during the current season, but also in future seasons. Therefore, good land-stewardship practices (e.g. “rest rotation”) and flexibility in adapting to changing conditions must be a part of staying in business.

(3) Available Resources:

The generally arid western states are subject to periodic drought conditions. In other words, water is a limited resource. A way to alleviate stresses associated with those drought years is to maintain sustainability of water as a renewable resource by protecting watershed integrity. One concern centered around the uncertainty associated with both long- and short-term weather predictions. Given enough advanced warning, management is willing and able to make adjustments to successfully operate under adverse or extreme conditions. A major challenge is to provide reliable timing of water to meet grazing needs.

Other resource concerns mentioned were riparian and wetland degradation due to overgrazing practices, competition from threatened and endangered species, and unpalatable weed species invasion.

(4) Economics:

Because of the climatic characteristics of the arid west, retaining an economically viable livestock operation is difficult. It can be even more difficult for those

ranchers currently operating on the margin. Interruptions of “normal” resource availability, such as amount of available forage and/or water volume, can generate conflict among permittees and management agencies resulting in economic hardship: For example, adjustments to timing on allotments because of limited grass growth. If cattle are turned out, where can they be put? One option is to have “base property” on which to locate the animals. Another option would be to conserve (or not to maximize) the “preference”; in a way, hold it in trust for possible future negotiations. A “preference” was defined as the optimal possible forage available as measured in Animal Unit Months (AUMs) and adjusted by continual monitoring. This would be a determinant of grazing fees.

Temperature Increase, No Change in Precipitation

(1) Livestock Resource Management:

- Change in seasonal forage quantity, quality, and use patterns.
- Earlier forage growing season and/or less forage availability may necessitate adjusting the number of animals or season animals are put out on range.

(2) Animal Health:

- Expected rise in animal diseases.
- Outbreak of plant diseases such as smuts and root fungi.

(3) Available Resources:

- Increase in evapotranspiration.
- More severe drought-like conditions.
- Decrease in hay production.
- Wildlife may have easier gestation increasing likelihood of more competition with livestock for limited forage and water resources.

(4) Economics:

- Shift in optimal geographic livestock growing zone will force operations to permanently move to higher elevations or more northern latitudes.
- Operations financially unable (or unwilling) to move will fail.

Temperature Increase, More Summer Less Winter Precipitation

(1) Livestock/Resource Management:

- Change operations to different species (e.g. Brahma) or breeds.
- Adopt more flexible management policy.

Incorporate different regional range-management strategies (e.g. southwest grazing practices may now be appropriate to use in northern Utah).

- Adjust to changes in seasonal use and variability in forage production.

(2) Animal health:

- Change timing of breeding strategies

(3) Available Resources:

- More water storage required.
- Increased use of more efficient irrigation systems.
- Haul water for winter stock.
- Increase weed production. Solution may be to bring in sheep and goats to keep weeds in check.
- Change in plant species.
- Increase in plant biomass and fire fuel load.
- Increase in erosional conditions.
- May provide opportunities to use uplands.

(4) Economics:

- Increased costs associated with changing breeds (or species) and adjusting water-delivery systems.

Temperature Increase, Less Summer More Winter Precipitation

(1) Livestock/Resource Management:

- Plant phenology/livestock husbandry concerns.
- Flexibility in adopting unfamiliar regional range-management strategies.

(2) Animal Health:

- Floods bring in new diseases.
- Calving problems.
- Floods washing out holding ponds.
- Decrease in use of summer ranges may result in increase of wildlife/livestock competition on higher winter ranges.

(3) Available Resources:

- Water storage held longer in snowpack increases potential rain-on-snow event resulting in severe flooding.
- Stream functionality jeopardized (stream-channel scouring).
More stable (boulder/cobblestone structure) stream systems may withstand flooding impacts.
- Increased moisture translates into more weeds.
- Floods bring in weed seeds.

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- Floods may replenish stream benches and restore riparian areas.

(4) Economics

- Opportunity to increase crop yield through increased flood irrigation practices.

Information to Plan for Predicted Climate Changes

The discussion centered around several broad areas of concern about the types and availability of information necessary for mitigating impacts of possible climate change. These included types of data, delivery of information, reliability of information, accurate interpretation, monitoring, and incorporation of research data into meaningful policy. For a list of specific recommendations, see Table 1.

Several other issues arose during this phase of the session. Throughout the meeting, participants emphasized that they can adapt to changing conditions if they are presented with reliable, accurate, and unbiased information. It was also brought up that current environmental problems must not be neglected by focusing on possible future problems. Solve the present problems now, then work on mitigation strategies for future climate change.

Summary

Generally, the group agreed that there will always be concern for resource protection. In the case of climate-pattern change, some microclimates benefit while others do not. Humans are adaptable to incremental increases in climate change. Other species that are widely adaptable may also be favored. But what about the threatened and endangered species already stressed due to our past and current practices of altering the environment? Are their conditions due to our changing the climate (for example) or not adapting management to those changes?

Some suggestions for coping with climate change would be to emphasize multi-discipline, trained, “cross-agency” decision-making committees. There needs to be a common base of knowledge held by all stakeholders on which to derive rational decisions. What may also be required are non-traditional decision-making forums. An example would be the affected public-land resource agencies and stakeholders getting together to make management decisions on a case-by-case basis (“cooperative resource management”). This does not necessarily mean micromanaging for every contingency, but may involve only a one-time meeting with multi-year, periodic reviews. One thing that may not be desirable as a result of climate change and restructuring policy is an increase in regulatory requirements.

Participants recognized that directly impacted stakeholders and those “hidden stakeholders” have an interest in most every resource contained on public lands. A way of understanding those interests involve all parties needing to get out on the land often in order to make more informed decisions. Ranchers ranch because they enjoy the work. Hikers hike because they enjoy the walk. In the end we may all agree on resource values. What we may not understand is their complexity.

Table 1

Information Sources and Dissemination

- 1 understandable presentation of information
- 2 reliable baseline data
- 3 more accurate/timely weather predictions (e.g. location of front)
- 4 website of current weather conditions, front location, help on use of available information
- 5 predictive modeling systems based on changing factors (soil temperature, soil moisture content, etc.)
- 6 monitoring at various scales (e.g. shift in vegetative communities)
- 7 incorporation of weather information into GIS receptions
- 8 unbiased reporting
- 9 up-dated information on climate-change information
- 10 truth about data limitations
- 11 user-oriented predictions
- 12 extension service to help interpret information
- 13 interpretation/information gathered at different scales
- 14 standardized methodology of data gathering
- 15 long-term (e.g. five year) trends
- 16 information on potential health problems (diseases, parasites, etc.)
- 17 technical information on alternatives to possible problems
- 18 install accurate monitoring now
- 19 information on global progress about carbon dioxide, etc.
- 20 ways to diversify, other ways to increase feasibility (e.g. "Grass-Banks")
- 21 help identify thresholds of change
- 22 concern for over-centralized decision making

EFFECTS OF CLIMATE CHANGE ON MINING AND ENERGY

Douglas Larson, Chair
James Udall, Co-chair

Major Current Climate-related Stresses

- (1) Precipitation-related stresses: Sediment control, large storm events, ore transportation in winter; use of water for dust control, smelters produce air-quality problems associated with inversions. Salt Lake salinity decreases with increased precipitation making mineral extraction more difficult.
- (2) Interrelationships with hydropower: Variations in precipitation, water releases for anadromous fish, the 7-year western drought cycle, and year-to-year variations in snowpack create variations in hydropower production. Variations in hydropower production in the Pacific Northwest can cause coal plants to be “backed down” which create planning and management problems. It is really precipitation that drives hydropower generation capacity. Coal “takes over” when there is a drought.
- (3) Powerlines are susceptible to weather aberrations. Are these ENSO or early global-warming signals?
- (4) Vegetation management in transmission corridors affected by weather. Vegetation may grow earlier with higher precipitation.
- (5) Powerline losses and electrical resistance are higher at higher temperatures, and this comes at a time of highest load due to air-conditioning demand.
- (6) Problems with utility restructuring: There is increasing demand for coal-produced power and its transmission. There is some relief of the congestion by building load-based plants like gas.

Scenario 1: No Precipitation Change, 7^o Winter and 4^o Summer Temperature Increase

- (1) There will be an increase in air conditioning, hence higher summer power-demand peak, and decrease in winter heating.
- (2) It will be easier to mine in winter and increase the coal quality.
- (3) Hydropower production will decline due to higher evaporation off reservoirs. Hence greater need for coal power.
- (4) More water will be needed for dust control. Mineland revegetation will be more difficult, will require different species.
- (5) Great Salt Lake Minerals will achieve more efficient production due to higher evaporation and higher mineral concentrations.
- (6) Hardrock mining impacts will be reduced due to lessened discharges.
- (7) Winter air-quality inversions will be less severe but summer problems (ozone, visibility) may be greater.

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- (8) Conversion efficiency at coal-fired power plants will be reduced because of altered temperature differential of water. Result will be increased coal burning.

Scenario 2: Temperature Increases As in 1, -15° Winter, +15° Summer Precipitation

- (1) Significant hydropower impacts due to lower reservoir build-up and reduced generation capacity. Result will be greater demand for other energy sources, e.g. coal.
- (2) Higher summer precipitation will reduce severity of summer drawdown, but to limited degree because of low summer precipitation.
- (3) There will be less cooling demand if the summers are cloudy.
- (4) We should be doing everything to keep economic strength and adaptability high.
- (5) We need to be more efficient. This is another form of adaptability. Those who come up with higher efficiencies will meet the higher demand, especially in a deregulated environment.
- (6) It is important that the price signal reaches the consumer faster. Is the consumer's concern for the environment greater than concern about buying power? We live in a selfish society. But there is a clear trend toward higher efficiency in the West. People will pay for perceptible cleanup. There is a program in Colorado in which people voluntarily pay for cleaner industry.
- (7) If gas, solar, wind provide a better product at the same price, it will drive some of the change. But they may not have the same price.
- (8) Deregulation is coming. Current prices are very low. When prices are low, there is very little incentive for efficiency.
- (9) Scenario 2 will not make big changes in mining. Higher precipitation means better vegetation regeneration, easier reclamation, less dust problems.

Scenario 3: Same as 2 But with Precipitation Reversed

- (1) There will be more rain than snow in the winter. This should favor hydropower. Will there be reservoir-overfill problems?
- (2) This is the worst scenario for air-conditioning loads (hotter summers).
- (3) Mining reclamation will be more difficult. It will pose additional pressure for dust suppression.
- (4) How much will technology save us? Increases in thermal efficiencies? Will other technologies come along? Where do people live? Will population distributions shift?
- (5) Prevention vs. adaptation: Given that China and the rest of the developing world are likely to pose a huge problem, is it better to roll with it? Do we buy our way out?

How to Adjust Operations to Cope with Effects

- (1) Re Scenario 1:
 - (a) Reclamation practices will need to be altered.
 - (b) Will there be more power plants or just increased capacity?
 - (c) Deregulated scenario: One self-contained system instead of passing power around the way it is done now?
 - (d) West will be more susceptible to calamity because it is now under stress for electricity. Energy moves around by wire, pipeline, and railroad.
 - (e) Oil and gas reclamation costs are lower than for coal. But economically gas might be more stressed because of problems of storing it, delivering it during winter cold snaps. Northward, and toward Canada, gas is more of an option.
- (2) Re Scenario 2:
 - (a) Mining will need to adapt. The industry is used to running into water sources when mining, and increased precipitation might exacerbate this.
 - (b) The industry will also need to cope with higher sediment loads.
 - (c) But will added costs of mitigation inhibit adaptability? The external environment is not so permissive. The industry will need to generate more peak power.
 - (d) Less time of snow cover in the far north may mean less operating time for oil and gas production (damage to the tundra in summer).
 - (e) It is doubtful that Utah refineries will be operating in the future. The Flying J refinery is built for high-paraffin fuel which is cheaper to pipe in. The refining process is not particularly affected by temperature differences. These influences may also affect Montana and Wyoming refineries, although Montana's may go longer.
- (3) Re Scenario 3:
 - (a) Refineries are under pressure to reduce ozone production although cars may be major source. The problem could be intensified with warmer summers. If auto technology continues to improve, the problem may ease along with pressures on refineries. But No_x production will be a continuing problem.
 - (b) Increased winter precipitation will ease mining's water need, help with dust suppression, and contribute to peak power demand.

Needed Additional Information

- (1) What will be the effects of cloud cover?
- (2) What are the signals of climate change? Effects on ENSO and Gulf Stream?
- (3) What is man-made vs. natural background? More understanding is needed on breakpoint analysis, nonlinearities. How does one define a breakpoint?

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- (4) What is our ability to mitigate change through parallel hazard mitigation and planning? There is congruence with the kind of work FEMA does.
 - (5) What is the history of CO₂? How high has it been in the past and what were the environmental consequences? How long to reach those levels?
 - (6) What will be the frequency and distribution of precipitation, both seasonally and geographically?
 - (7) Better understanding of global science: Better computers, better models, higher-resolution climate models that give better regional resolution. We need an emerging technology inventory: What's coming along, how will it help? Energy Department has released one such report. What is anticipated over the next few years?
 - (8) Understanding of oceans. What about carbon sequestration technologies? How does the rate of temperature change relate to changes in CO₂? Is it gradual, or is there a breakpoint? How does cloud cover affect temperature increases?
 - (9) Information, communication: Science must be accessible so that changes can be made. No more "one handed ecologists" (on the one hand this, on the other hand that). People want definitive answers. The information providers must be understood - - what is their information framework?
 - (10) Tradeoff analysis has to be done. Assign probabilities to specific scenarios. Much more motivating. Also the probabilities associated with solutions.
 - (11) Planning for future generations. How well can it be done? What is the ethical obligation of our generation to those who follow? This is a huge missing piece. We all agree that optimizing quality of life for future generations is the goal. But Adam Smith and capitalism say that optimizing our own self interest is what works out the best. Operate to minimize the risks to future generations. Since we cannot agree on what "optimization" is, we should classify global warming as a risk, if only because of inundation of coastal areas, etc.
 - (12) Can we identify the risks? For energy: What is the risk of not having access to reliable and affordable energy sources?
 - (13) Mitigation vs. conservation? Changing lifestyles? But without an ethical driver, how deep can we go with this question? We are slowly developing an energy ethic in the United States. But for the last 100 years, cheap has been the sole guiding principle.
 - (14) What is the big message? Adaptation to climate and market forces. But the larger policy questions dwarf the concerns that deal with climate directly. These are the higher risk potentials (e.g. reclamation). For many years the mining industry did not have to reclaim land. Policy now is that they have to, so they do it.

Afternoon Session General Discussions

- (1) Policy Issues
 - (a) Where to put policy focus: Mitigation or adaptation?

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- (b) Los Alamos CO₂ fuel project. Not sure if cost effective.
- (c) Mitigation options: Cut CO₂ and other GHGs, reduce space litter, coal-bed methane recovery, sequestration.
- (2) How to accomplish goals: Shift away from low-mileage and single-occupancy vehicles to electric vehicles.
- (3) Taxes: Give people economic incentive to use energy efficiently. Europe has a \$1,000/ton equivalent CO₂ tax. It is a reflection of people's willingness to pay for the mobility afforded by cars. Alternative to a tax is no-drive days. These are command and control approaches.
- (4) New technologies (e.g. CO₂ scrubbers). This is proactive and not penalizing energy use.
- (5) Interurban transport. Encourage trains.
- (6) Mandatory building standards: Cut demands for space heating and cooling.
- (7) Pricing to change behavior - - pricing signals. How congested does the traffic situation have to get before people change behavior? Problems: Massive economic impacts. What about developing other technologies, etc. (CO₂ scrubbers). Proactive, not penalizing energy use. More likely what is going to work? Inter-urban transport: Encourage trains? Mandatory building standards: Cut demand for space heating and cooling.
- (8) Level the field for subsidies. There is a perception that solar, wind, etc. are heavily subsidized: e.g. wind gets 1.5 cents per kilowatt hour produced. Nothing comparable in fossil fuels. Should encourage more research and development of non-fossil-fuel energy sources.
- (9) Local co-generation plants? Central district heating. But people do not want power plants in their residential areas.
- (10) Electrical industry restructuring fall out:
- Deregulation of the energy industry. Opening to competition. Bring in more green energy. Use of waste heaps for other purposes. No more big plants are to be built. Increases in efficiency.
 - What falls out in the market is fine with the coal industry. They just do not want policy imposed from above that makes no sense to them.
 - Cost sharing among customer classes.
- (11) Efficiency tax credits: Overcome barriers to efficiency in low-cost states. Maybe it is better to have a tax-credit incentive rather than tax penalties. The tax code could be improved.
- (12) Environmental externalities: Are they corrections, or bogus means to force action in some direction?
- Info disclosure on emissions/total costs of energy, not just rates.
 - Sequestration credits from farmers.

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- Concern about CO₂ sequestration in the ocean.
 - Cap and trade emissions system.
 - There is no substitute for petroleum. Natural gas is clean, but there is less of it.
 - Reforestation: Short-term sequestration.
 - What about requiring more than just mining to revegetate, e.g. real estate? Shopping centers.
 - Accelerate power-plant retirement.
 - Technology transfer to developing countries. There is not much happening. Perception that the Chinese are not interested. The highest payoff for money invested would be to clean up China's plants. They are building many. They will be in a position to get all the technology out of us that they want. Their plan is to double coal production by 2025.

(13) CO₂ budgets for developing countries.

(14) Coal is "infinite" in supply relative to petroleum.

(15) How do we choose priorities? Divide institutional strategies (e.g. tax) research and development sequestration, end use, supply options (CO₂ as fuel).



Rick Colling

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CLIMATE-CHANGE EFFECTS ON SKIING AND TOURISM

*Rick Colling, Chair
Jack Troyer, Recorder*

Current Climate-Related Stresses on Operations

At present, ski-area development is subject to certain topographic limitations. They must be established on east- or north-facing slopes. The lower elevations are limited by poor snow, upper elevations often by rough or excessively steep topography. Weather stresses interact with these constraints, and they are limitations on adaptations to climate change.

Effects of Scenario 1 and Warming Trend

- (1) Lower-elevation snow rot.
- (2) Possible problems with fog, visibility, wind, rain, storms, sleet, lightning.
- (3) Threat of a shortened season including early- and late-season rains. October and November more of a concern than spring, especially a late-forming, early-season snowpack.
- (4) Quality of man-made snow would be compromised by temperature increase.
- (5) Travel costs for skiers likely to increase if more southerly areas die out and skiers are forced to travel to more northerly areas.
- (6) Impacts on esthetics: Vegetation and animal-life changes would change the whole context of how a ski area exists. These are important to skiers. Increasing forest fires would exacerbate this.
- (7) Threatened and endangered species (e.g. grizzly bear) emerging earlier (mid-March) could legally mandate early closure of a ski area during the spring skiing peak.
- (8) Human-waste management would be more difficult under warmer conditions.
- (9) There would be increased pressures on operators for year-round operations to offset reduced winter revenues. Therefore year-round impacts would greatly change. Snow is a great styrofoam cushion for the mountain to protect the land.
- (10) Warmer temperatures could make skiing more enjoyable.
- (11) Climate change could affect avalanche conditions.
- (12) If skiing operations were forced to move to higher elevations (with steeper terrain), this would limit access to the lower-ability skiers. Result would be lost revenue since expert skiers contribute the least to resort revenue. Environmental issues and higher costs of moving up slope would limit adaptability to change.
- (13) Increasing value and shrinkage of alpine ecosystems might prohibit expansion in this area.

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- (14) With higher precipitation, there would be more water available for snow making. Shortage of water would increase competition with other water users.
 - (15) Snowmobilers and cross-country skiers can go to snow, but downhill resorts are in fixed locations. However, steeper (higher) elevations might place these recreators at risk.
 - (16) Snow sports moving to higher elevations would require moving trail heads, possibly incurring environmental problems.
 - (17) Resorts will benefit from wet snows which build a better snow base.

How Would You Adjust Operations to Cope with Change?

Limiting factors are cost, environmental issues, and altitudinal positioning of resorts. There are limitations to moving to higher elevations: cost, terrain and its demands on skiing ability with consequent limitation to high-ability skiers, and environmental considerations (increasing value of alpine ecosystems). Only possible coping might be to develop year-round recreational opportunities.

Additional Information Needed for Planning

- (1) Snow sports operate under a different set of stresses than other forms of outdoor recreation. Hence need more definite predictions on effects of climate change on snow.
- (2) Need focused discussions on Rocky Mountain/Great Basin region ski areas because of heterogeneity of area. There may be winners and losers in the region. Temperature measurements may help understand heterogeneity.
- (3) Need better spatial resolution in predictions and data.
- (4) Need increased cooperation between government and ski areas for obtaining long-term data sets.
- (5) It is economically questionable to develop more low-elevation ski areas.
- (6) The ski industry has not really bought into the global-warming issue.

CLIMATE-CHANGE EFFECTS ON WATER RESOURCES

Scott Chaplin, Chair

Introduction

The water-resources group addressed issues of concern related to water quantity, water quality, and equity among the many users and sectors of society. A preface to the discussion of water resources, and one that permeated the discussion, was that water supplies of the Rocky Mountains and Great Basin are simply insufficient for all the uses and sectors discussed below.

Water supplies in the Rocky Mountain and Great Basin regions of the United States are remarkable in their variability. The bulk of precipitation falls in high mountain areas, or as patchy monsoonal rains, creating uneven spatial distribution in the availability of water. And whereas other parts of the nation have relatively predictable yearly precipitation patterns, the Rocky Mountains and Great Basin are better characterized by their unpredictability. The climatic system switches between El Niño and La Niña years, but additional influences such as longer-term and subtle climatic processes render prediction of water timing and supplies difficult.

An extensive water- storage and -supply infrastructure has been created to develop a more dependable supply, and has worked quite well for providing water for agricultural and urban needs. However, there is growing recognition that other groups and needs for water have not been adequately considered by water managers. Western water management is conducted through a complex overlay of federal and state bureaucracies and laws for regulation and allocation. The rigidity of these institutions, much of it a cultural legacy from European settlement, has made it difficult to accommodate changing values and needs for how western water should be used. The challenges that face western water managers and users are a very public debate, with frequent new coverage and recent reports, such as the Western Water Policy Review Advisory Commission (1997). This is the context, then, with which the water-resources breakout group met to consider consequences of climatic change to the Rocky Mountains and Great Basin.

Current Users of Water Resources of the Rocky Mountains and Great Basin

The changing face of Rocky Mountain and Great Basin water priorities was evident in the list of water-use sectors that the working group defined. Traditional users, those to whom water has historically been allocated, were identified. But also users that have not been recognized until recently by water managers include sectors with legitimate and substantial needs, such as aquatic ecosystems, tribes, and recreation. In addition to new sectors requiring water allocation, there is a change in the proportion of water needed to support the rapid population growth and changing economies that characterize today's Rocky Mountains and Great Basin.

“The challenge for the future is to manage the West’s water in a way that sustains both prosperous cities and viable rural areas, allows Native American reservations to participate more fully in the prosperity of the region, and promotes and enhances healthier aquatic ecosystems” (Western Water Policy Review Advisory Commission, 1997).

Use Sectors

Traditional

- Agriculture
- Municipalities
- Commercial
- Industrial
- Mining
- Electric Power
- Navigation

Non-traditional

- Environment
- Recreation
- Tribes

Current Stresses to Water Resources Under Present Climate

The lack of abundant and consistently available water underlies many of the conflicts related to current water resources. A rapidly expanding population in Rocky Mountain and Great Basin states strains water-supply systems. Water quality downstream from urban areas can be degraded, limiting the uses to which downstream water can be put. The South Platte River below Denver Colorado, for example, is essentially all treated sewage water. Traditional water-allocation practices are being altered as cities or industries (such as computer chip manufacturing) purchase rights to water that historically has been used by agriculture. Unanticipated consequences of water-rights transfers include harm to small rural communities. Small farmers and ranchers with already marginal economic status are often unable to withstand pressures to sell their water rights. Other demands for water require reapportioning what water there is to support obligations to Tribes and aquatic ecosystems, including endangered species. Streams and rivers are not getting enough water (in-stream flow) or natural variability required to maintain the integrity of aquatic ecosystems.

Conflicts arise from multiple, competitive uses for limited amounts of water. Control structures that provide flood control and drought mitigation, for example, are directly conflicting with recreational demands and natural flow regimes necessary for maintaining aquatic species and habitats.

Land use, both past and present, influences water resources. Erosion caused by development, mining, or grazing increases stream turbidity, thus influencing aquatic-ecosystem health. Mine drainage in Colorado has caused 25% of the mountain-stream miles to be acidified. Wetland and riparian areas are extremely valuable ecosystems of the Rocky Mountain and Great Basin landscapes, supporting the greatest number of plant and animal species. They are also the most attractive to cattle and sheep, which trample and degrade them. In the Rockies they are often the only flat land, making them desirable for urban and suburban development. Invasive species travel up stream and riparian corridors, and some, such as tamarisk or salt cedar, require so much water that they alter the hydrology and geomorphology of rivers and streams.

Structural and institutional capabilities add to regional strains on water resources. Current federal and state water policies can have conflicting goals, so that agencies compete with or contradict each other. Surface and groundwater, although often part of the same hydrologic system, are managed separately in some states. As some agencies are phased out or restructured there is a very real possibility that expertise will be lost. Many dams and diversion systems are approaching their expected life span, increasing the risk of failure and necessitating costly renovations.

How Will Climate Change Influence Water Resources?

Three climate-change scenarios were explored: warmer with no change in precipitation; warmer with 15% less winter and 15% greater summer precipitation; and warmer with 15% greater winter and 15% less summer precipitation. These scenarios will influence both the Rocky Mountains and Great Basin, where moisture comes primarily from snow accumulation and melt.

Warming would affect the form of precipitation, the timing of snowmelt runoff, and the altitude of snowline position. Rain would occur at higher elevations. A shift in the form of precipitation could increase erosion rates. Reduction in water amounts from increased

evapotranspiration would add to already fierce competition for water. There will be less aquifer recharge. Lower, summer stream flows will strain natural aquatic communities. Warming may push water temperatures above the maximum survival threshold for some species in some parts of their ranges, such as cold-water trout. Warming may enhance both terrestrial and aquatic non-native species invasions. Downstream pollutants will be more concentrated with lower flow rates. Rates of salinization will increase. Municipalities will have a longer demand season, and a shorter supply season from which to replenish supplies. A warmer atmosphere also increases the probability of more intense and more frequent storms, so the risk of flooding, and also wildfire frequency, will increase.

Warming with greater summer precipitation will affect erosion, flooding potential, and reservoir storage capacity. As with warming alone, there may be increased flooding. Summer moisture may increase the risk of flash floods and storm intensity. Increased moisture is expected to cause increased cloudiness that will, to some degree, moderate the land-surface warming expected from greenhouse gas increases. Because a 15% increase in precipitation is not expected to make up for that lost through evapotranspiration, all of the stresses described in the warming-alone scenario will also apply to a warming with increased summer-moisture scenario.

Warming with greater winter precipitation actually will mean an increase in water supply, since evapotranspiration will be less important. There will be more rain at lower elevations, but greater snowpack at higher elevations. There is a possibility of larger spring floods if melt happens quickly. Drier summers will lead to greater water demand, lower water quality, possibly enhanced groundwater recharge, and a decrease in water supplies for those areas dependent on the monsoon rains. There will be shifts in vegetation to adapt to different precipitation and temperatures.

Adjustments for Coping with Climate Change

Given that nearly all climate scenarios lead to greater water stresses due to lower water quantities, water qualities, and more tension for insufficient amounts of water among the many user communities, two directions of coping strategies were suggested. The first is institutional, to help remove the barriers to sensible and equitable water allocation that exist today. Coping strategies here included:

- (1) Rethink water policy, especially to include considerations of current environmental needs;
- (2) Include “in-stream” water use on federal lands to maintain a minimum level and flow regime for biological resources;
- (3) Remove legal and administrative barriers to water transfers away from agricultural uses;
- (4) Shift to regionally sustainable agriculture;
- (5) Let the market help decide, but not dictate, water use;
- (6) Remove incentives for using all allocated water (move away from the use-or-lose philosophy);
- (7) Stay flexible in making water-use decisions; decisions on water use should be reviewed on a regular basis;

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- (8) Consider extreme events and climatic/hydrologic variability in water-systems planning;
 - (9) Consolidate and standardize existing and future records of precipitation and temperature;
 - (10) Support and publicize local weather monitoring and also increase support of federal monitoring.
 - (11) Ensure that existing clean-water regulations are implemented. Recognize that all water-quality problems are more severe with less water.

The second strategy is societal and community-based, and coping strategies included:

- (1) Conservation, including tax incentives, rate discounts, dry-year lease options;
- (2) Foster innovation in water-use efficiencies for different user groups;
- (3) Increase land-use planning, including no floodplain development, xeric landscaping;
- (4) Improve accessibility of information about climate and water. An informed public is able to make better judgements. Distribution mechanisms can include extension services, community groups, news media, the internet.

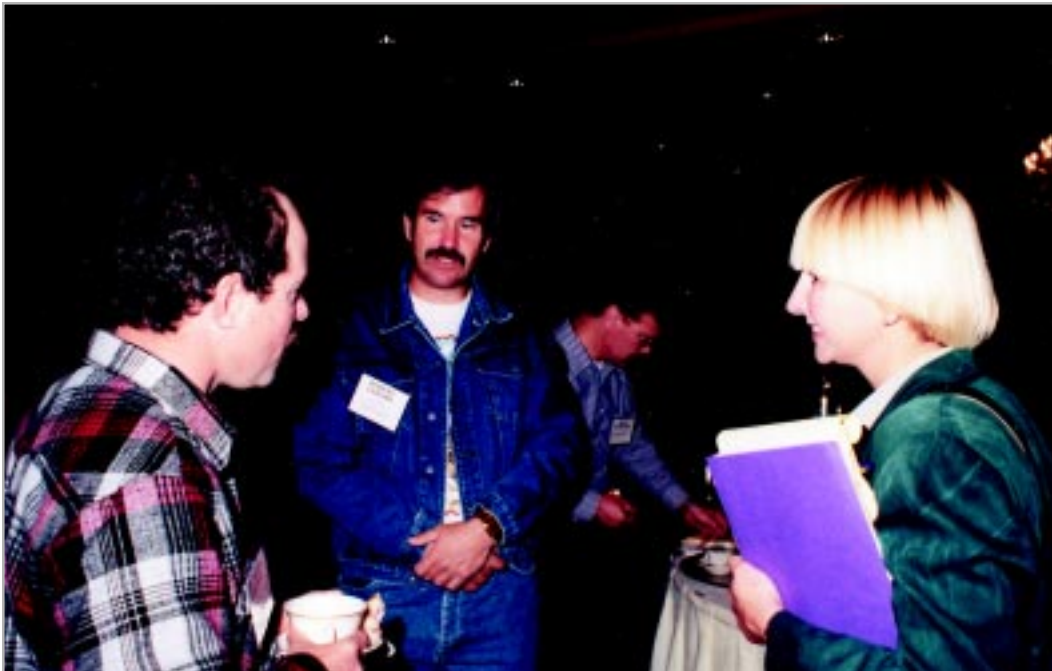
Additional Information and Research Needs

Information and research needs fell into three important categories of research, information transfer, and monitoring. The group members agreed that it is important to increase the predictive power of climate-change scenarios so that more citizens will seriously consider the topic of climate change. This is not an easy task for the Rocky Mountains and Great Basin given the extreme topographic and climatic complexity, so it is equally important that scenarios be presented along with their uncertainties. If presented well, scenarios with levels of confidence can then be incorporated into regional planning and risk analyses. There was also agreement that more small-scale research is important, in order to examine and better understand results of climatic variability on watershed processes. The results of research must be relayed to decision makers in a timely fashion, and this was clearly recognized as a dynamic, two-way process. Scientists must be responsible for providing accessible data, and also provide readily understood interpretations. Decision makers, however, are not only on the receiving end; dialog with scientists about the kinds of information that are most useful ought to occur regularly. Managers and decision-makers need to be well-enough informed that they can interpret the findings and use them for sensible actions. As stated above, an informed public makes better decisions, so information transfer to communities needs to be part of the communication link.

Without adequate monitoring of water resources there will not be feedback on how climate change will affect water resources, nor on how changes in our uses of water are influencing water quality and quantity. There has been a decline in the number of stream monitoring sites throughout the Rocky Mountains and Great Basin as federal funding has decreased. This trend must be reversed, records must be maintained, and gauging efforts must be standardized so that a regional picture of water resources can be built. The group agreed that a regional clearinghouse of information should be established that integrates climate and water records, including records of water demands as well as supplies.

BREAKOUT SESSIONS
for
Cross-Cutting Sectors

Wednesday, February 18, 1999



A Breakout Session Group

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CONSEQUENCES OF CLIMATE CHANGE ON LOCAL COMUNITIES

*Phyllis Breeze, Chair
Douglas Reiter, Recorder*

Abstract

Local communities may be adversely affected by changing climate conditions. Topics discussed include: (1) broad effects on local communities; (2) information dissemination; (3) provisional strategies; and (4) information flow. The effects on communities are identified as those dealing with water/sewer, transportation/energy, and human-health concerns. A major factor in coping with the effects of climate change is acting on reliable and understandable scientific information. That information is necessary if proper planning, contingency, and mitigation measures are to succeed. Given good information, local communities can adapt to changing climate conditions and continue to thrive.

Participants and Process

Important to any discussion of potential climate-change patterns are the direct effects those changes have on the everyday lives of the citizenry. One sector that all of us occupy is that of the local community. Participants in this breakout session included representatives from the Office of Science and Technology Policy from Washington, D.C., a private mining firm, western rancher and former county commissioner, western state climatologist, college graduate student, Utah Farm Bureau officer, and a Denver public health official. The number of participants was approximately ten.

Participants were asked to consider four major areas of concern to local communities in light of possible climate-change scenarios discussed during the previous day's breakout sessions. Those climate-change scenarios were: (1) no change in current climate; (2) an increase in average winter temperature by 7° F and average summer temperature of 4° F with no change in precipitation; (3) same temperature increase as 2 and with a 15% decrease in winter precipitation and 15% increase in summer precipitation; and (4) same temperature increases as 2 and with a 15% increase in winter precipitation and 15% decrease in summer precipitation.

The four areas of concern discussed were framed in the following four questions: (1) If the climate-change and resource-effect projections (discussed in the previous conference sessions) become reality, what will be the broader effects on your communities? (2) Given the possibility of these effects, and in view of the uncertainties and time-delays surrounding the issue, how should your people be informed without unduly alarming them at this point, but at least start them thinking about it? (3) What are some provisional strategies your people might adopt to cope with these changes if they come about? (4) What procedures should be put in place to keep your people apprised as new knowledge comes out on the issue? The discussion was an informal brain-storming session that mostly addressed the topics above. The following report is sectioned by those specific topics.

Broad Effects on Local Communities

(1) Water/Sewer

Important to maintaining viable communities is the provision of adequate water supplies. Most water in western states is characterized by its short supply and timing. The majority of water precipitates in the form of snow in the winter months and is stored and released to insure a continual supply. The planning horizons for water delivery have been established based on these unique, existing climatic characteristics. A change in the precipitation amount and timing due to projected climate-change scenarios would probably necessitate major infrastructural improvements. These could manifest themselves in the forms of more dams and reservoirs, water-delivery systems (e.g. culverts, pumps), and/or treatment plants.

There was also concern that current storm-sewer systems would be taxed by weather-pattern changes such as more intense summer storms. The capacity of these systems would likely have to increase in order to offset economic and social effects of flooding. A problem with increasing sewer capacity has to do with receiving matching federal dollars to offset local tax and bond burdens. It was pointed out that shorter-term, sewer-capacity planning determines grants received from government funds. In other words, long-term planning horizons taking possible climate change into consideration may restrict or negate federal government funds because the increased capacity requirements may appear unrealistic.

(2) Transportation/Energy

Flooding may also threaten other public works that would require major infrastructural changes. Major highways and side roads could be washed-out, inundated, or broken apart by increased frost-heave occurrences. Airport runways and railroad corridors are also subject to similar climate-related damages disrupting other links in the transportation system. These types of disruptions not only require major economic investments in repair or rebuilding, but also could affect individuals' economic livelihood. Increased commuter time, higher food and other goods transportation costs, increased fuel taxes to cover road-construction costs, were a few of the likely economic and social consequences climate changes may inflict.

A major consideration, given that there would be higher summer temperatures, would be an increase in demand for air conditioning. To satisfy that demand may require not only larger-capacity power plants (or maximizing load-producing capacity in existing plants) with the associated increase of fuel consumption, but also changes in energy-delivery systems to accommodate the additional loads.

(3) Human Health

Public health considerations centered around two points of discussion, disease and pollution. Climate change could exacerbate the range of disease vectors and/or increase transmission rates. For example, a wetter and warmer climate would create favorable conditions for mosquito outbreaks which may be carriers of various diseases currently confined to more tropical regions. This scenario would not only be a threat to public health but would also increase the burden on public funds to eradicate the threat and treat the infected public.

Localized air-pollution levels (particulates, ozone) might increase due to the climate-change scenarios. Inversion (common in western valleys) development patterns might change with increased atmospheric moisture. This scenario favors more frequent and longer-lasting inversion events trapping high levels of particulates in the inverted atmosphere. As mentioned above in the discussion centering around disease, this would have a detrimental effect on the public's health but would also impose an economic cost on society to treat both the health and pollution problem. Current technology has the capability to treat air pollution, and laws are in place to insure that people breath clean air, but capping air-pollution levels comes at a high cost.

Information Dissemination

In approaching the subject of how best to inform the local public about the consequences of climate change without unduly alarming them, two important issues were raised, framed in the form of questions: (1) Is this workshop going to result in direct communication with the community leaders with what to look for in monitoring climate patterns and how best to deal with potential impacts? (2) How can we make communities more resilient to changes? The key factor underlying this part of the discussion was developing and nurturing cooperative relationships with all parties impacted by potential climate change.

The discussion generated eight specific ideas (see Table 1) on ways to present climate-change information to the impacted local public. These ideas were based on several, general-communication principles: (1) There should be more emphasis on local activity as opposed to federal direction. (2) The public is better informed than we often give them credit for. (3) Repetition drives the information home. (4) Keep the debate open. (5) Keep lines of communication open, direct, and short.

Table 1

Information Dissemination Strategies

- 1 Presentation of scientific information to national groups of public officials such as the National Organization of Mayors.
- 2 Use of local TV forecasts as an avenue of information dissemination.
- 3 Continuous supply of scientific information to local weathercasters.
- 4 Continuous supply of scientific information to local mayors and commissioners.
- 5 Small soundbites by TV weathermen on scientific evidence of climate change.
- 6 Increase the profile of state climatologists (local meteorologists probably have more credibility than federal scientists).
- 7 Expand the role of the federal government to include funding university, public, and private research besides carrying out its own agency research.
- 8 Information dissemination "mouth-pieces" need to be believable and impartial and maintain strong network ties with researchers.

Provisional Strategies

When the discussion centered around ways that local communities can cope with impacts of climate change, several important issues were raised. The first had to do with infrastructural improvements. The foremost question was: do you invest in infrastructural improvements based on the available (speculative, incomplete) information? It was noted that some infrastructure has the capacity designed into it for additional loads. In other words, there is some adaptability for short-term inconveniences but long-term redesign may not only be economically burdensome but impossible due to current cost-share and granting requirements.

In order to mitigate consequences of climatic change, management plans should not only address emergency response (which they currently do) but also include long-term contingency strategies. Catastrophic events (e.g. flooding of the Great Salt Lake) usually result in better preparation for future similar events. Compounding the issue is the continual population growth experienced by the western states.

The participants spent a considerable amount of time discussing zoning issues as a way to address possible climate change. Dispersed zoning could spread the effects of extra pollution. Rethinking traditional zoning could also result in alleviating economic consequences such as the necessity to increase highway capacity by encouraging less commuting. There is a need for public officials to garner public support for alteration of zoning requirements. It was also suggested that local planners can help to relieve the social stress brought on by climate change by efforts such as preservation of green space, providing outdoor recreational opportunities, and reducing energy consumption by increasing the urban forest (more trees cool the microclimate, decreasing air-conditioning loads).

There are currently fundamental problems associated with current building practices that may compound effects of climate change. Some cities still allow building construction on playas that are subject to inundating flood events. To counter these type of practices, the federal flood-insurance program should make flood insurance contingent on not building on playas and flood plains. There is also an economic incentive for builders to re-build rather than include features that enable buildings to withstand flooding. Wind damage results in the second largest insurance claim (e.g. Hurricane Andrew cost Utah insurance payers \$45 million). In order to mitigate wind damage, designers and planners need information on how wind patterns and speed may change as the result of climate change. Local wind effects are somewhat unpredictable and difficult to model given the lack of reliable data.

Problems associated with developing *a priori* coping mechanisms can be identified along three dimensions: (1) treating the U.S. homogeneously (local effects of climate change result in unique results); (2) forward thinking as limited as backward thinking (historical lessons are forgotten); and (3) economic investment based on incomplete probabilities (is it cheaper to pay for damage or over-design?). The participants offered some suggestions that may help in overcoming some of those problems. Good government/scientific communication with the public would reduce social stress. Public involvement, such as citizen advisory groups presenting information to the public, would help people cope with change. They suggested that scientists present uncertainty up front and focus less on cause and more on effect. The participants also thought that scientists' direct involvement in local community concerns would increase the likelihood of workable solutions.

Information Flow

The final part of this workshop session was spent on strategizing ways in which new information could be successfully communicated to the affected public. Local leaders need long-term information but need to be apprised on updated short-term material. Some relevant ideas are presented in Table 2 that could enhance the communication process.

The three ways that scientists think and speak about climate change are: (1) measured observed changes; (2) theories about the way the world works; and (3) modeling. It is important that the non-science audience understand scientific interpretation of data within that context. However, it is equally important that scientists both understand the public and their concerns while separating the facts from theory. As one of the participants remarked “get the hay down to where the calf can get it.”

Conclusion

This session’s participants reinforced the notion that the people living in the Intermountain West and Colorado Plateau regions are resilient, adaptable to change, open to reliable information, and strongly tied to their local communities and land. The established community boundaries that help define communities further strengthen those ties. The people’s sense of connectiveness to the land also helps define their high degree of land stewardship. While keeping those ideas in mind, the lesson policy makers and researchers need to understand is that local communities rely on better, more flexible information in order to plan for realistic, projected outcomes.

Table 2

Fostering Good, Reliable Information Exchange

- 1 Keep issue alive by having periodic short newspaper articles on interesting climate facts.
- 2 Develop monthly newsletter targeted to local political leaders focused on local conditions.
- 3 Creation and sorting of information specific to local needs.
- 4 Write scientific information in such a way that it is accessible to the public.
- 5 Get the local newspaper science writer interested enough to write about it.
- 6 Enhance information to local leaders in a form that is already used and that they are comfortable with.
- 7 Supplement with information about conserving resources so that people can adapt.

POSITION PAPER OF ENVIRONMENTAL GROUP I

*Rose Strickland, Chair
Sherm Janke, Recorder*

[Editorial note: The environmental breakout group initially met as a single group of 13 individuals. But there were differences of opinion on what to accomplish and procedures. So it divided into two to explore somewhat different directions.]

Recorder's Note: The make-up of this Wednesday morning caucus consisted of environmentalists, primarily from the Sierra Club, and one representative of the agricultural community. Because that person had to leave early, the discussion began with a consideration of issues facing agriculture. Thus this report begins with a summary of those issues, and continues with conclusions reached by the environmentalists.

Summary of Agricultural Conclusions/Recommendations

- (1) Agricultural community should voluntarily adopt practices which tend to reduce greenhouse gasses (e.g. low-till or no-till reduces fuel consumption).
- (2) The agricultural community needs to involve itself in science/technology.
- (3) It needs support from the environmental community and collaboration from other constituencies as well, in order to remain viable.
- (4) Concerns:
 - (a) The cost of fuel is sure to escalate.
 - (b) Agriculture, as practiced in the U.S., is energy intensive; can it make the major shift to a fuel-scarce scenario? (This shift will occur regardless of any policy implemented to reduce greenhouse gasses.)
 - (c) Are alternate fuels, e.g. ethanol, hydrogen, practical/viable?
- (5) Possible (partial) remedies:
 - (a) Local marketing would be less transport-intensive.
 - (b) Low-till/no-till farming.
 - (c) Fuels from appropriate biomass.

Position of the Environmentalists Present at Workshop Caucus I

- (1) Given the uncertainty in predicting extent of global warming:
 - (a) Err on the side of caution: Adopt mitigation measures.
 - (b) Avoid large additional investment in traditional infrastructure that may become outmoded, e.g. coal-fired power plants.
 - (c) Curtail use of fossil fuels; emphasize/reward conservation.
 - (d) Create incentives for alternative, renewable energy sources and

energy efficiency. (Note: there is a difference between energy efficiency and its conservation. As we make this recommendation, we emphasize our serious reservations about fission-type nuclear reactors and the storage of spent fuel.)

- (e) We strongly emphasize: Regardless of the uncertainty about global warming and its effects, all the measures/policy options that we recommend to mitigate global warming would have been advocated anyway for other reasons, including mitigating the legacy of a resource-poor earth to our children; stewardship.
- (2) Population: Given the industrial and lifestyle aspirations of developing nations and their attendant escalating energy usage, as well as our own, any means by which we collectively agree for addressing/mitigating global warming are likely (if not certainly) to be rendered moot by population increase and the resulting extreme stresses on all resources. We simply must learn to control our own numbers.
 - (3) Communication mechanisms: how do we share information? Nothing will change unless we can “spread the word, tell our story.”
 - (a) Within existing organizations: websites, magazines, newsletters. We believe that most organizations do this well already.
 - (b) Inter-organizational communication needs improvement.
 - (c) Websites and the “ordinary” media can both be better utilized. Follow-up to conferences/workshops such as the present one: we suggest the formation of an advisory panel, or panels of scientists working in the global-warming area, and environmentalists.
 - (d) A serious obstacle: this issue, (global warming) is not “on peoples’ radar screens.” The issue is perceived as too arcane, too esoteric, and too far in the future to folks whose main concerns are next month’s paycheck and bills.
 - (e) And, if people find that they do care about this matter, what about the resulting feeling of helplessness? (What can one person or one family, or even one city do about such a world-wide problem?)
 - (f) In view of points d and e, the framing of our message, or how we tell our story, becomes extremely important (assuming WE take global warming seriously):
 - (1) The message must include a component of empowerment. Even though empowerment has become a kind of buzzword, it’s important that we communicate steps that ordinary folks can take to mitigate global warming. We need to spell out what is obvious to us, it may not be obvious to them.
 - (2) If there’s anything that’s important to almost everyone, it’s what kind of legacy they are leaving to their children and grandchildren. Without being fearmongers, we need to relate, in a non-accusatory and hopefully simple way, how we are collectively affecting that legacy.
 - (3) By providing a list of positive responses that almost anyone can implement, we can provide incentive for hope in a scenario that has extremely negative implications.
 - (4) No one of our constituencies can do it alone; we need to collaborate - - we’re back to the recommendation of our representative from the agricultural community.

POSITION PAPER OF ENVIRONMENTAL GROUP II

*Patrice Engels, Chair
Robert Gerard, Recorder*

This was a diverse group of six individuals representing environmental, livestock, agriculture, coal company, and health interests. Its conclusions follow:

The environmental community needs to adopt an active position in relation to the uncertainties of our common climatic future. Although the environmental community must take an active position, there is perhaps not enough research or extension of information to develop a good working strategy.

Our environmental group feels that it has a basic understanding of the issues and does have the ability to take a firm stand. The necessity for a follow-up workshop on the environment is very important. The environmental community as a group needs to discuss ways to reduce greenhouse-gas production and find ways to adapt to climate-change impacts.

We think that the communication mechanisms for this change are adequate, but the idea of the environmental community needs to be amplified to include people who are not traditionally thought of as environmentalists: ranchers, miners, farmers, and so forth. The environmental community should be considered in a broad, encompassing manner, including groups that work closely with the environment as well as the environmental organizations and societies.

We feel that there is plenty of information and no real barriers to getting it. However, facts are often obscured and the truth, the most important facet of climate-change studies, is often muddled by a lot of bad information. Categorical I don't know's and maybe's should be considered as ethical responses for some of the questions posed by the public and would be respected more by the public than fear mongering and calculated guesses. We feel that we need factual information without a spin. We also feel that the information needs to be presented at several technical levels, with margins of errors and probabilities noted. Uncertainties should not be apologized for nor hidden, but the information should be described and its usefulness stressed.

As part of the communication link between sectors, proper communication skills and philosophy of science should be taught so that all people may better ascertain the importance of the information they are receiving.

We feel that climate change will induce and increase tension between all stakeholder groups (everyone!) as each attempts to continue working in his/her traditional ways. As each stakeholder group attempts to keep working in a changeable environment, it is imperative that a system be developed whereby techniques for listening, negotiating, resolving conflicts, cross-training, and making decisions in a collaborative manner can be utilized. There should be space created in the future under greater societal and environmental pressure for well-trained meeting facilitators and philosophers.

We believe that response is imperative to prevent and mitigate sources of human-caused climate change as we identify them. Work must take place within all parts of society: government, business, the public sector, and science - ASAP!

Not wanting to give up our current endeavors, we must work to increase the adaptability and flexibility of our businesses, farming operations, and government. We should consider climate change as a challenge and opportunity - with a no-regret and it-can't-hurt attitude to adapt positively to changes.

The hard questions of the future are: "Can we still have it all?" and "What falls off the table?" What must be sacrificed as we move toward conservation and preserving the environment? Can we continue to have: children, cheap energy, cheap food, consumer 'stuff', recreation, pets/livestock/wildlife without long-range consequences?

In our group we found striking similarities between the very diverse energy and farming sectors. We found that both use resources; energy uses coal, and farming uses soil and water. Both energy and farming have very low profit margins for their products leaving a large percentage of profits to utility companies in the case of mining, and processors in the case of agricultural commodities. Market prices don't reflect the suffering of the producers, only the gain of the middle man.

Business pressures create a situation where less money is invested in an operation. In energy, plants are forced to work at fuller capacity and for a longer life to keep profits. Greater pollution occurs and conservation is placed at the wayside. Technology arrives not as an innovation but as a retro-fit. In farming, big agriculture has been pressed to produce with small profit margins, leading to the kind of farming that often degrades the soil and the environment.

A positive aspect of deregulation is that some of the environmental degradation will be reduced by opening up the market to realistic pricing of products. Properly priced energy products will stop full-capacity production and will help make the move toward conservation and alternative energy sources. Efficiency will be the rule of the day.

In agriculture, deregulation has already taken place with the removal of many subsidies. This in essence, puts farmers out of business who farm poorly. Wasteful practice, such as over-irrigation, overuse of pesticides and fertilizers, and poor farming techniques, when unsupported by the taxpayer, become more thought out by the farmer as to their cost effectiveness and necessity. Perhaps the removal of financial incentives to overuse water, pesticides, and synthetic fertilizers, will help move farming operations in a more "earth friendly" and less expensive direction. Perhaps without subsidies, the true expense of high-input farming will push farmers to adopt low-impact techniques such as no-till, low-till, cover cropping, intercropping, and rotations. In this regard, it is imperative that more research be done on these techniques as to their cost effectiveness (Can we afford to pursue them at the present low price of the product?), flexibility to different operations, and specificity to location.

We ended our discussion by talking about the importance of small farms, realizing that the loss of small farms is not just a matter of aesthetics but of our ability as a nation to produce food into the future. Nationally, small farms produce a large percentage of all our food, yet receive a pittance of agricultural funding. We feel it is prudent for agricultural policy in a changing world climate to pursue a system whereby many different sizes and kinds of operations are present nationwide. By amplifying the diversity of farming operations and geographical location, we felt we would be better able to weather the storms of the future.

Addendum by Robert Gerard

Market forces are in a sense artificial to the natural state of the environment. It is foolish to emphasize the big operations because they succeed so well in our economic system. It must be more commonly realized that agriculture works by a different set of rules than industry, largely because it is based on biological systems rather than physical.

What of large farms' inherent weaknesses and shortfalls, such as: their vulnerability to plagues, and the necessity in such operations to use exploitive farming techniques that damage the soil and the environment of the farm. Will the use of so many synthetic chemicals have effects beyond the field and onto the consumers' food plates? Will large farms be able to buffer the natural changes of the future? Do we want to put all our eggs in this particular basket?

ISSUES ON TRIBAL LANDS

*Harold Trujillo, Chair
Bob Gough, Recorder*

The Rocky Mountain and Great Basin region, along with the Southwest, are home to most Native Americans in the United States. Roughly one fifth of the land in the interior is owned by Indian tribes, and Native Americans are the majority in several counties of Montana, New Mexico, and Utah. Tribal rights to water, natural resources, and sacred sites are being reclaimed, and many tribes are experiencing economic gains. There are still many problems facing Native Americans, however, some of which will be made worse by changes in climate.

Stresses Under Current Climate

Social and economic issues dominate the types of current stresses facing tribes today. Populations on tribal lands today are growing, and there is a large young population. Many Native Americans are poor and do not have access to adequate health care, nutrition, or clean water. There is a finite amount of tribal land, so land- management issues, such as conflicting uses, can lead to tension. This tension can occur among tribal members as well as between tribes and other groups. The water- rights doctrines by which western water is distributed today were developed by and for settlers of European descent; only recently have Native Americans been able to assert legitimate claims to a fair share. An unfortunate twist to re-negotiating water rights is that tribes and environmental needs often compete for water. According to Riebsame (1997), there was a resurgence of Native culture in the 1960s that has fostered economic diversity on tribal lands. Some tribal members are shifting back to traditional crops and lifestyles for sustainability, others, prepared with college and legal educations, are boosting economic growth through gaming, sale of water resources, and promotion of industry. This all promotes conflict of land and natural-resource uses among tribes.

How Will Climate Change Influence Tribal Land and Resources?

It was noted that a warmer climate could lead to shorter winters and a longer growing season, but increased evapotranspiration would increase pressures for scarce water supplies. This could influence growing-season length, and would almost certainly increase the current tensions over water use. Among the problems raised was livestock needs for water. Warmer night temperatures could lead to higher plant respiration rates, thus lower-quality hay for livestock.

Concerns were raised about changes in storm types, such as increases in ice storms, storm frequency and intensity. These extreme weather types are directly harmful to agriculture and livestock. They can be directly and indirectly harmful to human populations as well, possibly leading to direct mortality from weather (extreme heat, drought), and increased incidence of disease (such as outbreaks of hantavirus and water-borne diseases). Environmental quality could degrade to the point where tribal members are forced to migrate off reservations to seek employment, thus reducing tribal cultural and economic structure.

Warming, with increased summer and decreased winter precipitation, added some different concerns among breakout-group members. Less water storage in snowpacks

would lead to greater uncertainty for meeting summer water needs, while the Great Basin might experience more monsoonal moisture. This could enhance conditions for annual grasses at the expense of shrublands, and this could increase occurrence of wildfire. One positive aspect of warmer winters would be a decreased demand for fuelwood.

Warming, with increased winter precipitation and decreased summer precipitation, could relieve water pressures in regions that rely on snow, but would increase drought pressure in the Great Basin. A decrease in range quality would accompany decreased grass cover in pinyon-juniper vegetation types.

What are Strategies for Coping With Increasing Climate Change?

A number of creative ideas for coping were raised by the breakout group.

(1) Water-related:

- Increase water planning.
- Alter water infrastructure - increase reservoir and irrigation capacity.
- Adjust agricultural practices for more sustainable farming and ranching.
- Increase cooperation between tribal governments and natural-resources departments.

(2) Energy- and economy-related:

- Diversify economies.
- Utilize more renewable and more efficient energy resources.

(3) Education- and information-related:

- Increase education levels, especially of younger Native Americans.
- Use community meetings for information exchange.
- Draw on historical strategies for coping with climate variability, communicate these with scientists.
- Overlay climate data with oral history for baseline data.
- Augment Internet information systems.
- Inform local tribal representatives, such as Elders, so they can pass information to others.

Additional Information and Monitoring Needs

The information and monitoring needs expressed by members of the tribal- lands breakout group were related primarily to increasing the availability of information on trends to government, tribal members, and leaders. There is not nearly enough monitoring going on today on tribal lands. Specific recommendations were:

- (1) Increase the flow of high-quality information from reservations. Promote locally-based monitoring of weather, water, vegetation, long-term health and epidemiological data.
- (2) Provide remotely-sensed data in user-friendly formats.
- (3) Overlay climate records with oral history for baseline data.
- (4) Use tribal colleges as monitoring and research centers.

ROLE OF PUBLIC EDUCATION

*Linda DeKort, Chair
Sandra Henderson, Recorder*

Public education was one of the cross-cutting breakout groups that met to discuss whether and how issues related to climate change should be taught in the public schools. Participants were asked to address four questions, but the group also went further than that by describing some ailments of the current public-education system that need correcting in order to be able to effectively teach complex issues such as climate variability and social, economic, and natural-resource responses.

Ailments of the Current Public Education System

Breakout group members felt that critical-thinking skills are not taught, or taught adequately, by the American education system. Issues such as climate change and effects are extremely complex, and the media often present opinions alongside, or in place of, objective scientific results. The schools can help students to reach their own conclusions by providing better opportunities to distinguish fact from hype. Students need to learn and understand that the scientific process is one of exploration. One group member emphasized that science is not a black and white enterprise. New knowledge is critiqued; public debate about issues doesn't mean scientists "don't know what they are talking about." Scientific understanding evolves, and hypotheses are supposed to be tested critically in order to test their validity. If students are grounded in basic science-- physics, chemistry, mathematics, statistics and probability--they will be better prepared to evaluate a public debate on topics as complex as global change. Other topics that were suggested included atmospheric sciences, ecology, and economics. Group members also thought students ought to be better prepared to deal with complex issues, perhaps by introducing topics such as global change at high-school levels.

An important topic that was raised was bias in teaching. Education is not balanced in many schools, allowing students to reach their own opinions. One comment was that children are a captive audience in the schools, and can be vulnerable to political commentary. Students may not be given adequate appreciation that maintaining a civilized standard of living requires raw materials, such as metals, fiber, and food. Balancing societal needs for materials with environmental goods and services such as clean air and water requires compromise, another topic that could be better taught in the public schools.

Should Issues of Global Change Be Taught in the Public School System?

Breakout-group members agreed that global change is too specific a topic to stand alone, and a foundation is needed in order to approach global change. It is difficult to teach science at all in elementary school, because the reading preparation alone is a burden on primary school teachers. Elementary school teachers are overwhelmed with many other requirements, and this may not be the place.

High schools could use global change as a case study that encourages critical thinking and the evolution of scientific ideas. Global change could be taught as part of the ongoing pattern that characterizes the Earth's climate and variability. Nuclear winter scenarios from the 1970s can be introduced. Scenarios of the consequences of rising

carbon dioxide to climate could be debated. Many issues of the societal consequences can also be brought up in a social-studies context; what are the probabilities of increased flooding, disease, drought, etc?

What are Some Ways to Bring the Subject to School Districts Without Burdening Teachers Excessively?

This is an issue where external involvement can help. Graduate students, industry, parents with expertise can all enlist to bring the subject, including different sides of the subject, to students. Local information groups, such as the League of Women Voters, the American Association of University Women, and Partners in Education program are valuable resources.

Science teachers are encouraged to keep their understanding of the science current, by following the literature and taking continuing-education classes. Teacher preparation materials can also be made available through inservice and summer workshops such as are offered at the National Center for Atmospheric Research, and the University of Montana Biological Station, regional information workshops, and interactive distance learning classes from universities.

How Can Teachers Get the Information from Those Who Have It?

There is an obligation on the part of teachers, scientists, and industry to make sure information is shared. An information clearinghouse, such as the US Global Change Research Program, is a good idea. Although many web sites are available via computer, there is at present no quality control. Apolitical groups such as the National Academy of Sciences and the National Science Foundation were recommended as locales where reliable information could be found. Teachers can share good information sources with others, perhaps through the clearinghouse or through professional teaching and scientific societies. The Desert Research Institute web site was mentioned as a good, objective, regional source for information. Workshops, such as are taught at the University of Montana Biological Station, are another good way for teachers, scientists, and industry to get together for intensive short courses.

What Other Public Education Measures Should Be Used to Get Information About Global Change Out to the Public?

The public was defined as citizens, leaders of community, decision makers, and educators. It was noted that most people get their information from television, so news and feature reports on TV are a good medium for many Americans. Printed media and radio are also good broadcasters of information. Town meetings and presentations to civic groups and local stakeholder groups are valuable ways to transfer information about global change. University extension agents are effective at reaching certain societal groups, such as farmers and ranchers.

ROLE OF FEDERAL AND STATE LAND-MANAGEMENT AGENCIES

Martha Hahn, Chair
Susan Selby, Recorder

Major Climate-Related Stresses Under Current Conditions

The following are the collective views of participants from both federal and state agencies, including both land- and water-resources agencies, who attended the workshop. Major, current stresses included the following:

- (1) Increasing frequency and severity of fires, in part due to past land-management practices. These change vegetation composition, destroy wildlife habitat, facilitate noxious-weed invasion, alter hydrology, and reduce forage quality for livestock.
- (2) Natural fluctuations in animal populations. These are difficult to document and predict, and to inform the public. They create an outdoor-recreation problem.
- (3) Agencies' ability to provide customer services. A number of factors are impinging on the agencies' efforts at serving the public:
 - (a) Most basic is the growing constraint of shrinking budgets. A number of stresses follow from this.
 - (b) The public has a wide range of perceptions on problems and solutions which tend to pull the agencies in numerous directions. We need more resources than we have to put out enough public information to inform the public more adequately.
 - (c) Rate of change in our problems is rapid relative to our planning processes. The agencies have lost commitment to long-term assessments, and have shifted to short-term, multi-disciplinary research. We need to improve mechanisms for prioritizing and strategizing good plans within the agencies. Pressures toward micro-management from outside the agencies often stop implementation of good plans.
 - (d) There is increasing difficulty in meeting state regulatory objectives (e.g. water- and air-quality standards) because of changing climatic and resource conditions.
- (4) Lack of interagency coordination. This is a problem both on vertical (administrative) and horizontal (interagency) scales. Agency and private boundaries don't coincide with ecological boundaries, so we are all trying to manage the same resources. This problem won't change without legislation.
- (5) Inadequate budgets. We are always operating on a reaction-to-crisis mode. This tends to use up the funds and prevent commitment to longer-term, proactive programs contributing to the short-term mentioned above. An example is that it is politically untenable not to fight forest fires although letting them burn might be better resource management in many cases, and the money could be better spent elsewhere.

Effects of the Climate Scenarios

The group combined the above stresses into four categories and then checked which would be affected by the three climate-change scenarios. These are summarized in the following matrix, with an X indicating some affect on each stress category.

Current Stresses	Temperature Increases Precipitation Unchanged	Temp. Increases, Summer Ppt. Increases, Winter Ppt. Decreases	Temp. Increases, Summer Ppt. Increases, Winter Ppt. Decreases
Natural & Environmental Variability	X	X	X
Agency constraints =>budget =>jurisdiction	X	X	X
Scientific Capabilities	X	X	X
Externalities (eg. policy, mandates sci. budget, regulations)	X	X	X

Solutions and Coping Strategies

- (1) We need multi-year, non-erodible budgets with more flexibility for shifting between budget sections. An example is fire budgets. A manager would never cut it because fire has become such a crisis item. If there is any surplus, it may be reclaimed by higher administrative levels so there is a tendency to spend it out. Secretary Babbitt allowed agencies to 'save' funds for a rainy day, but eventually took them back. Money could be used more effectively by allowing it to be carried over without penalty.
- (2) We need to capture and coordinate existing talent and focus it, either with effective inter-agency coordination or a new agency. We need to clarify and refine the roles of federal, state, and local agencies and tribes with respect to climate change. We need to foster a climate of trust among agencies and Congress.
- (3) We need more effective, long-term strategic planning focusing on climate change. This includes prioritizing, understanding existing capabilities, and a commitment to long-term research.
- (4) Regarding the mining and energy sector:
 - (a) The challenges to the sector of adapting to the climate-change scenarios are dwarfed by the larger questions of adapting to new policies to control GHG emissions.
 - (b) The mining, oil, and gas industries can adapt to all scenarios. (The climate conditions the industry presently operates under are often more extreme than the climate conditions posed by the three scenarios for the Great Basin-Rocky Mountain region.) Examples of adaptations: changes in revegetation strategies to adapt to hotter temperatures and changes in precipitation. In some scenarios, e.g. wetter summer conditions, reclamation and dust control would be easier.

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- (c) In the energy sector, we expect change in consumption patterns, such as increased reliance on air conditioning, in the three scenarios. This will lead to increased peak-load electricity demand.
 - (d) Hydro-electric production will decrease in Scenario 2 (due to increased evaporation), may decrease in Scenario 3 (due to less precip stored in the snowpack and, under the assumption of a 15% decrease in winter, overall precip will drop).
 - (e) Thermal powerplant efficiency will drop in all scenarios due to higher ambient temperatures.
 - (f) The transmission system will be stressed with the evolution of competition in the electric power industry. Severe precipitation changes could further stress the transmission system. Line losses will increase with temperature increases.
 - (g) Heating load will drop in all scenarios and this combined with the likely increased use of natural gas to meet increasing peak load, will tend to level natural-gas demand.
 - (h) Better price signals for both producers and consumers (including green-power purchasers) improve adaptability.
 - (i) Huge technology uncertainties over climate-change time span make prediction difficult.
 - (j) Risks of not having access to reliable and affordable energy services.

Research and Information Needs

- (1) Re funding: Need more “hard money,” less “soft money.” Soft money shortens lengths of projects when we need long-term research. And it promotes competition for funds which inhibits sharing results with colleagues because it will make them more competitive in next round. At the federal-agency levels, research gets second shrift. States are getting out of research and going to federal or university cooperatives (soft money again) for research. We need a recognition that research is important and needs funding.
- (2) The land-management agencies need to be connected into the Global Change Research Program (GCRP). Some 80% of GCRP funding goes to agencies like NOAA, not to land-management agencies. The latter are not in any way connected. This is a huge disconnect. If we don’t have some connection we will be having these same meetings in 10 years. This division of funding was an appropriate place to start, but it is time to involve the land agencies. The climate-atmospheric agencies are going to resist it.
- (3) Stronger federal, state, and tribal commitments to long-term ecosystem science:
 - (a) Appropriate and reallocate funds to landscape and ecosystem scale.
 - (b) Adopt flexible budget cycles (base funds, carry over).
 - (c) Improve science capabilities (trainer personnel, tools, data analysis and synthesis capabilities).

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- (4) Increase emphasis on the effects of global change on natural resources at landscape and ecosystem scales:
 - (a) Provide better match between data needs and agency priorities.
 - (b) Evaluate the relevancy and use of existing monitoring data (synthesis).
 - (c) Encourage more meso-scale climate modeling, refine predictions to landscape and regional levels emphasizing effects on natural resources.
 - (5) Better coordination and access to local, regional, agency, and academic data sets related to climate and natural resources:
 - (a) Increased comparability of data.
 - (b) Increased access and use of data (linked web sites).
 - (c) Access to computer capabilities and trained personnel.
 - (6) The societal aspect. We need to have increased involvement of all stakeholders in the process:
 - (a) Stronger role of land-management agencies in U.S. Global Climate Change Research Program.
 - (b) Increased efforts at communication and education (the teachable moment). We need to have science available at the teachable moment. We are still arguing whether to build in floodplains, yet we watch homes wash away every year because the teachable moment hasn't arrived. There is a lag time between science and the teachable moment, but teaching needs to be ready.
 - (c) Issue of credibility. People keep asking if catastrophic meteorological events (coastal houses falling into the ocean) are the result of global warming. There was agreement in the group that we should use "global change" rather than "global warming." The former will cover increased variability. If we use warming, and someone sees a cooling effect in his/her area, it will create credibility problems.
 - (7) There is a need for probabilistic rather than deterministic analysis, spatially and temporally. Need increased tolerance for probability statements as with weather forecasts. Land managers need probabilities, not information in the drawings and not global scenarios. They want this information even if it is messy. Management will usually accept scientists' best guesses, although scientists don't like to guess.
 - (8) Generic information needs:
 - Cloud cover (in the region and as a global, climate-feedback mechanism).
 - Intensity of precipitation events.
 - Seasonal and geographic pattern of precipitation.
 - Rate of climate change (better understanding on a greater level of resolution):
 - (a) Relationships between the rate of CO₂ and temperature change.
 - (b) Signals of rapid climate change (e.g., El Niño).

(c) Man-made versus natural causes (man-induced break points).

(d) More information on the past record of climate change.

- Ability to mitigate climate change.
- Ability to adapt to hazards (regardless of if the hazards are driven by climate change).
- Seasonal and daily changes in temperature.
- Emerging technology inventory and timing of the commercialization of new technologies (including carbon sequestration technologies).
- Information must be useful to all parties (and tailored to the assimilation rates of information users).
- Need information to conduct tradeoff analyses (e.g., economic and quality-of-life tradeoffs).

SUMMARY
from the
Breakout Groups

SUMMARY FROM THE BREAKOUT GROUPS

*Jill Baron, Research Ecologist
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More than 100 people participated in the breakout groups, from all sectors of society. The only similarity among most of the participants was residency in the Rocky Mountains or Great Basin. In spite of this diversity, clear and strikingly similar conclusions came from nearly all breakout groups. Together, they provide a clear map of how the Rocky Mountains and Great Basin region can increase preparedness for the possibilities brought about by global change.

Most sectors of western society, with the possible exception of the winter recreation industry, are adaptable to change. People, communities, agriculture, ranching; all are adaptable to change, particularly in a region defined more by change than continuity. Weather extremes are already a reality. Even recreation and tourism displayed evidence of flexibility by putting forward the idea of year-round resort use to supplement winter skiing use. Given the information, communities can change so as to minimize the consequences of change; in short, they can adapt. The cross-cutting group phrased it especially well: "People living in the Rocky Mountains and Great Basin are resilient, adaptable to change, open to reliable information, and strongly tied to their local communities and land. The peoples' sense of connectiveness to the land also helps define their high degree of land stewardship."

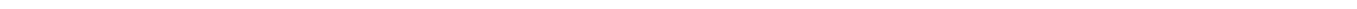
Unlike the communities they serve, existing infrastructure may be far less adaptable to change. Energy and water-supply networks are rigid, and will undergo losses of efficiency and stress under climatic change. Existing policies and institutions are impediments to increasing the ability of societal infrastructure to change. Many were developed through "accidents of circumstance" (such as the Doctrine of Prior Appropriation for water rights) without regard to physical processes and constraints. Some, such as providing federal flood insurance, invite ill-advised and dangerous behavior.

Natural resources are going to be most vulnerable to climate changes, because of the existing stresses placed on them by past and present management. Habitat fragmentation, alteration of natural disturbance regimes, introduction of aggressive non-native species, and appropriation of water resources are all imposed on natural communities, making them more vulnerable to climatic variability or change.

Virtually all the breakout groups agreed that reducing the current stresses placed on each sector, whether natural resources, communities, industry, agriculture, or tribal lands, was the most important way to improve quality of life and ability to adapt to change. All breakout groups expressed the need to address these current concerns first, in order to be best prepared for additional stresses from climate change.

All the groups expressed a desire for more and consistent information regarding climate-related issues. The education and community breakout groups had especially thoughtful suggestions on ways to increase awareness of complex societal issues such as climate change. The common themes from all groups were a desire for adequate, objective, and timely information in clear plain language. There was a strong message that uncertainty, if addressed honestly and up front, was not a deterrent to thoughtful treatment of climate-change issues.

WHERE DO WE GO FROM HERE?



WHERE DO WE GO FROM HERE?

*Fred Wagner, Director
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This Workshop has been the first step in the Assessment of the Potential Effects of Climate Variability and Change on the Rocky Mountain/Great Basin Region. That effort is part of 19 other regional assessments, 6 sectoral assessments, and the national synthesis which make up the U.S. National Assessment. The results must be submitted to Congress by December 31, 1999.

The Rocky Mountain/Great Basin assessment is being coordinated by Fred Wagner at Utah State University and Tom Stohlgren of the Biological Resources Division, U.S. Geological Survey, based at Colorado State University. The effort is being supported by a grant from U.S.G.S. to Utah State University.

Several of the participants in the February workshop are on the Regional Assessment Steering Committee and Assessment Team. The coordinators intend to keep all invitees to the February workshop informed about developments in the assessment.

**Rocky Mountain-Great Basin
Workshop Steering Committee**

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14. Jack A. Stanford, Director, Flathead Lake Biological Station, University of Montana, Polson, MT
15. Ted Stewart, Director, Utah Department of Natural Resources, Salt Lake City, UT
16. Rose Strickland, Chair, Public Lands Committee, Sierra Club, Reno, NV
17. Jack Troyer, Acting Regional Forester, U.S.D.A. Forest Service, Ogden, UT
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APPENDIX B

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