THE RIO GRANDE BASIN

GLOBAL CLIMATE CHANGE SCENARIOS

The greatest extremes of climate
are not to be attributed to the
abnormal development of any one
factor, but to the cooperation of
a number of different factors
acting in the same direction.

C.E.P. Brooks, 1926
Preface to 1st edition
Climate Through the Ages

Satellite photomap of New Mexico and adjacent states showing the Rio Grande and the varied terrain through which it flows (compiled by the Agricultural Stabilization and Conservation Service, U.S. Dept. of Agriculture). Color or black and white copies available from NM Bureau of Mines & Mineral Resources.

THE RIO GRANDE BASIN
GLOBAL CLIMATE CHANGE SCENARIOS

Proceedings of Workshops and Conference
June 1-2, 1990
Albuquerque, New Mexico

sponsored by

The City of Albuquerque
New Mexico Institute of Mining and Technology
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New Mexico Water Resources Research Institute
Sandia National Laboratories
US Army Corps of Engineers
US Bureau of Land Management
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US Forest Service
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US Soil Conservation Service
The University of New Mexico

compiled by

William Stone
Michele Minnis
Eleonora Trotter

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COMPILERS' NOTE

To maximize the usefulness of this document we organized the material thematically rather than chronologically. For workshop results we emphasized what was said rather than who said it. Appendices give useful contacts as well as information on current data, research efforts and perspectives.

We would like to thank Robin Morgan, UNM Natural Resource Center, for compiling workshop tear sheets, Marta Henriksen, UNM Natural Resource Center, for transcribing taped sessions onto disks, Lynne McNeil, NM Bureau of Mines and Mineral Resources (a division of NM Tech), for reformatting everything into final proceedings style, and Gary Eyster, U S Army Corps of Engineers, for financial support of publication. Carol Hjellming, NM Bureau of Mines, and Waleed Ashoo, Dataco, Inc., provided valuable advice relative to format and printing. Drafting of various figures and the cover was also provided by the Bureau.

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FOREWORD

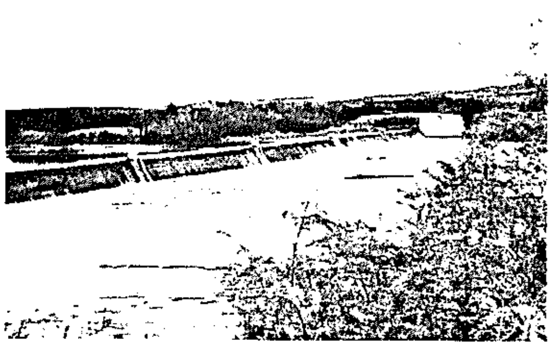
For the past three years it has been difficult to pick up a newspaper and not see some type of story written about global warming, greenhouse gases, holes in the ozone layer or deforestation. The message is that we humans are fouling our own global nest; that the globe will warm and melting polar ice will flood coastal areas, that vast areas of productive farmland will become desert and other bad things will happen. As often happens with environmental issues, there are zealots who are quick to pick up the human-induced global warming scenario and aggressively preach a doomsday message to policy makers. Others claim this scenario is not backed by any solid scientific justification and is yet another emotionally charged argument used to advance a special interest. More moderate and cautious individuals have taken positions opting to carefully evaluate the situation.

Whether or not you are a believer, non-believer or an agnostic on this issue, all seem to agree that climate *does* change and for whatever reason, it is likely to change again in the future as it has in times past. When climate changes, it can have profound affects on water resources regardless of whether the globe warms or cools, producing ecological, economic and social impacts.

To date, most research on global climate change has focused on developing a better understanding of the effects of greenhouse gases on the atmosphere. Much less effort has been placed on evaluating possible environmental impacts of different climate scenarios. That's what this conference and workshop is all about.

Those of us who live in the Rio Grande Basin are acutely aware of our dependence on this river for our livelihood. From its headwaters high in the Colorado Rockies to where it empties into the Gulf of Mexico, it transcends cultures and ecological zones; forms an international boundary; and supplies water for cities, industry, crops, wildlife and recreation. Change in climate means change in the river's hydrology and change in everything that depends on the river. Understanding these relationships requires an enormous effort of closely coordinated interdisciplinary study. The universities, national laboratories and governmental agencies in the basin have a wealth of expertise and scientific talent that can be focused in such a manner. These workshop/conference proceedings outline the important first steps that have been taken by the scientific community in the Rio Grande Basin to advance our knowledge of this important subject.

Tom Bahr, Director
New Mexico Water Resources
Research Institute



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* abbreviations as above

PREFACE

Global warming presents a serious and widespread threat to the earth's inhabitants, as its ramifications will be manifested in virtually all physical, biological, political, and socioeconomic systems. In contrast to the attention which has been devoted to predictions of warming, relatively little consideration has been given to the consequences of the phenomenon, particularly with respect to ecological and institutional environments. Recognizing this, a group of researchers at the University of New Mexico initiated an interdisciplinary project to develop the concept of the Rio Grande Basin as a field laboratory for investigating potential impacts of climate change on these systems. The members of the group were Chuck DuMars (professor of law), Jim Gosz (professor of biology), Michele Minnis (associate director of the Natural Resources Center), Chris Nunn (assistant professor of economics), Steve Thompson (assistant professor of geography), and Bruce Thomson (associate professor of civil engineering).

They were able to work together on this project during the summer and fall of 1989 through support provided under the auspices of the UNM Faculty Scholars Program. The objective of this program, initiated by UNM provost and Vice President for Research Paul Risser, is to relieve faculty from their teaching duties for one semester to allow them to pursue interdisciplinary research that would not otherwise be possible within the confines of their departmental responsibilities. Sandia National Laboratories expressed strong support for a research program on the regional impacts of climate change and contributed the services of Senior Staff Engineer Mike Edenburn, who worked very closely with the UNM team.

One of the first tasks undertaken by the group was to organize a regional conference to generate public awareness of the impacts of climate change on the basin, and to serve as a forum for exploring ways in which personnel from the natural resource management agencies could develop working relationships with members of the research community. It was immediately recognized that organizing such an event was a far greater task than could be accomplished by any single institution, thus a Conference Organizing Committee was formed (see opposite page).

Several members of the committee made special contributions to the success of the conference. Tom Bahr and Bob Creel, director and associate director, respectively, of the New Mexico Water Resources Research Institute, organized funding for the conference and served important roles as facilitators of communications between the conference planners, who were principally from the research community, and institutional sponsors of the conference, public agencies responsible for management of natural resources. Lee Brown, professor of economics, co-director of the Natural Resources Center and director of the Division of Public Administration at UNM, who had previous experience with similar efforts, contributed wisdom and insight in organizing the workshops. Sarah Kotchian, director of the Environmental Health Division for the City of Albuquerque, thoughtfully added the practitioner's perspective to our efforts. Bill Stone, senior hydrogeologist with the New Mexico Bureau of Mines and Mineral Resources and adjunct professor of geology at New Mexico Tech, added a large quota of enthusiasm to the organizing process, as the rest of the committee began to wear down through the drudge of too many conference obligations heaped onto professional careers already overflowing with responsibilities, by agreeing to oversee publication of the proceedings.

Two people deserve special mention. Eleonora Trotter, research assistant professor in the biology department, UNM, and Leslie Blair, information coordinator, WRRI, handled virtually all of the administrative details associated with putting the conference together, including everything from pre-conference publicity to cleaning up the meeting rooms afterward. This meeting would not have been possible without their dedication.

Bruce Thomson, Chairman
Organizing Committee

CONFERENCE SPEAKERS

Thomas Baerwald is director of the Division of Social and Economic Science at the National Science Foundation. This NSF division funds research related to the social, economic, demographic, governmental, legal, and institutional aspects of global climate change. The funded research develops a greater understanding of how individuals and institutions affect and respond to environmental processes at a multinational or global scale.

Senator Pete Domenici has developed legislation strengthening the role of the National Laboratories and their accessibility to private business. He has worked on many environmental issues including the creation of El Malpais National Monument and the Masau Trail, the Bisti Wilderness, and protection of Albuquerque's petroglyphs.

Mitch Foushee is a legislative assistant to Senator Jeff Bingaman in his Washington, D.C. office. He has served in this capacity for eight years.

Anthony Janetos is the program manager for the Environmental Protection Agency's (EPA) Global and Climate Change Research Program in the Office of Research and Development. The program involves impacts at regional levels.

William Kellogg served as associate director of the National Center for Atmospheric Research for ten years, and is now a retired senior scientist at NCAR. He is one of the original investigators of the greenhouse effect and climate change.

Paul Risser is provost and vice-president for research at The University of New Mexico. An internationally known ecologist, Risser is vice-chair of the U.S. National Academy of Science Committee on Global Change. He is also editor of a forthcoming book entitled *Long-Term Ecological Research: An International Perspective.*

Limberios Vallianos is senior coastal engineering policy analyst at the Institute for Water Resources, US Army Corps of Engineers and has 31 years experience in coastal zone management. He is also the US delegate to the Coastal Zone Management Subgroup of the Intergovernmental Panel on Climate Change.

WORKSHOP AND CONFERENCE PROGRAM

FRIDAY, June 1, 1990 WORKSHOPS I-III

8:00 - 9:00	PLENARY SESSION I – Introduction – Bruce Thomson (Civil Engineering, UNM) THE INTERNATIONAL PANEL ON CLIMATE CHANGE (IPCC) — COMPOSITION, PROCESS AND ACTIVITIES - Limberios Vallianos
9:15 - 10:15	WORKSHOP I - Response to Rio Grande Laboratory Concept
10:15 - 10:30	Break
10:30 - 12:00	WORKSHOP II - Identification of Information Needs
12:00 - 1:30 PM	Lunch ENVIRONMENTAL EDUCATION—CHALLENGE FOR THE FUTURE - Mitch Foushee (Senator Bingaman's office) Organizing Committee Synthesizes Workshop II Results
1:30 - 2:30	PLENARY SESSION II - Workshop II Results
2:30 - 2:45	Break
2:45 - 5:00	WORKSHOP III - Development of Research Topics Task 1 Modeling Task 2 Data Bases Task 3 Paleohydrologic and Paleoclimate Research Task 4 Maximizing Benefits and Minimizing Costs Task 5 Prototype Flagship Project

SATURDAY, June 2, 1990 CONFERENCE AND WORKSHOP IV

9:00 - 9:10	WELCOME - Tom Bahr (WRRI)
9:20 - 9:30	ENERGY USE AND CLIMATE CHANGE—THE REAL CHALLENGE - Senator Pete Domenici
9:30 - 9:35	Introductions - Susan Christopher Nunn (Economics, UNM)
9:35 - 10:05	CLIMATE CHANGE EXPRESSED IN HUMAN TERMS - William Kellogg (formerly NCAR)
10:05 - 10:40	RESEARCH OPPORTUNITIES RELATED TO THE HUMAN DIMENSIONS OF GLOBAL ENVIRONMENTAL CHANGE - Thomas Baerwald (NSF)
10:40 - 10:55	Break
10:55 - 11:30	IMPACTS OF GLOBAL CLIMATE CHANGE AT THE NATIONAL AND REGIONAL SCALES WITH EMPHASIS ON THE SOUTHWEST - Anthony Janetos (EPA)
11:30 - 12:05	IMPACTS OF CLIMATE CHANGE AND VARIABILITY ON ECOLOGICAL SYSTEMS - Paul Risser (Provost and Vice President for Research, UNM)
12:15 - 1:45 PM	Lunch RIO GRANDE LAB/CONSORTIUM CONCEPTS - James Gosz (Biology, UNM) SUMMARY OF FRIDAY WORKSHOPS - Charles DuMars (Law, UNM)
1:45 - 2:00	Break
2:00 - 3:00	WORKSHOP IV - Gearing Up Task 1 - Development of a Consortium Task 2 - Follow-up Conference Task 3 - Public Education and Information Transfer
3:00 - 3:15	Break
3:15 - 5:00	WORKSHOP IV - Results
5:30 - 6:30	REVIEW OF CURRENT RESEARCH, RIO GRANDE NATURE CENTER

THE PROBLEM

Proceedings, The Rio Grande Basin--Global Climate Change Scenarios, 1990, WRRI Rept M24

CLIMATE CHANGE EXPRESSED IN HUMAN TERMS

William W. Kellogg, National Center for Atmospheric Research (Retired),
Boulder, Colorado 80307

INTRODUCTION

There has been so much attention paid by the media to the greenhouse effect and the resulting global warming that it will not be necessary to repeat all the arguments here. To be sure, there are a few scientists and politicians who seem to question the whole concept of humankind's ability to influence the balance of the entire planet earth, and they may even claim that a global warming is going to be good for us if it occurs. However, these doubters are in a shrinking minority. It would be delightful if they turned out to be right, but unfortunately that is very unlikely.

In this paper I will review briefly the facts in the matter, then explain the theory of the greenhouse effect and its future influence on the vast system that determines the earth's climate, and finally talk about what the countries of the world might be able to do about the situation if they really wanted to.

As I understand it, nothing significant will be done to stop or slow the global warming until a majority of the people of the world and their leaders finally conclude that the environmental change taking place is going to be unacceptable. That clearly involves a value judgment. Furthermore, different people in different countries will undoubtedly see the change differently, and for a variety of good reasons. This confusion is compounded by the uncertainty in our predictions of the way the change will occur, so we cannot yet foresee the best course to take.

All this suggests that my function here should be to summarize where we stand in the greenhouse debate, the reality of climate change, and how we visualize those patterns of future change. I must tell you at the start that we climatologists are frustrated by the immensity of the task of understanding the global climate system and how it may behave in the future, and our crystal ball is still a bit cloudy. However, there are some important predictions that can be ventured even now. A few of them appear to be on fairly firm ground, while others still have to be taken as more tentative, as I will indicate.

SOME ENVIRONMENTAL FACTS

The greenhouse effect (which will be discussed further in the next section) is caused by the absorption of a part of the infrared or heat radiation being emitted by the surface. The sun obviously warms the earth's surface, and it gets rid of this heat by emitting infrared radiation back to space. There is thus a long-term balance between the incoming solar radiation and the outgoing infrared radiation, a balance that determines our mean temperature.

The important point here is that certain trace gases in our atmosphere absorb some of the outgoing infrared radiation, and therefore less radiant energy escapes to space. This warms the lower atmosphere. In the case of earth, our surface temperature would be about 32°C colder than now if it were not for the greenhouse effect—and life as we know it would not exist on earth.

The most important greenhouse gas by far is water vapor, but we will not talk much about it. The next most important is carbon dioxide, and that we will talk about a great deal. Also important are the trace gases methane, nitrous oxide, and the infamous chlorofluorocarbons (CFCs). As we add these greenhouse gases to the atmosphere, their atmospheric concentration increases, and the result is a turning up of the greenhouse thermostat and a consequent further global warming.

Carbon dioxide obviously is produced when we burn fossil fuels or wood, and also some is released in the production of cement. Over geologic time there is a long-term balance between the release of carbon dioxide by volcanoes and the removal from the atmosphere to form carbonate rock—the latter subsequently volatilized by the earth's internal heat. Now we are influencing that long-term balance by our enormous use of fossil fuels and (to a lesser extent) by cutting and burning trees in the tropics.

Here are a few facts. In 1989 we released about 6 gigatons (billions of tons, if you prefer) of carbon in the form of carbon dioxide by our fossil-fuel burning. Since the Organization of Petroleum Exporting Countries embargo of 1973 the rate of this release had gone up about 2% per year, a doubling time of 35 years, and before that it had been going up at about 4% per year. Carbon dioxide is a chemically stable gas that remains in the atmosphere for a very long time, and its main sink is the world ocean. For the past thirty years or more about 56% of the carbon dioxide produced by fossil-fuel burning has remained in the atmosphere, not taking account of the additional carbon dioxide released by deforestation (whose magnitude is uncertain), and the remainder has been taken up by the oceans (Kellogg, 1987; Gammon et al., 1985).

On the slopes of the Mauna Loa volcano, continuous observations of the carbon dioxide concentration have been made since 1958. These are conducted by C.D. Keeling of the Scripps Institution of Oceanography in collaboration with the National Oceanographic and Atmospheric Administration, which runs the Mauna Loa Geophysical Observatory. This long record shows a more or less steady increase of carbon dioxide concentration of about 0.35% per year (which has increased in the past two or three years); and if we go back before the Industrial Revolution began, the total increase to the present has been almost 30%. Records of observations of carbon dioxide kept at Point Barrow, American Samoa, Australia, the South Pole, and elsewhere, all give the same story (Keeling et al., 1984 and C. D. Keeling, personal communication).

The concentration of methane, another greenhouse gas, has been increasing three times faster than carbon dioxide—about 1% per year. It is a very strong absorber of infrared radiation, and its importance as a cause of global warming will equal that of carbon dioxide early in the next century if current trends persist (Ramanathan et al., 1985). Still another source of greenhouse warming is CFCs, increasing at about 3% per year, but their increase may slow down if the countries of the world abide by the Montreal Protocol that legislates a phasing out of their production (for reasons having to do with the destruction of the ozone layer—but that is another story).

With such an increase in greenhouse gas concentration, it is not surprising that the global mean surface temperature, measured at both land stations and ships for the past 120 years or more, has increased about 0.7°C (Jones et al., 1986). The increase has been less in the tropics and more in the Arctic. The trend shows up about equally in both hemispheres, but there are some small differences in the year-to-year and decade-to-decade rates of change (Jones et al., 1986; Kerr, 1989). These shorter-term changes are due to a combination of volcanic eruptions that put particles into the stratosphere, in the total output of radiation from the sun (we now know that it is a slightly variable star), and complex changes in the interactions between the atmosphere and oceans (one well-known example being the quasi-periodic El Niño events). It has also been claimed that the nuclear tests of the late 1950s and early 1960s may have put enough nitric oxide into the stratosphere to cause a temporary cooling (Kondratyev, 1988). However, there is a great deal left to be explained concerning the global response to all these external influences.

Climatologists have been searching for other evi-dence concerning the greenhouse warming. For example, our theoretical calculations show that there should be a cooling in the stratosphere along with the warming in the troposphere. Indeed, a small stratospheric cooling has taken place in the forty years or so that upper air observations have been made at enough stations to be representative (Labitzke et al., 1982; Ramanathan, 1988). It was expected that the warming would cause polar ice in both hemispheres to retreat, but this has not occurred to any significant degree (Parkinson and Cavalier, in press). The most recent experiments with dynamic climate models show why: during the early stages of the warming, the North Atlantic and the North Pacific are now expected to actually cool for a while due to changes in the circulation pattern bringing cooler air over those northern oceans, and in the Southern Ocean the answer may lie in the changes in ocean mixing as the earth grows warmer (Washington and Meehl, 1989; Stouffer et al., 1989).

The most heralded and widely discussed changes have been, and will continue to be, changes in rainfall and soil moisture. These will be discussed below, where it will be shown that the shifts of these patterns are hard to predict, and in any case the natural variability of precipitation makes it hard to prove that a trend is significant until it is well established over many decades.

These facts about what has been occurring in the world should be convincing enough for a thoughtful person to see that a climate change is on its way, albeit in the early stages. In the next section we will discuss such observations in the light of our theoretical understanding, to determine the degree to which the real world and the theoretical world of our climate models are consistent with each other.

CLIMATE MODELS

For at least 200 years, scientists have known that the greenhouse effect was taking place and main-taining the surface of the earth at a liveable temperature (Kellogg, 1987). In 1896 the distinguished Swedish chemist, Svante Arrhenius, made some truly brilliant calculations about the temperature change that would take place if we doubled (or halved) the concentration of atmospheric carbon dioxide. With rather primitive data on the absorption characteristics of carbon dioxide and water vapor, and an astute assumption about how water vapor distribution would change during a global warming, he concluded that a doubling of atmospheric carbon dioxide would result in about a 4°C global average warming. He also showed that the warming probably would be greater in the arctic than in the tropics, and that the response would be a logarithmic function of the concentration change (Arrhenius, 1896).

With our powerful computers and much better data on the physical factors involved in such a calculation, experiments with state-of-the-art climate system models arrive at conclusions remarkably similar to those of Arrhenius. The five most advanced models predict a 3 to 4°C warming for an equilibrium calculation of the response to a doubling of carbon dioxide. A dynamic calculation, in which the change in greenhouse gas concentration is introduced gradually in a more realistic way, shows a delay of two or three decades in the warming due to the thermal capacity of the oceans—it simply takes a few decades for the upper part of the oceans to warm up, and the deep oceans will take centuries (Washington and Meehl, 1989; Hansen et al., 1988).

This is not the place for a detailed explanation of how climate models work. Indeed, they represent one of the most ambitious applications of computers, and they are exceedingly complex. In brief, they integrate the six or seven time-dependent equations governing the motions, conservation of mass, and thermal conditions of the atmosphere by taking 10- to 20-minute time steps and applying these equations to each of some 10,000 to 20,000 grid points or boxes over the globe, such grid boxes being set at around ten levels in the vertical (the number of levels varies from model to model, as does the size of the grid). Not only is the changing atmosphere analyzed, but the oceans must be included as well. The shapes of the land and mountain ranges also are fed into the model. They not only create maps of winds, temperatures, clouds, precipitation, and so forth at each time step, but they also keep track of such factors as snowcover on land, sea ice distribution, sea surface temperature, and soil moisture. The atmospheric part of a climate model, known as a general circulation model, or GCM, is quite similar to the computer programs used by the weather forecasters to determine the next few days' weather.

Numerous climate models are being developed and improved, most of them in the US and one in the United Kingdom, and they give us a great deal of information about how the earth's climate system can be expected to respond to a change of some boundary condition (such as greenhouse-gas concentration, solar output, changes in the earth's orbit around the sun, and so forth). Although these theoretical models are run on the fastest computers available and take as many of the factors in the climate system into account as human ingenuity will allow, they are clearly highly oversimplified compared to the real thing. Thus, we have good reason to wonder whether they can be relied upon to give a truly reliable and credible simulation of our climate system.

The point to keep in mind, however, is that they are the best tools we have at this time. Furthermore, we can test them in a number of ways against the real system, and this gives us both a measure of our success and suggestions for how to improve them further (Kellogg, 1987 and 1989). In what follows we will discuss some of these tests of model results against lessons from the past.

While the temperature of a region is certainly important in determining where things can grow, it is really precipitation and soil moisture that are the most crucial. That is why farmers, ranchers and wood producers are so concerned about rainfall and evaporation, and why droughts are so devastating to agriculture.

Our more advanced climate models not only calculate where precipitation will occur, but take the next step and calculate how much evaporation and runoff will take place at each grid point. Thus, it is possible in a climate model experiment to take the difference between the soil moisture on a model earth with doubled carbon dioxide and the same model earth with conditions as they are now. This reveals where it may, according to the models, become wetter or drier in the future. Some results for five such climate model experiments for North America and the region dominated by the Asian monsoon circulation are presented in Figures 1 and 2.

LESSONS FROM THE PAST

We have already admitted that we are not certain that our climate models are capable of reliably simulating the response of the earth to a doubling of greenhouse gas concentrations, and calculations of the distribution of soil moisture are particularly difficult. However, fortunately we have a way of checking on the model results, and that is to ask the paleoclimatologists to describe the conditions during periods when the world was warmer than normal, either in this century or in the more distant past.

On the whole, such comparisons have proven very gratifying. Agreement between the modeled warmer earth, shown in Figures 1 and 2, and maps of conditions during warmer periods in the past do not show agreement everywhere and in all seasons of the year, but the larger scale patterns at mid-latitudes of North America and Eurasia are similar. Perhaps most significant from a practical standpoint are the indications of summertime droughts in the middle of the continents, and generally more moist conditions in wintertime. Also, the monsoon circulations and their resulting summer rainfall were shown to be intensified in the model experiments, in agreement with the history of rainfall in such places as the Rajastan Desert of northwest India (Kellogg, 1982; Kellogg and Zhao, 1988; Zhao and Kellogg, 1988).

PREDICTIONS

We have seen that the models predict a global average warming of 3 to 4°C when the doubling of carbon dioxide takes place. This condition will be delayed by the thermal lag of the oceans, but hastened by the addition of other greenhouse gases, notably methane and the CFCs. The warming in the Arctic is expected to be two or three times greater than in the tropics. Along with this warming will be changes in the global circulation patterns that determine temperature and rainfall distributions, and there will be shifts of the probability of droughts and floods.

We have not mentioned the rise of sea level, but, of course, any sea level rise as a result of the warming will have important impacts on every coastline. In spite of some rather overplayed fears of a slippage (or surge) of the massive west Antarctic ice sheet and an imminent rise of sea level by 5 to 7 m (!), now the consensus of the glaciological and oceanographic community is that in the next century we may expect about a 1 m rise (perhaps even less; NRC, 1985). It is believed that this would be due primarily to the expansion of the sea water, mostly in the upper part of the oceans, as it gradually grows warmer. In the Netherlands they are using this prudent estimate in their program of dike improvement and maintenance.

Returning now to temperature and precipitation, so far we have geared the discussion to what will happen when carbon dioxide atmospheric concentration is doubled and the other greenhouse gases are correspondingly increased. But when will that occur? The answer depends to some extent on biogeophysical factors, such as how the ocean will behave as a sink for these trace gases, how ocean plankton will respond, how the Arctic tundra may either decay or grow as it grows warmer, the probability of major volcanic eruptions, changes in solar activity, and so forth.

However, the chief player in this drama is *us*, humankind. We must ask how humanity will use fossil fuel in the decades ahead. We must ask whether alternative energy sources will be either proven economically competitive to fossil fuels or mandated by governments. We must ask whether nuclear power will come back into favor in the U.S. and elsewhere. We must ask whether hydrogen will replace petroleum and natural gas as fuel for our vehicles, ships, and aircraft.

All these questions are clearly in the domain of economics and politics, but I have tried to bracket the range of possibilities by invoking a high scenario and a low scenario of future fossil fuel consumption. The high one assumes a continued growth worldwide of fossil fuel use at 2% per year, which is about the same rate of growth as observed since 1973. The low one assumes that we will rapidly reduce our dependence on fossil fuels, so that our consumption drops back to the present level in fifty years. I believe the first is

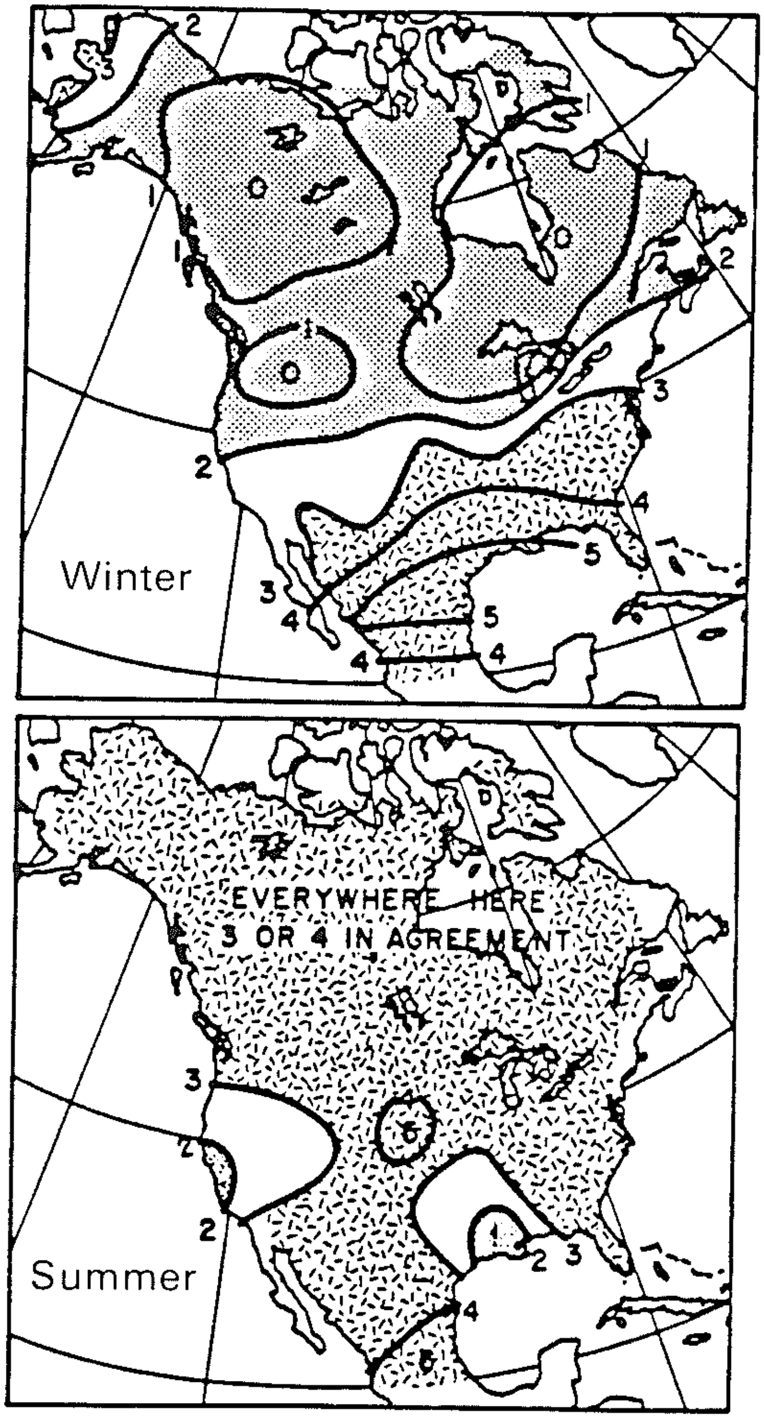

Figure 1. Map of North America showing the degree of agreement among the five climate models on the direction of the soil moisture change (a) in winter and (b) in summer with a doubling of atmospheric carbon dioxide concentration. Areas shaded with hen-scratches show where three or more of the models agreed on a decrease of soil moisture; areas stippled with small dots show where three or more agreed on an increase. (Source: Kellogg and Zhao, 1988)

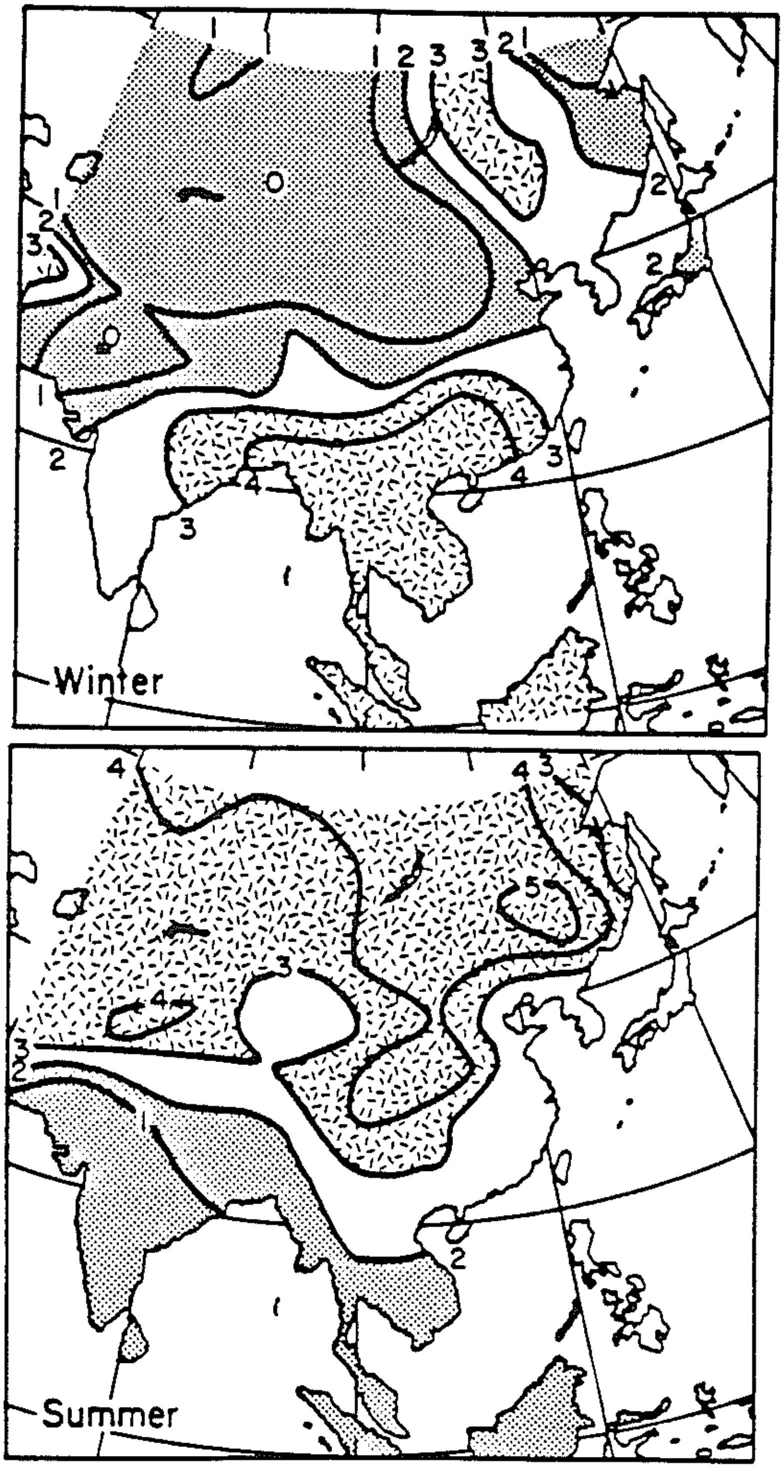

Figure 2. Map of Asia showing degree of agreement among five climate models as to direction of soil moisture change with doubling of atmospheric carbon dioxide concentration; patterns same as in Figure 1 (Zhao and Kellogg, 1988).

too high, and the second is too low, but they are useful bounds to allow us to talk about the climate change time scale.

If you believe the high scenario, then you should expect the doubling to occur a little before 2050, as shown in Figure 3. That means an expected rate of increase of global mean surface temperature of almost 1°C per decade. Following the last ice age, which climaxed about 18,000 years ago, a 1°C warming generally took place over a period of 1,000 years or more—regional rates of warming may have been as much as ten times faster, however, or possibly 1°C per century. It is such a rapid change in the future, unparalleled in the long history of humankind, that worries ecologists and agriculturalists. Natural ecosystems usually could not move fast enough to remain in their climatological niches. Would farmers and ranchers be able to adjust in time? Will the change of climate result in a loss of our forest plantations before they can be harvested? These are but a few of the problems that come to mind (Houghton and Woodwell, 1989).

If you prefer the low scenario, then you can buy another fifty or so years, and the doubling may not take place until around 2100. It will continue to rise as long as we go on burning fossil fuels. It seems highly unlikely that the countries of the world will agree to cut back on their use more rapidly than I have hypothesized in the low scenario. So let us then look forward to a minimum rate of warming of about 0.5°C per decade.

Climate modelers are aware of some factors not taken into account adequately in their models, as I have said. Both the models and the real system have a large number of feedback mechanisms that can hasten the change (if positive) or slow the change (if negative). My impression is that the important negative feedbacks are already included, but that there may be some rather important positive ones that are still left out—feedbacks that would hasten the warming when they come into play (Kellogg, 1983).

Here are two examples of positive feedbacks that are not taken into account in our current climate models. They both have to do with changes in the climate system that can affect the fluxes of carbon dioxide, and consequently its concentration. First, consider the way in which the oceans take up the added carbon dioxide that we put in the atmosphere. Each year less than half of the added carbon dioxide goes into solution in the upper ocean, as dissolved gas, as bicarbonate, or as carbonate, and then it is slowly stirred downward into the intermediate and deep ocean water where it can reside for centuries. If this downward transport and diffusion did not take place, the upper ocean would come to a near equilibrium with the atmosphere, and little further carbon dioxide would be taken out of the atmosphere. As the upper ocean warms, there will be two effects on this takeup: the increased stability caused by warm water over cold water would slow the stirring downward, and secondly, warm water cannot absorb as much carbon dioxide as cold water. Thus, with the oceanic "sink" for atmospheric carbon dioxide slowing down, more will remain in the atmosphere—the airborne fraction will be greater than the present 56%.

The second positive feedback that I will mention has to do with the carbon dioxide and methane locked in the deep deposits of peat that cover the taiga and tundra of the Arctic. As the climate warms, the summer melting season will grow longer, and more of the surface layer of peat will melt and be drained of its water. That will permit the peat to decay and release its carbon dioxide, and the methane that is now locked into the peat in the form of hydrates, or clathrates, will also be released. Thus, the warming will cause an increase in the greenhouse gas concentration, and that will in turn cause a further warming (Houghton and Woodwell, 1989).

These two positive feedback mechanisms are mentioned here to show that there is a variety of complex interactions in the climate system that we do not deal with adequately in our current models, but they may be important (Kellogg, 1983). We have singled out two that would act to accelerate the warming, and there may be others (not yet clearly identified) that could either accelerate or slow the warming. As our climate models continue to improve, and the computers available become more powerful, we will incorporate more and more of these factors into the models. That is our major challenge.

WHAT CAN WE DO?

Again we must emphasize that the greenhouse warming of the earth is due to mankind, in particular the burning of fossil fuels, and to a lesser extent it is due to the deforestation taking place in the tropical rain forests. Contributions to the warming are also being made by our activities that produce methane, and in that case the blame probably rests with our agricultural practices such as growing rice, raising more herds of cattle, and encouraging termites by forest-cutting in the tropics, with some further contribution due to leakage from natural gas wells and pipelines. Still another source of a greenhouse gas is the CFCs that are used as refrigerants, aerosol spray propellants, for cleaning electronic parts, and so forth (Ramanatan et al., 1985).

Figure 4 shows a kind of decision tree, displaying the range of choices open to governments, industry, agriculture, and the public as we contemplate the future of the earth and its climate. These policy choices range from taking charge of the situation and stopping the climate change (or at least slowing it down) on the left, to just muddling through, shown on the right—that's what we usually do when decisions are hard to make. And in between these two extremes is a very broad area of actions that we can take to lessen the undesirable impacts of the change, assuming that we perceive it as inevitable.

The taking charge option, if adopted, would mean that all nations will have to reduce their consumption of fossil fuels. There have been numerous high-level meetings to discuss such a policy, the most recent being held in the Dutch city of Noordwijk in early November 1989, titled the "Ministerial Conference on Atmospheric Pollution and Climate Change," attended by 70 governmental delegations. The US delegation to this conference was led by Dr. William K. Reilly, head of the Environmental Protection Agency (EPA), and several heads of state were there to represent other countries. It seems there was little disagreement concerning the seriousness of the global environmental crisis, and the proposal that seemed to gain the most favor was an initiative calling for the industrial nations to freeze their carbon dioxide emissions at 1988 levels by the year 2005. While there seemed to be general support for this idea, it did not become a part of the conference's final declaration. Four economic superpowers—the US, the USSR, the United Kingdom, and Japan—all refused to agree to it (Ralof, 1989).

It is not hard to fathom some of the reasons for reluctance on the part of a government to promise that it will limit fossil-fuel use. In the case of the US and the USSR, there are enormous reserves of coal and other fossil fuels. In most industrial countries, the corporations that control the production, distribution, and use of fossil fuel energy are among the most powerful, and they are not likely to welcome any government constraints. Furthermore, the less developed countries are struggling to become more industrialized, and they can hardly do this without resorting to the cheapest and most convenient energy source, fossil fuels (Kellogg and Schware, 1981; 1982; Schneider, 1989).

On the other hand, the Noordwijk proposal does not seem to constitute a very drastic cutback on carbon dioxide production, at least for us and other wealthy countries. The US is presently one of the most wasteful users of fossil fuel energy in the world, vying with East Germany for that dubious distinction with a conspicuous per capita consumption of about 5 tons of carbon per year (1986 figures). West Germany and Japan, for example, use less than half that much per capita, but have equally high living standards (Marland, 1989).

The most obvious path to follow in an effort to cut back on carbon dioxide emissions is to conserve energy. The industrial countries are indeed making progress in this respect, and most of them have leveled off in the rate of increase of use of fossil fuels (except, in the case of the US, in fuels for automobiles and electric generation; MacKenzie, 1988). There are various suggestions for encouraging further reductions, such as higher gasoline taxes (the US currently has about the lowest of any country), penalties for driving large gas-guzzling cars, a charge to a factory or utility for its carbon emissions, a program of introducing more efficient lighting, heating, and refrigerating equipment, better insulation of buildings, and so forth.

The biggest step forward in this respect will be taken when alternative, non-fossil, energy sources become economically competitive. Solar, biomass (a form of solar energy in a sense), and wind are gaining in acceptance. It is undoubtedly time to have another look at nuclear energy reactors that may make them more acceptable to the public (Weinberg, 1989). Furthermore, if hydrogen replaces gasoline and natural gas, then the release of carbon dioxide would be greatly reduced. Reducing carbon dioxide emissions is likely to become an increasingly inescapable imperative as the global climate change grows more calamitous.

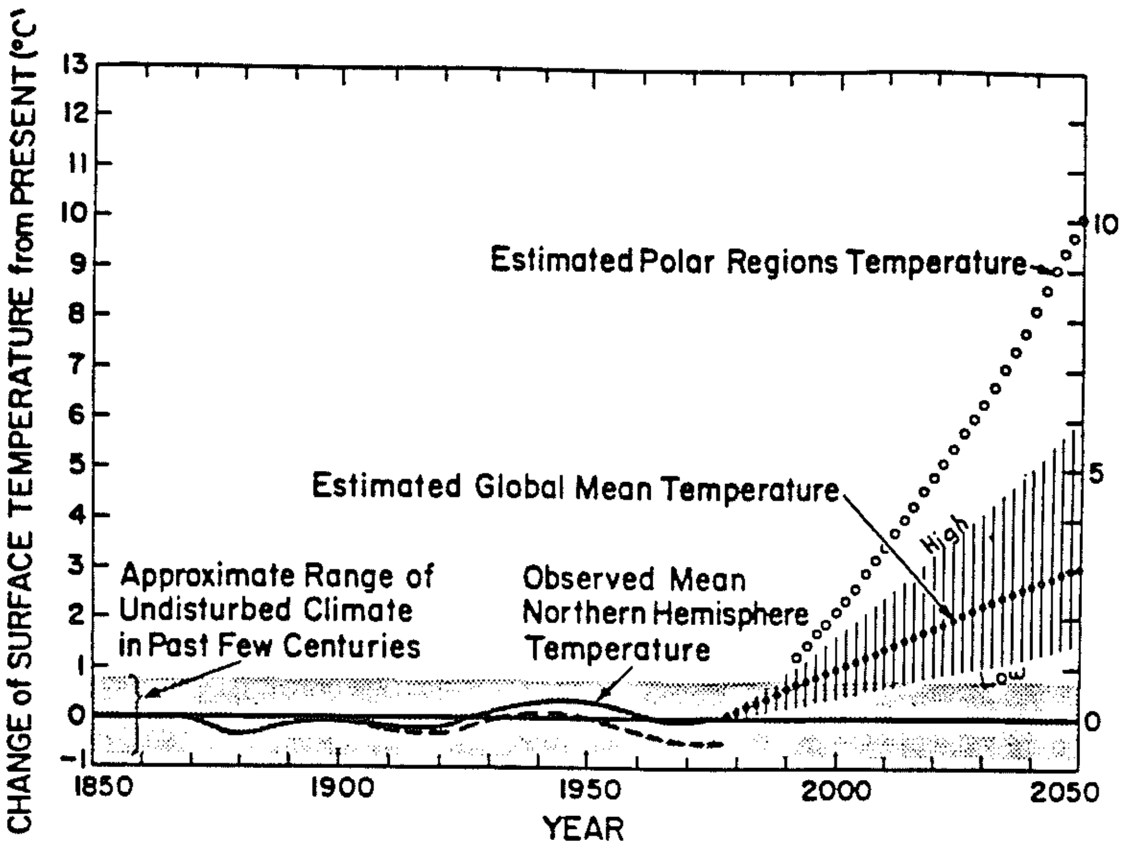

Figure 3. Past and future temperature trends. Dashed line indicates probable record without addition of greenhouse gases. Vertical bars indicate temperature over range of fossil-fuel use scenarios.

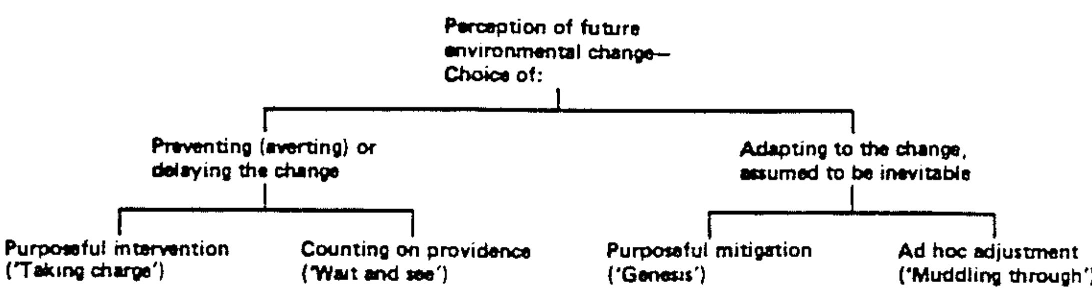

Figure 4. A decision tree showing the range of choices for coping with climate change: those on left require worldwide participation, but those on right can work at any level of society.

Sooner or later the switch will have to take place.

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ENERGY USE AND CLIMATE CHANGE--THE REAL CHALLENGE

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There are a few things we can say with certainty about tomorrow. The sun will rise. If you happen to be in New Mexico, the weather will be lovely. And there will be more people alive on this planet than there are today.

In a generation—35 years from now—there may be as many as 100 billion humans living on the planet— twice as many as today. And about 90 percent of that increase will occur in Third World nations, nations that will justly demand their fair share of the economic growth. What that means, of course, is that the world of the early 21st century will be not only a far more populated world, but it will almost certainly be a world of far greater consumption than exists today. A year ago during a major Clean Air conference here in Albuquerque, I talked at some length about this challenge. Since that time, the issue has become far clearer.

A United Nations (UN) report recently came to some very startling conclusions. It determined that even if the industrialized nations can hold their carbon dioxide (CO_2) emissions—maybe the most significant component among the so-called "greenhouse gases"—to today's level, the production of CO_2 in the developing nations will overwhelm us. Worldwide, CO_2 production will triple by the year 2025. Clearly, we confront a situation we dare not avoid. Can we suddenly scale down energy use? I don't think so. Such a change would be politically unsustainable in the United States and Europe. And the developing nations, obviously will not accept the fact that they cannot improve their standards of living.

Because of what America is—the richest and most powerful nation, the nation that is responsible for about 25 percent of the man-produced carbon dioxide—we must take the lead in addressing a climatic situation that would dramatically affect all human beings. We must develop a comprehensive international energy policy to meet the challenges ahead, moving toward energy sources that will not endanger our planet. If we don't, I can assure you that no one else will. The reason this is so important is that the fundamental component of economic growth is energy. Without energy, our standard of living will collapse and humanity's survival is threatened. So we must find ways to become far more efficient in our energy use.

Not long ago, at my urging, the Senate passed a resolution urging an international energy convention. While that never passed the full Congress, I believe we have moved forward on any number of fronts since then. For one thing, President Bush has asked the Congress to step up dramatically our commitment to global change research and development. He seeks more than $1 billion during fiscal 1991—an increase of 57 percent from this year's spending. The increase is even more impressive from 1989. This money covers seven interdisciplinary science elements and data management—from climate and hydrologic systems to ecological systems and dynamics. And it stretches across seven departments and agencies of the federal government, with most of the money focused through the National Aeronautical Space Administration (NASA). No money is being spent. And we are giving new directions to the program, across the board.

Just a couple of weeks ago, the Senate Energy Committee approved legislation to strengthen greatly the research efforts to control global warming. This bill, which has not yet reached the Senate floor, creates a planning and research program that will examine our entire national energy policy, making certain it is as sensitive as reasonably possible to the danger of global warming. The bill would set up new efforts to improve the efficiency in energy intensive industries, and directs Federal agencies, where feasible, to use energy efficiency technologies in the construction or acquisition of Federal facilities. It sets our goals for new technologies for a variety of energy sources, from hydrogen and fusion to coal and natural gas. The Department of Energy (DOE) will be asked to look at strategies that are cost effective, ones consistent with other national goals—social, economic, and environmental.

Our bill mandates no particular change. But it sets us on course, a course where we will soon be in a position at the Federal level to identify the appropriate mix of policies with the potential of stabilizing the production of CO_2 and other greenhouse gases. But as the UN study I cited on worldwide CO_2 production demonstrates, we can achieve very little acting alone. So our Energy Committee bill in the Senate creates the push for a framework international convention by 1992.

Another absolutely critical component of any sound global climate bill is tech transfer, particularly transferring usable technology to the Third World. We must move toward a long-term worldwide energy policy, particularly one that encourages technology transfer assisting the Third World. During the deliberations of the Energy Committee, I sponsored a tech transfer amendment, an amendment that I believe carries vital importance in this effort. My amendment directs DOE to operate a special program to move DOE-created technologies out of the basic research stage to the point where they would become commercially viable. This is such a vital issue, one where New Mexico can—and will—play a major role through our national labs and vast scientific infrastructure.

Certainly, our national laboratories—including Los Alamos and Sandia—have the skills and knowledge to become leaders in this effort. And there is one other thing I intend to do when this bill moves to the Senate floor. I will offer an amendment encouraging solar research, which must be an important component of any global warming strategy. You may recall that we have a law that says that electric utilities must purchase solar energy, but only up to a certain limit. My amendment would remove that limitation, permitting solar entrepreneurs to expand their projects, making certain that new energy production is integrated into the grid.

But there are so many things that must be undertaken. We must make a stronger stand on chlorofluorocarbons (CFCs), which appear to be an important greenhouse gas. I recently joined with Senator Chafee and others to write to the President to express our strong concern over his reluctance to spend more money to assist the developing world meet the CFC standards set in the Montreal protocols. And just last week, a Senate environment subcommittee approved another proposal of mine, one that directs the Secretary of the Interior to contract with Los Alamos, as well as Tom Bahr's Water Resources Research Institute and other water institutes, to examine some of the impacts of global warming.

The world community may never have faced a more difficult challenge. It is one that will require our every skill—both scientifically and politically—even if the problem is only a fraction as bad as some have forecast. Yet I remain an optimist. I believe we can meet this challenge. But we will only meet it if we recognize it for what it is—possibly the greatest challenge in the history of this beautiful planet. Thank you and good luck in your important deliberations.

REGIONAL ASPECTS OF THE PROBLEM

Proceedings, The Rio Grande Basin--Global Climate Change Scenarios, 1990, WRRI Rept M24

THE RIO GRANDE BASIN[1]

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INTRODUCTION

The term "Rio Grande Basin" applies to the area drained by the Rio Grande (Figure 1). While the region has much in common with other parts of the American Southwest, it is unique in several respects. Thus, before considering how global climate change might affect the Rio Grande Basin or how such changes might be investigated, it is instructive to summarize the physical and socio-economic characteristics of the region. Although much previous work has been done on these topics, space does not permit a complete review of all the information gathered to date. However, an effort was made to cite the more comprehensive works, each of which gives still further references, should the reader desire additional information.

GEOLOGY

The region is topographically and geologically diverse. The Rio Grande traverses or drains five physiographic provinces (Figure 1). In the Santa Fe area the river flows through the Southern Rocky Mountains Province. Much of its course below that lies within the Basin and Range Province. Some western tributaries in New Mexico drain part of the Colorado Plateau Province. Below the Big Bend area of Texas it crosses the Great Plains Province (Pecos River drainage) and finally below Del Rio, Texas it enters the Coastal Plain Province.

From Colorado to just upstream of Big Bend, the Rio Grande flows through a structural depression known as the Rio Grande Rift. This feature is a north-south trending break in the continental crust, separating the seismically active Colorado Plateau in the west from the relatively stable interior in the east (Chapin, 1988). The rift is actually a series of separate basins. Geophysical investigations have shown that in New Mexico it consists of thirteen basins, separated by faults or bedrock highs (Figure 2). Based on studies in the Las Cruces area (Seager, 1975), three major stages of activity contributed to the structural geology we see today: Laramide uplift (late Cretaceous/early Tertiary time), middle Tertiary volcanism/tectonics (Eocene-Oligocene time), and late Tertiary volcanism/rifting (Miocene-Holocene time). In northern New Mexico, rifting occurred approximately 30 million years ago in late Oligocene-early Miocene time (Chapin, 1988).

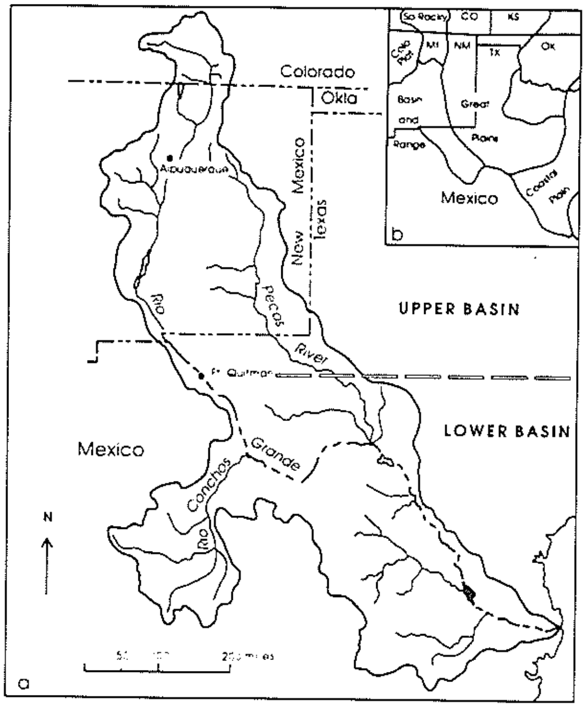

Figure 1. The Rio Grande Basin; a) major rivers and area drained, b) physiographic provinces in the region (modified from Hawley, 1986; Shimer, 1972).

A variety of igneous, metamorphic and sedi-

[1] This paper was not given at the conference but is included for background information.

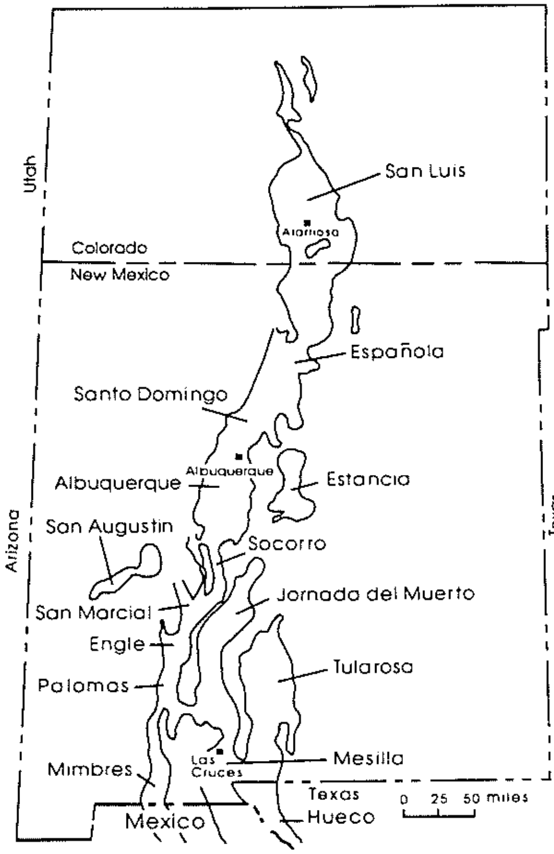

Figure 2. The Rio Grande Rift and major component basins (modified from Chapin, 1971).

mentary rock units of Precambrian through Tertiary age crop out on both sides of the valley. Alluvial and bolson-fill deposits of Tertiary and Quaternary age underlie the valley floor. Volcanic features, ranging from simple flows to extensive cauldrons with long histories of eruptive activity (Tertiary-Quaternary) complete the picture.

CLIMATE AND VEGETATION

The Rio Grande Basin is characterized by a variety of climatic conditions (Table 1). In the north, where the upper basin is bordered on the east by the southern Rocky Mountains, annual precipitation exceeds 50 in in the highest elevations and occurs primarily as snowfall during the winter. Moving down the valley, both in latitude and elevation, precipitation decreases so that the climate is predominantly arid and semi-arid. The annual precipitation at Albuquerque averages only 8 in. Annual precipitation in the middle basin takes on a more bimodal distribution with frontal precipitation in winter and convective precipitation (afternoon thunderstorms) in summer. In the river's terminal reaches the climate is classified as

Table 1. Climatic data for selected stations in New Mexico portion of Rio Grande Basin; precipitation, temperature, and water balance values from Gabin and Lesperance (1977).

Station	Mean Annual Precipitation (inches)[1]	Mean Annual Temperature (°F)	Climatic Index[2]	Net Water Balance (inches)[3]
Taos	12.46 (73)	47.3 (59)	0.56	-19.29*
Española	9.35 (47)	49.4 (27)	0.38	-27.12*
Albuquerque (WSO airport)	8.61 (89)	55.7 (83)	0.28	-39.14
Socorro	9.35 (76)	56.8 (69)	0.29	-36.81*
T or C (FAA airport)	8.53 (25)	59.6 (25)	0.24	-40.64
Las Cruces (NMSU)	8.57 (92)	60.1 (80)	0.24	-41.24

[1] based on yearly means; numbers in parentheses below indicate years of record
[2] = 100 (mean annual precipitation); channel seepage is significant (mean annual temperature) where values are <1 (Mockus, 1964)
[3] = mean annual precipitation - potential evapotranspiration; negative values indicate a deficit
* surplus occurs some months of the year at this station

humid subtropical. Here, too, there are two precipitation maxima, one associated with mid-summer convective storms, the other with occasional fall hurricanes (Mueller, 1975).

Not only does precipitation vary with latitude and elevation, but also with time at a given location. At least some of this variation is due to global processes. Analysis of 68 years of data from the Pecos River has shown that spring flow, and thus mountain snowfall, is significantly increased in El Niño years which are characterized by elevated sea-surface temperature and reduced barometric pressure in the eastern tropical Pacific or (Molles and Dahm, 1990).

Growing season also varies with latitude and elevation. The growing season near the New Mexico-Colorado border is only three months, while at the Gulf of Mexico, it extends through the entire year. Vegetation follows these changes in moisture and temperature and four major biomes are recognized in the basin: conifers in the northern mountains give way to piñon-juniper woodlands, then plains grasslands in the east, and finally Chihuahuan desert grass/shrub lands in the lower reaches.

In recognition of the arid Southwest's sensitivity to global climate change, two of the nation's seventeen Long-Term Ecological Research (LTER) sites are located in the New Mexico portion of the Rio Grande Basin. One is located at the Sevilleta National Wildlife Refuge, north of Socorro, and is run by the University of New Mexico. The other is located in the Jornada del Muerto basin near Las Cruces and is administered by New Mexico State University. Recent research in the Chihuahua Desert biome, at the Jornado LTER, has led to a better understanding of feedback mechanisms that will be important in predicting global climate-change impacts (Schlesinger et al., 1990). Because the Sevilleta LTER is located at the convergence of four biomes, research there is focusing on broad-scale interactions of physical and biological processes in transitional settings (Gosz and Sharpe, 1989). Such transition zones are the most sensitive areas to climate change.

HYDROLOGY

The hydrologic system is a natural outgrowth of the climatic and geologic settings described above. The annual precipitation and temperature dictate that, although there is more moisture in the higher elevation areas upstream than in the desert lowlands downstream, water budget deficits will be the basinwide norm (Table 1). High evaporation rates also lead to generally high salinity in the river. The geologic setting controls the distribution of water resources. For example, porosity and permeability of bedrock aquifers in the uplifts are generally less than those of the basin-fill aquifers in the adjacent valleys. Similarly, water quality may be poorer in the uplifts where low permeability or the presence of gypsum layers causes excessive dissolved-solids contents.

Water consumption in the Rio Grande Basin is primarily for urban, agricultural, and recreational uses, with some water used for hydroelectric power generation and cooling. The largest water-use category is irrigation (Garrabrant, 1988). The bulk of the irrigation water comes from the river. A significant fraction of the total water used is pumped ground water. Most cities along the valley depend completely on ground water for domestic use.

Surface Water

The Rio Grande heads at an elevation of 12,000 ft. east of the Continental Divide in the San Juan range of the southern Colorado Rockies. Descending to the southeast, the main stream is fed by several tributary creeks and the Conejos River as it flows into and through the San Luis Valley of southern Colorado. Here, flanked by the Sangre de Cristo Range, the river turns more directly south and enters New Mexico through a steep gorge. Several tributaries, principally the Rio Chama, the Rio Puerco, and the Rio Salado, merge with the Rio Grande in New Mexico. The river crosses into Texas 23 mi north of El Paso.

At El Paso, 8,000 ft below its source, the river has completed roughly one-third of its journey to the sea. For the remaining two-thirds of its course, the Rio Grande defines the US-Mexico boundary and is alternately known by its Mexican name, Rio Bravo. Weakened by upstream diversions and accumulated silt, the river slows to a crawl in the flat, desert reach southeast of El Paso, and is little more than a trickle for over 200 mi beyond Fort Quitman (Eaton and Anderson, 1987), the place that by international agreement demarcates upper and lower Rio Grande Basins. Although Mexico and Texas share equally the waters of the lower basin, below Fort Quitman, three-quarters of the supply is contributed by Mexican tributaries (Eaton and Anderson, 1987).

Approximately 300 mi downstream of El Paso, near the twin cities of Presidio/Ojinaga, the river is joined by a powerful tributary, the Rio Conchos, which originates high in Mexico's Sierra Madre Occidental and is nourished by five major tributaries. Flow from the Rio Conchos essentially remakes the Rio Grande and enables its run through a wide valley that precedes the river's arch to the northeast near the Big Bend wilderness and National Park. Below the deep canyons of the Big Bend area, the river continues to its confluence with the Pecos and Devil's Rivers, from the Texas side, at Amistad Reservoir above Del Rio, Texas/Ciudad Acuna, Coahuila.

The middle reach of the lower Rio Grande extends from Amistad Reservoir to Falcon Reservoir, both of which are owned jointly by the US and Mexico. Through the long and relatively straight stretch south of Amistad Dam, the river receives the waters of four major Mexican rivers: the Rio San Diego, Rio San Rodrigo, Rio Escondido, and Rio Las Vacas. From Falcon Reservoir to its terminus, the river's main channel is augmented by three contributors from the Mexican side: the Rio Salado, Rio Alamo, and Rio San Juan Catarinas. In the area surrounding Brownsville, Texas/Matamoros, Nuevo Leon, as elsewhere upstream, much of the river's flow is extracted for irrigation. The Rio Grande empties into the Gulf of Mexico 23 mi east of Brownsville.

To the extent that it suggests a through-flowing stream system, the preceding description of the Rio Grande drainage basin is misleading. The rate and timing of the river's movement are controlled. This control is made possible by a network of dams, reservoirs, diversion projects, and gaging stations on the mainstem and its tributaries. Most of these works have been constructed since the turn of the century, with the help of substantial funding from the US and Mexican governments, and are administered by federal agencies. There are nine major dams and associated reservoirs in the upper basin (Shupe and Folk-Williams, 1988), nineteen in the lower basin (Eaton and Anderson, 1987).

The two largest upper basin reservoirs, Cochiti and Elephant Butte, are located in New Mexico on the river's mainstem. Cochiti Reservoir (capacity 602,000 acre-feet [AF]) is located in the northern part of the state below Española and the confluence of the Rio Chama and the Rio Grande. The dam at Cochiti, a primary flood-control structure on the mainstem, coordinates release of spring and early summer runoff with the operations of dams sited downstream on the river's tributaries (Shupe and Folk-Williams, 1988). A certain quantity of water is retained in Cochiti Reservoir as a permanent pool for recreational purposes.

Elephant Butte Reservoir (capacity 2.1 million AF) is located in southern New Mexico 125 mi above El Paso. Like Cochiti Reservoir, Elephant Butte Reservoir prevents seasonal flooding and is a prominent water-recreation area. More broadly important, however, is the role of Elephant Butte Reservoir in the Rio Grande Project. Built and operated by the Bureau of Reclamation, the Rio Grande Project comprises multiple structures and purposes. It includes, in addition to Elephant Butte Reservoir, nearby Caballo Reservoir (capacity 331,000 AF) and five downriver diversion dams. Elephant Butte Dam is used to regulate the release of Rio Grande water to meet US delivery obligations to Mexico (60,000 AF annually), to generate hydroelectric power, and, in conjunction with Caballo Reservoir and the diversion dams, to provide irrigation for 160,000 acres of highly productive farmland in the Rincon, Mesilla, and El Paso valleys (Shupe and Folk-Williams, 1988).

Operation of Rio Grande Project facilities is closely monitored by the International Boundary and Water Commission (IBWC). A 100-year-old institution, the IBWC was first established as the International Boundary Commission and charged with the resolution of disputes between Mexico and the US about the exact location of the boundary. Since its renaming in 1944, however, with the signing of a international water allocation treaty, the IBWC has assumed the additional responsibilities of supervising enforcement of the treaty provisions, facilitating cooperative water development efforts by the two countries (Shupe and Folk-Williams, 1988), and, in some degree, maintaining water quality and sanitation standards (House, 1982; Dworsky, 1978).

Among the nineteen major reservoirs in the lower basin, three are located in Texas, fourteen in Mexico, and two on the river's main channel. The latter, Amistad and Falcon, are international reservoirs built in response to the 1944 treaty between the US and Mexico. Both are managed by the IBWC. Amistad Reservoir (capacity 5,658,000 AF) stretches over 75 mi. Its dam, completed in 1969, sits 12 mi upstream of Del Rio, Texas/Ciudad Acuna, Coahuila. Flood control, water conservation, power generation, and recreation are the dam's main functions. Falcon Reservoir (capacity 26,294 AF) originates at the confluence of the Rio Salado with the Rio Grande, approximately 709 mi above Falcon Dam. The dam, located a few miles above Rio Grande City, Texas/Ciudad Camargo, Nuevo Leon, was completed in 1954 and serves basically the same purposes as does Amistad Dam.

Ground Water

The way one views the geology of the basin determines how one perceives its hydrology. Early geologists distinguished numerous rock units in the uplifts but failed to do so in the basin fill. This led hydrologists to envision the Rio Grande Valley as an impermeable bath tub, or chain of bath tubs, filled with permeable material (Bryan, 1937; Dinwiddie, 1967).

Integration of available geologic and hydrologic data and appropriate geomorphic models for basin evolution has led to a better conceptualization of the ground-water/river system (Stone and Summers, 1987). Studies of the water table configuration reveal that the valley margins are not impermeable boundaries (Purtyman and Johansen, 1974; Stone, 1977). Although there are differences in hydraulic properties of the uplifts and valley fill, they are hydraulically connected. Most ground-water development is associated with the basin fill. Its water-producing potential is illustrated in Table 2. An estimate of the water budget for the Rio Grande in New Mexico is given in Table 3 and Figure 3. Such estimates are hard to make as most parameters are difficult to determine at a given point, let alone over the entire basin. Hydrologists can readily obtain precipitation records and stream-flow histories. But, recharge, evapotranspiration (ET), and ground-water underflow must be estimated. ET estimates from irrigated areas are probably pretty good, because agronomists have studied water use by crops extensively. But estimates of ET elsewhere in the basin and recharge are difficult to defend. ET is usually assumed to be the difference between precipitation and other water-budget parameters. Hydrologists have made only a few "point" measurements of recharge (Phillips et al., 1984; Stone, 1986), and ideas about the validity and representativeness of these measurements vary. We know

Table 2. Hydrogeologic characteristics of some Rio Grande Rift basins in New Mexico.

Basin	Unit	Aquifer[5]	Tkns (ft)	Description[6]	T (gpd/ft)[7]	Yield (gpm)[8]
San Luis[1]	valley fill	upper (u) lower (c)	0-200 50-30,000	cly,slt,sd,gvl cly,slt,sd,gvl w/volcanic flows	1,000-2,500 1,500-1,500,000	3,000 4,000
Albuquerque[2]	basin fill	upper (u) lower (c)	>3,000	cly,slt,sd,gvl		
Socorro[3]	Santa Fe Group	Sierra Ladrones Fm (u) lower Popotosa Fm (c)	1,000 3,000	cly,slt,sd,gvl ss,cgl	50,000-200,000	
Mesilla[4]	floodplain alluvium Santa Fe Group	upper (u) lower (c)	<80 1,000's	cly,slt,sd,gvl cly,slt,sd,gvl	10-150,000	1,050-1,500

[1] Emery (1971)
[2] Anderholm (1986)
[3] Anderholm (1987)
[4] Wilson and others (1981)
[5] u = unconfined, c = unconfined
[6] cly = clay, slt = silt, sd = sand, gvl = gravel, ss = sandstone, cgl = conglomerate
[7] T = transmissivity; gpd/ft = gallons per day per foot (of width over full thickness of aquifer)
[8] gpm = gallons per minute

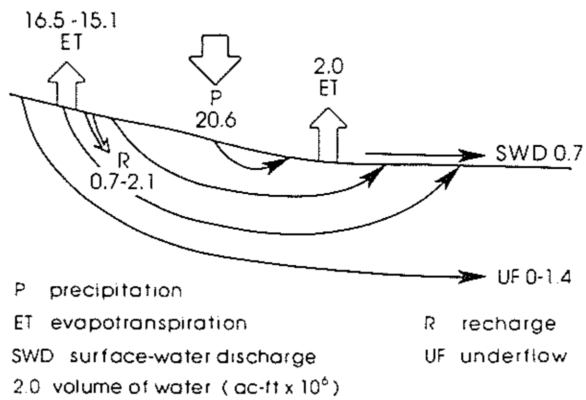

Figure 3. Schematic diagram of the water budget for the Rio Grande valley based on data in Table 3 (Stone and Summers, 1986).

recharge occurs through direct infiltration and percolation of precipitation as well as seepage along mountain-front stream channels.

In some places within the Rio Grande trough in New Mexico the river is a gaining stream; in others it is a losing stream. That is, the Rio Grande gains water from the ground-water part of the system in some reaches and gives water up to the ground-water reservoir in others. Thus, the distinction between surface water and ground water becomes blurred. Wilson et al. (1981) found, for example, that in the Rincon/Mesilla Valleys, both gaining and losing reaches occur. Tributary streams crossing the mountain front lose water to the ground-water reservoir. Heath (1983) concluded that average seepage rates along a 48-mi reach of the Rio Puerco, where it flows over valley fill, average approximately 5 ft³/second (cfs) in the winter and 10 cfs in the summer. Water diverted to acequias from streams in northern New Mexico lose as much as 5 percent of their water per mile (Lee Wilson, personal communication, 1984).

Conceptualization of flow nets and discharge depend on both availability of data and interpretation of those data. Figure 4 shows the flow paths in a cross section from the San Andres Mountains to the Rio Grande obtained by a numerical model (Bedinger and others, 1984). It shows that although the ground water circulates to depths of more than 6,000 ft, most of the flow occurs above 3,000 ft and must have its origin at the mountain front. The model also shows that discharge occurs to a zone that is perhaps as wide as 600 ft. Because the model is two-dimensional and conditions imposed on the model allow no other solution, the model cannot show underflow and must show all ground water in the plane of the section discharging to the river.

The predicted effect of pumping wells on the river depends upon the model one uses. One analytical method that engineers have used for years to predict pumping effects (Glover and Balmer, 1954) assumes that the river and the well fully penetrate the ground-water reservoir and that initially the water table is flat, therefore excluding recharge. This model predicts that eventually 100 percent of the water pumped comes from the river. Other methods, that assume the river only

Table 3. Water-budget for Rio Grande Basin in New Mexico (in part from West and Broadhurst, 1975).

Parameter		Low Recharge Estimate (ac-ft x 106)	High Recharge Estimate (ac-ft x 106)
Input			
Precipitation		20.6	20.6
Output			
Runoff		0.7	0.7
Recharge			
ground-water discharge		0.7	0.7
underflow		0.0	1.4
Evapotranspiration			
use areas		2.7	2.7
elsewhere		16.5	15.1
	Total	20.6	20.6

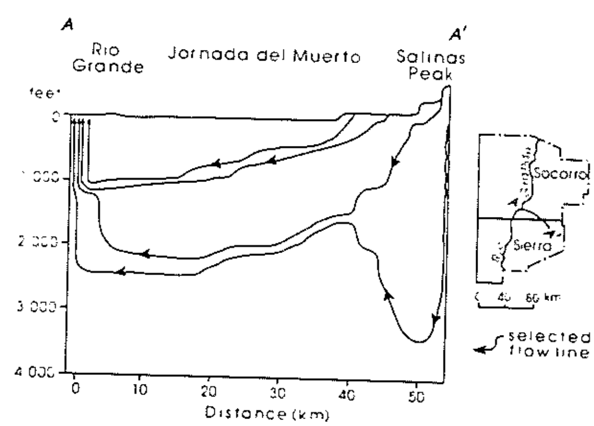

Figure 4. Cross section of a portion of the Rio Grande Valley in New Mexico showing flow lines generated by a two-dimensional vertical model (Bedinger et al., 1984).

partially penetrates the reservoir and allow for recharge, show that less than 10 percent of the water discharged by a well comes from the river (Emery, 1966; Wright, 1958). In Albuquerque, the city's south valley wells and drains, installed by the Middle Rio Grande Conservancy District to prevent water logging of irrigated land, have created a situation where the river is a recharge source. As a consequence, the ground water for approximately 1/4 mi on either side of the river is in fact river water that has moved into the ground (Dennis McQuillan, EID, personal communication, Oct. 2, 1986).

Water Quality

One prevailing water-chemistry concept is that more or less continuous layers of differing salinity exist within the valley fill. Kelly (1974) applied this concept to the entire Rio Grande Basin in the United States. In his model, fresh ground water lies at or very near the water table. Beneath the fresh water are layers of increasingly higher salinity, ranging from slightly saline to brine. Other hydrogeologists working in the valley (Bushman, 1962, Cliett, 1969, and McQuillan, 1984) have noted and employed a slightly different layered model. They reason that shallowest water is of poorer quality than somewhat deeper water, because irrigation return flow, evapotranspiration, and pollution from septic-tank effluent increase the salinity of the shallow ground water.

The quality of valley ground water is a reflection of mountain ground-water quality. Hiss and others (1975) showed that the chemical characteristics of ground water in the northern part of the Albuquerque/Belen Basin could be correlated with those of probable source areas on both sides of the basin. Stone and Foster (1977) and Stone (1984) found that ground water along the western margin of the Rio Grande valley in the Socorro area was much fresher than that underlying the valley proper because of leakage of fresh ground water from an elevated side basin through the mountain front. This freshwater occurs in tongues associated with the more conductive fracture zones in the mountain (Figure 5). Such tongues no doubt occur in other favorable settings along the valley, such as the Nutt-Hockett Basin, southwest of Hatch. Summers and others (1981) also recognized tongues of differing quality in the Socorro area. They attributed this to infiltration from

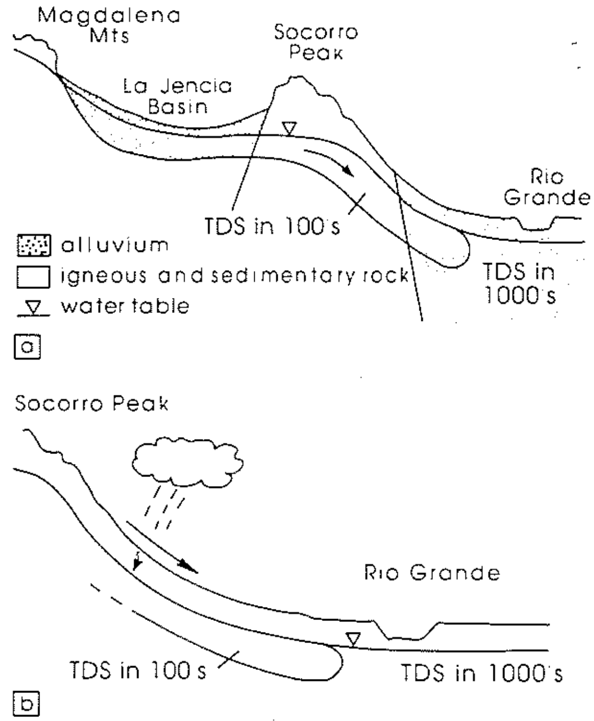

Figure 5. Schematic cross sections in Socorro area showing fresh-water tongues in ground water; a) due to elevated side-basin discharge (Stone, 1984), b) due to mountain-front recharge (Summers et al., 1981). TDS refers to total dissolved solids content (mg/L).

mountain-front recharge (Figure 6). Depending on relative salinities, these tongues may freshen or degrade valley ground water.

Based on the prevailing conceptual hydrogeologic model of the valley, pollutants from solitary sources, such as landfills, septic tanks or gasoline storage tanks, ultimately wind up in the river through natural flow/discharge processes. The river dilutes the contaminated discharge and effectively eliminates the problem. But, if levels of pollutants are high, the river becomes a source of contamination.

Pumping water from wells reverses the process and high-salinity or contaminated river water moves into the ground-water body and flows toward wells. Gallaher and others (1986) have identified pollutants in Albuquerque's south valley at depths of 220 ft that could only have come from the surface. Presumably pumping the city's wells has reversed hydraulic gradients and water now moves downward from the water table (and from the river). Pumping may also short circuit the natural flow of polluted water toward the river and divert it to wells. In Santa Fe County, McQuillan (1986) identified 17 locations at which one or more wells were polluted.

HISTORY, CULTURE, AND ECONOMY

The Rio Grande Basin has a long history of human occupation and cultural integration. When Antonio Espejo entered the region in 1539, he found the native American Indians irrigating approximately 25,000 acres along the river (Burkeholder, 1928). The Spanish proceeded to overlay their irrigation-based culture during the seventeenth and eighteenth centuries. Anglo Americans, who entered the region in the 1800s, introduced the concepts of water as private property and large-scale commercial agriculture.

Today, more than 3.5 million people reside with-in the Rio Grande Basin. Population is heavily concentrated in the metropolitan areas of Albuquerque, New Mexico (pop. 500,000) and El Paso, Texas/Ciudad Juarez, Chihuahua (pop. 1,000,000), as well as in four sister cities near the river's mouth on the Gulf of Mexico: Brownsville and McAllen, Texas, and Reynosa and Matamoros, Tamaulipas (combined pop. 1,000,000; Eaton and Anderson, 1987). Expanding rapidly over the last several decades, these large cities and a handful of the basin's smaller municipalities have encroached on the position of dominance in water use historically held by agricultural producers. Various economic factors are given in Tables 4-7.

The major economic activity in the Rio Grande Basin is irrigated agriculture. Crops vary with location. Apples are typical of higher elevations. Alfalfa is ubiquitous but especially common in the middle valley in New Mexico. Cotton, chile and pecans characterize the Las Cruces area. Various citrus fruits are grown along the lower reaches of the river.

There is both commercial and what might be called culturally significant marginal agriculture. The middle valley of the Rio Grande has one of the longest histories of continuous cultivation in the United States. In the northern basin in New Mexico, native American (pueblo Indian) and Hispanic (acequia) agriculture dominates. The acequia is a community ditch for delivering irrigation water. This community ditch has given rise not only to farms, but also a sense of community

Table 4. Population parameters for New Mexico portion of Rio Grande Basin (Anonymous, 1988).

County	1986 Population	% Urban	Density (Persons/mi2)	Projected 2010 Pop.
Rio Arriba	33,300	19.3%	5.7	49,100
Taos	22,000	17.3%	10.0	30,800
Sandoval	51,100	47.5%	13.8	97,900
Santa Fe	87,600	70.6%	46.0	116,500
Bernalillo	474,400	96.4%	405.8	626,100
Valencia	36,400	40.7%	24.6	55,500
Socorro	14,700	57.1%	2.2	24,000
Sierra	9,400	61.7%	2.2	10,500
Doña Ana	123,000	67.3%	32.2	211,100

Table 5. Land Ownership in New Mexico portion of Rio Grande Basin (Anonymous, 1988).

County	Federal	State	Indian	Private
Rio Arriba	51.9%	2.9%	17.2%	28.1%
Taos	50.8%	6.7%	4.3%	38.2%
Sandoval	41.5%	3.4%	27.3%	27.8%
Santa Fe	27.5%	7.0%	6.5%	59.0%
Bernalillo	20.7%	4.3%	29.7%	45.3%
Valencia	19.3%	7.0%	23.5%	50.2%
Socorro	54.7%	14.4%	1.3%	29.6%
Sierra	67.8%	13.4%	--	18.8%
Doña Ana	74.8%	11.8%	--	13.4%

Table 6. Income measures for New Mexico portion of Rio Grande Basin (Anonymous, 1988).

County	1986 per capita Income	% Persons below Poverty, 1979	1986 Unemployment
Rio Arriba	$ 7,827	28.3%	19.9%
Taos	$ 8,337	27.5%	26.8%
Sandoval	$ 11,082	18.6%	8.7%
Santa Fe	$ 14,047	13.7%	6.3%
Bernalillo	$ 13,742	13.2%	6.4%
Valencia	$ 10,436	14.3%	10.2%
Socorro	$ 8,637	29.6%	9.4%
Sierra	$ 10,059	22.4%	7.4%
Doña Ana	$ 9,544	22.7%	7.3%

Table 7. Source of cash receipts in New Mexico portion of Rio Grande Basin.

County	Agric.	Tourism	Construct.	Mining	Manufact.
Rio Arriba	7.2%	2.6%	16%	16.3%	1.8%
Taos	2.5%	10.4%	10.9%	--	4.0%
Sandoval	4.7%	2.6%	25.6%	25.6%	8.0%
Santa Fe	1.0%	6.7%	14.0%	--	6.3%
Bernalillo	0.3%	3.6%	11.2%	0.6%	7.2%
Valencia	7.1%	4.7%	14.6%	--	3.1%
Socorro	23.4%	6.7%	17.9%	--	3.9%
Sierra	28.5%	7.5%	17.6%	0.2%	0.7%
Doña Ana	12.2%	4.3%	16.0%	0.3%	5.2%

and a way of life based on marginal irrigation agriculture. While this does not represent an important economic sector from the national or international perspective, it is important to the state and the region especially for its cultural value. The same can be said for the pueblo Indians with the added dimension that their water rights are being negotiated and guaranteed under federal law (DuMars et al., 1984).

A FINAL NOTE

In a 1986 survey of Water Resources Research Institute Directors in the Southwest, the chance of a major water crisis in their state before the year 2000 was deemed "very or extremely likely" by the Colorado respondent but "quite unlikely" by the New Mexico and Texas respondents (Miller, 1989). These answers obviously depended on their perception of "crisis." Presumably social, political, economic and regulatory factors were taken into account. How would they have responded if impacts of global climate change had also been considered?

From this summary it should be apparent that the Rio Grande Basin is complex. Furthermore, present information is not adequate for accessing impacts of possible climate-change scenarios. Multidisciplinary research into the physical, biological, social and economic systems involved is essential for even minimal preparedness.

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IMPACTS OF CLIMATE CHANGE AND VARIABILITY ON ECOLOGICAL SYSTEMS

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INTRODUCTION

By looking at different scales of remotely sensed images, one can learn different things about the earth. Seen from space, the Amazon Basin is a little rectangle in the middle of South America. Satellite photographs taken closer to the earth can be used to quantify vegetative productivity in the entire Amazon Basin. At this scale one can also see white spots on the images of the Amazon Basin. These are very large fires about which there is general concern because of the carbon dioxide (CO_2) released through burning to the atmosphere. Thus, one can determine that fires occurring in the terrestrial system of the Amazon Basin interact with the atmosphere to contribute to global warming. In turn, global scale phenomena have impacts on regions such as the Amazon or the Rio Grande Basin. This paper examines the interactions of processes that cause global scale changes and focuses on how these changes are occurring, or could occur at the regional level of the Rio Grande Basin.

THE CARBON CYCLE

Three different components of the carbon cycle are important with respect to global climate change: 1) the interaction of vegetation and carbon, 2) industrial production of carbon, 3) the role of the oceans in storing carbon. The *flux* of carbon from terrestrial systems and from oceans is equivalent; carbon *storage*, however, is much greater in the oceans than in terrestrial systems. Fluxes of carbon from industrial sources are much smaller than fluxes from either the terrestrial systems or oceans, so vegetation and biological processes in general determine the amount of carbon on earth and how it moves through various ecosystems.

The Northern Hemisphere has more land mass than the Southern Hemisphere. More carbon is evolved from a greater number of biological systems in the Northern Hemisphere than is stored. Less carbon is evolved in the Southern Hemisphere because there is less land mass, and subsequently, fewer biological systems.

Carbon in ecosystems is stored not only in accumulated biomass, but also in exchange rates of carbon through the processes of photosynthesis and respiration. Forests represent a large percentage of living biomass but productivity is low. Tree trunks contain a great deal of carbon but exchange very little carbon with the atmosphere. Green leaves, however, are very active at this exchange. In a Savannah (fewer tree trunks and more green leaves) productivity is higher than accumulated biomass.

Carbon is stored in soils as well, and the amount of carbon stored is different for different biomes. Tundra soils, for example, store enormous amounts of carbon, compared with other terrestrial ecosystems.

INTERACTIONS BETWEEN PLANTS, SOIL, CO_2, AND TEMPERATURE

Important interactions occur between available carbon and nutrients in soils, and water-use efficiency. Water-use efficiency is a measure of plant growth which determines how much water is used for biomass accumulated. Plants vary in their water-use efficiency depending on such things as whether or not they are stressed for nutrients. An example is Monterey pine (*Pinus radiata*) growing in parts of coastal California. If this pine has an abundance of nutrients from the soil, and the amount of carbon in the atmosphere increases as a result of increased CO_2, then this tree grows faster by converting atmospheric carbon into biomass. It also becomes more efficient at using water. If the pine is stressed for nutrients it will not grow faster, even if atmospheric CO_2 increases and the tree has abundant water.

How would an increase in atmospheric CO_2 and an increase in temperature change a successional sequence of tree species in a forest? In the western United States, short-lived aspen (*Populus tremuloides*) dominate after a forest fire but are replaced later by the slower growing conifers, which finally shade out the aspens beneath them. Both kinds of trees capture carbon through photosynthesis. The soils in these forests are very dark, indicating an enormous amount of stored carbon. In this system increased CO_2 would cause increased photosynthesis thereby taking up much of the extra carbon in the atmosphere. But increased air and soil temperatures caused by the trapping of heat under the growing "umbrella" of greenhouse gases (CO_2 and others) would cause an increase in soil respiration thus releasing more carbon to the atmosphere. Plants would take up more carbon, but soils would lose more carbon.

There is some indication that as we add carbon to the air the carbon/nitrogen ratio in tree leaves increases, making leaves harder to decompose. An increase in atmospheric CO_2 increases carbon captured by the plants, increases carbon lost by the soil and decreases the decomposition rate of plant tissue. Thus, it is difficult to predict what kind of alteration of a forest successional sequence would occur if there is an increase in both atmospheric CO_2 and temperature because of the complex of the interaction between terrestrial systems and the atmosphere.

In the Rio Grande Basin, not all green leaves are the same in the way they capture carbon during photosynthesis. Plants of one type are called "C_3 plants," and plants of another type are called "C_4 plants." C_4 plants, however, can operate more efficiently at high temperatures with less water than can C_3 plants. The Kentucky bluegrass (*Poa praetensis*) in New Mexico lawns is an introduced C_3 plant; the native grama (*Bouteloua* sp.) and buffalo (*Buchloe* sp.) grasses are C_4 species. These grasses are predicted to respond differently to an increase in atmospheric CO_2 because their photosynthetic pathways differ. Within C_3 plants there is a competition between CO_2 and oxygen to capture carbon during photosynthesis. That competition limits the amount of carbon captured by the plant. If there is more CO_2 in the plant as a result of higher CO_2 in the atmosphere, then the plant CO_2 should capture more carbon than oxygen. As a result, the C_3 plants should increase their rate of growth, and photosynthesis should increase by 10-15%. On the other hand, in C_4 plants, CO_2 and oxygen do *not* compete for carbon. C_4 plants, therefore, will not increase growth and rate of photosynthesis.

The CO_2 "fertilization effect" is the increase in photosynthesis caused by increased atmospheric CO_2. When transparent plastic experimental chambers are placed over tundra, and CO_2 is added, the rate of photosynthesis increases in the first year, but returns to pre-experimental levels by the second or third year of the experiment. When the same experiment was performed in an eastern US marsh, photosynthesis increased permanently. These two systems responded differently to increased CO_2, and this difference cannot be explained on the basis of a difference in the ratio of C_3 to C_4 plants.

Timing of temperature increases is also important. If there is an increase in summer temperature, there will be an increase in carbon fixation (incorporation) by plants, and a stimulation of organic matter decomposition—a process that makes more carbon available. If there are increases in winter temperature, soil respiration will increase the loss of carbon in soils and net primary production will decrease. There are also global differences in moisture and temperature which affect the response of different systems to changing climatic conditions. The change in CO_2 would affect not just primary production but would also increase water vapor, methane and albedo (the reflectivity of the earth).

OTHER GREENHOUSE GASES

Other greenhouse gases also will increase in the atmosphere. Nitrous oxide (N_20) is produced from terrestrial systems at a rate dependent on soil conditions and vegetation. Warming, wetting and human activities such as conversion of tropical forest to pasture and temperate forest harvest increase N_2O. Methane (CH_4) emissions increase during wet periods and decrease during dry periods. All greenhouse gases will respond to global warming and precipitation pattern changes.

GENERAL CIRCULATION MODELS

The complexities of interaction between the atmosphere and biological systems, above and below ground, are very difficult to incorporate into the large mathematical simulations used to predict the behavior of the earth's atmosphere and its influence on different vegetation types (two global circulation models are the Princeton University Geophysical Fluid Dynamics Laboratory [GFDL] Model and the Goddard Institute for Space Studies [GISS] Model). One model predicts an increase and the other predicts a decrease in different kinds of vegetation from the tropics, temperate and boreal forests and other biomes. Therefore, there is a high degree of uncertainty in global scale models, and even more uncertainty in regional models.

PLANT DISTRIBUTIONS AND RATE OF RESPONSE

Vegetation of the world is classified on the basis of precipitation, temperature, and how much evaporation stress there is. Any part of the world can be classified based on these variables. The question is, what would happen to the distribution of different vegetation types if we double atmospheric CO_2? One prediction would have the grasslands of the United States, for instance, move northward into Canada. Will the vegetation be able to move fast enough to occupy new conditions, assuming that CO_2 were going to double by the year 2050? What previous examples of changes in plant distributions are there in the earth's history? A very recent one is the drought of the 1930s and 40s. Another is the pattern of vegetation before and after the Pleistocene or some earlier glaciation period. The pollen records during the Pleistocene show how fast species migrated during glacial periods. In North America, a 10°C change in temperature displaced isotherms about 100 kilometers (km).

The predicted rate of temperature increase caused by an increase in CO_2 or another greenhouse gas is quite variable but if an intermediate value of 0.4°C per decade is used, the rate of change is about 250 km per decade. The pollen records during glaciation show a maximum rate of change of 20 km per decade. This record suggests that climate change now and its effects on the distribution of vegetation might be much greater than experienced during past glaciations. Plants may not behave in the same way today as they did in the past. Would plants have moved more rapidly if the climate had changed more rapidly? What does seem true from the pollen record is that each species moved independently. If this occurs again, unique biological communities might be formed. Additionally, since the ranges of so many species are fragmented by human activity, would these species be able to migrate across the landscape as they did during the Pleistocene?

COMMUNITIES OF VEGETATION IN NEW MEXICO

The four major biomes of vegetation in New Mexico are shown in Figure 1. Vegetation is classified in terms of its point of origin and its similarity. Plants which occur in the Great Basin are called the Great Basin flora; this biome enters the state from the northwest. The Great Plains flora enter the state from the northeast. The Chihuahuan Desert flora enters the state from the southwest, and finally, the Conifer Woodland flora occupy the mountains. The shaded area in the middle of the state is the Sevilleta Long-term Ecological Research (LTER) site. It is within this wildlife refuge that these four biomes collide. Central New Mexico is unique because these vegetation types overlap, forming transition zones. At these transitions there is an enormous amount of fluctuation of the plant and animal species inhabiting the area. It is expected, therefore, that these areas of overlap might be very sensitive to climate change. These "ecotones" are rich with information about how vegetation types, and other associated organisms, change with very slight or very large changes in climate and/or precipitation. It is an extraordinarily good part of the world in which to look at the ways biological systems and soils respond to climate change.

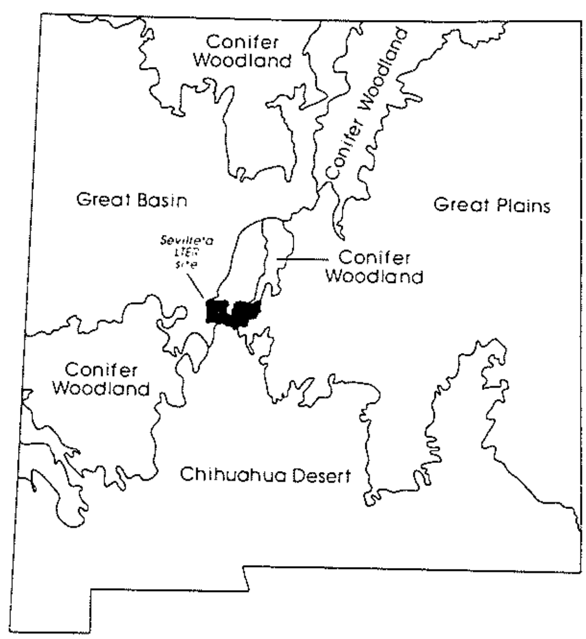

Figure 1. Major biomes in New Mexico. Four biomes callide in the Sevilleta National Wildlife Refuge, an NSF-funded Long-Term Ecological Research site.

THE EL NIÑO SOUTHERN OSCILLATION

We have recently discovered that climatic conditions (especially changes in temperature and pressure at the equator and in the southern hemisphere) generate change in the southwestern United States. This climate phenomenon is referred to as El Niño (the child) because it usually begins around Christmas and has an effect on climate in many parts of the world. A change in southern ocean water and air temperature and air pressure between Darwin, Australia, and Tahiti has a strong effect on the weather of the Southwest. In El Niño years (i.e. 1991) New Mexico has more precipitation, especially in the spring.

RELATIONSHIP BETWEEN PRODUCTIVITY, PRECIPITATION AND SOILS

In general, if rainfall is greater than 370 mm then plant production is good (Figure 2). Plant production is very good on clayey soils when precipitation is high. When precipitation is low, then there is good production on coarse and rocky soils. This is true because rain infiltrates down into coarse, rocky soils, doesn't evaporate, and can be "harvested" by plants. If there is little rain, very small particles of clay hold water very tightly and plant roots are unable to pull the water off. As precipitation changes there should be changes in plant communities in New Mexico. These changes are caused by the interaction of precipitation (amount and timing) with different soil conditions. Climate changes generated as far away as the southern Pacific influence the interaction between plant species, precipitation and soil type in New Mexico.

At the Sevilleta LTER site (Figure 1), Cliff Dahm and Jim Gosz from the University of New Mexico, are trying to relate phenomena at different scales. They are using a device called an FTIR (Fourier-Transform Infrared Spectrophotometer) which sends a beam of light across up to 1 km of landscape to measure the absorption of light by various gases being emitted along the beam's path. Light is absorbed at different wave lengths by different gases. Thus one can detect changes in the type and amount of gas flux from a landscape with different vegetation, soil and moisture conditions. The FTIR makes it possible to integrate processes occurring at the scale of the individual leaf along a kilometer path to understand how these processes function at the regional and global scale. The FTIR analysis is a critical link not only between local and global processes but also between specific events and long-term changes in an ecosystem.

LONG-TERM ECOLOGICAL RESEARCH AND RIO GRANDE BASIN

It is a great pride to New Mexico that it has two of the 18 LTER sites funded by the National Science Foundation. The Sevilleta LTER is run by investigators at the University of New Mexico; La Jornada LTER is run by investigators at New Mexico State. Other long-term research is occurring at El Malpais and Bandelier National Monuments. There is an emphasis on coordinated research at these sites, as well as with other sites in the United States and Puerto Rico. This network of long-term research sites has enormous potential to permit prediction, detection and synthesis of global climate change evidence at the local and regional level. Such efforts are critical to understanding global change and ecological variability.

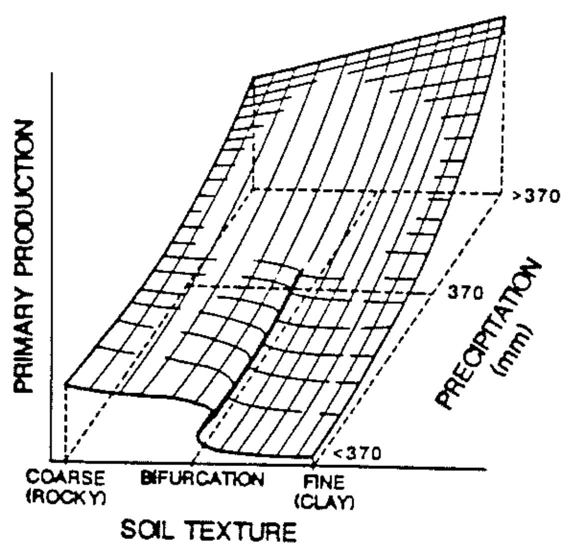

Figure 2. Relationship of soil texture, precipitation and plant production.

APPROACHES TO THE PROBLEM

Proceedings, The Rio Grande Basin--Global Climate Change Scenarios, 1990, WRRI Rept M24

RIO GRANDE LABORATORY/CONSORTIUM CONCEPTS

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INTRODUCTION

Global changes due to anthropogenic atmospheric insults have been a topic of much current political as well as technical interest. The popular press and a wide variety of professional scientific and engineering journals have devoted enormous attention to the triad of 1) stratospheric ozone depletion resulting from releases of halogenated compounds, 2) tropospheric air pollution problems including urban smog and regional acid precipitation associated with combustion of fossil fuels, and 3) predictions of global warming due to increasing concentrations of carbon dioxide, methane and other gases which have high spectral absorbance at infrared wavelengths, the so-called "greenhouse gases." Of these three problems, global warming unquestionably presents the most serious and widespread threat to the earth's inhabitants as its ramifications will be manifested in virtually all physical, biological, political, and socioeconomic ecosystems.

To date, research efforts on the problems of global climate change and variability have principally focused on developing an understanding of the phenomena resulting from man's assaults on the atmosphere. These have included investigations of atmospheric chemistry and physics, studies designed to measure historic and current atmospheric characteristics including identifying chemical and temperature changes, and developing numerical models to simulate atmospheric circulation patterns and weather which incorporate additional heat retention from accumulations of greenhouse gases. Comparatively little research has been devoted to determination of the impacts that possible climate change may have upon man's environment and his institutions. A notable study was that published by the National Academy of Sciences in 1983 which provided a preliminary assessment of the effects of global temperature increases on the North American continent.

Recently several federal agencies including the Environmental Protection Agency, the Department of Energy, the Corps of Engineers, the Forest Service, the Park Service, and the Geological Survey have established programs to investigate impacts of climate change upon resources which they manage. A serious limitation of these programs is that they are limited in scope to resources which fall under the purview of the particular agency; for example, the United States Geological Survey (USGS) program focuses on hydrologic impacts, while the Forest Service addresses potential problems from a forest and wildlife management perspective. Within these research initiatives, little effort is directed toward research which integrates investigations of physical, biological, and socioeconomic impacts resulting from climate change.

A major difficulty in designing an interdisciplinary investigation of climate change impacts on physical, biological, and socioeconomic systems is that of scale. For most studies of this nature, the number of variables increases geometrically with increases in the size of the domain. As a corollary, the resolution of the investigation decreases with the size of the domain, due in part to the increased variability and to the limited amount of information that can be developed regarding any single variable in a complicated system. This phenomenon was demonstrated in the National Academy of Science report (National Academy of Sciences, 1983) which considered impacts for the entire continent, and thus was able to develop only crude estimates of impacts on any one hydrologic system.

THE RIO GRANDE BASIN AS A LABORATORY

As an alternative to large, continental scale investigations of the impacts of climate change and variability, this workshop and conference considered the concept of utilizing the Rio Grande Basin as an intermediate-scale field laboratory for developing an understanding of the interrelated impacts on physical, biological and socioeconomic systems. The basin is suggested as an ideal system for this type of study because of the fragile nature of its environment, which is so dependent upon climate, and the diversity of man's activities, culture, and institutions within its bounds. The over-view of the basin by Stone et al. in this volume gives the physical, biological and human aspects of the region. A few of these are repeated here for emphasis.

Within the Rio Grande Basin, water is the unify-ing thread in two ways: it defines the basin and it acts as a medium which translates climatic change into physical impacts. This translation is a four-stage process. First, climate change will likely affect precipitation both in quantity and in temporal distribution. Second, changes in precipitation alter the quantity and quality of the flows into regional surface, ground and soil reservoirs. This affects the quantity and timing of annual runoff in streams and rivers, and subsequently irrigation systems; it alters natural recharge of ground water systems; and the moisture in soil systems which is available for vegetation is changed. Third, these changes in water supply are translated by legal institutions into changes in water availability to users. These legal institutions include the system of water law and administration, an international treaty, and an interstate compact and their manifestations in the concrete system of dams, reservoirs and canals. Fourth, the users, i.e., urban communities, agricultural interests, recreation and tourism industries, timber industries, and energy industries, respond to changes in water availability, taking advantage of opportunities and minimizing losses. In a less tangible, but equally important sense, the Rio Grande provides a sense of unity to residents within its basin, perhaps more so than in any other hydrologic system within the US. Following this dependence on water through the basin serves to identify the interrelationships among the physical, biological, social, economic and institutional systems which define its environment.

There are many factors that recommend the Rio Grande basin as an identifiable unit for climate impact assessment (Table 1). These factors apply to the entire basin. Although separated under the general headings of physical and social factors, this distinction is somewhat arbitrary. Many of these factors are an example of some type of threshold or "marginality." Marginality can be spatial, economic, or social (Parry, 1985). Geographic marginality represents a transition zone beyond which some activity or species cannot exist, e.g., an ecotone in ecology, or temperature as a climatically limiting factor for certain crops. Economic marginality describes an activity that is on the edge of profitability. Social marginality refers to groups that are at risk of losing their cultural identity and/or traditional resource base should conditions change and they are no longer able to maintain their livelihood. The hypothesis usually employed is that climatic change will manifest itself, first and to the greatest degree, at these margins. We should therefore focus on these for the impacts and the evidence of change. The Rio Grande basin is full of such margins.

Table 1. Attributes of the Rio Grande Basin

Physical	Social
Hydrologic unity	Water use exceeds availability
Climate variability	Culturally significant agriculture
Ecological patterns	Unique international boundary
Regional scale	Cultural history
	Institutional structures
	Sense of community
	Existing resources

Physical Factors

The first and perhaps most obvious physical factor for selecting a drainage basin in which to investigate impacts of climate change is its hydrologic unity. Water, sediment and associated soluble constituents are transported to a common outlet, so that activities in one part of the basin affect activities in another. For example, overgrazing upstream may lead to increased erosion resulting in downstream sediment problems. The drainage basin has long been recognized as a desirable unit for managing water and related land and mineral resources, although meaningful implementation of this concept has largely proven elusive (North et al., 1981).

Precipitation variability throughout the basin is the second physical factor. On a plot of annual precipitation variability in the US, one of the isolines of maximum variability in North America runs through the Rio Grande Basin. This threshold axis of variability may prove useful as a regional indicator of climate change.

Ecological patterns in the basin demonstrate a similar conjunction of margins. Four major biomes come together within the basin (see map in the previous paper by Risser). These ecotonal edges may also prove useful as indicators of the direction and magnitude of climate change. It was this unique pattern that was largely responsible for the establishment of the Sevilleta and Jornada

Long Term Ecological Research (LTER) sites within New Mexico. The basic ecological studies on these fragile environments will provide the basis for projecting change in other parts of the basin.

The basin also contains unusual abundance and diversity of mineral resources. Of particular significance are important reserves of energy-related materials including fossil (coal, oil, and natural gas), nuclear fuels (uranium), and renewable resources (solar, and to a limited extent, biomass and hydroelectric resources). These resources are important from the climate-change perspective in that their continued development will depend to a large extent upon national policies which may be implemented to limit atmospheric accumulations of carbon dioxide.

The last physical factor is the regional scale of the basin. While the issue is global, regional scale effects will determine social and economic impacts and policy response. The regional scale represents a common level being approached from both directions. That is, global modelers recognize the need to develop regional scale policy relevant information, while at the same time local officials are often faced with the dilemma that environmental issues transcend local boundaries.

Social Factors

In the Rio Grande Basin total water consumption exceeds naturally available supply (US Water Resources Council, 1978). The difference is made up through interbasin diversions and ground-water mining. The basin is extremely vulnerable to any change that would further decrease available supply. Very little work has been done on possible impacts to water supply in this region. Revelle and Waggoner (1983) in the NAS study predicted that a modest scenario of a 2°C temperature increase and 10 percent decrease in annual precipitation would reduce runoff by 76 percent. This was the largest percentage reduction for any basin in the United States. Water use in the Rio Grande Basin is primarily for urban, agricultural, and recreational uses, and includes some hydroelectric power generation and some use for evaporative cooling. A significant fraction of water used in the basin is ground water. Within New Mexico, for example, nearly 95 percent of all potable water supply is ground water. Decreased runoff will have important impacts on New Mexico communities by decreasing both the availability and quality of these ground-water resources.

The Rio Grande forms the international boundary between the US and Mexico below El Paso, Texas. It is the only river in the world that separates a developed industrialized nation from a developing third world country. Division of water between the US and Mexico is spelled out in two treaties. In the US, the water is divided between the three states of Colorado, New Mexico, and Texas by the interstate Rio Grande Compact. Thus, changes in water supply have an important international dimension. Climate change in this region raises very important issues of international development and equity. The treaties and compacts regulating water use in the basin are examples of existing institutions that are already in place and focus on the Rio Grande basin as a region. Other institutional structures exist that focus on the basin, e.g., water quantity and quality data collection by the USGS.

The basin therefore has a rich history of cultural evolution, development and integration strongly dependent upon its water resources. The basin's physical environment, likewise, is extraordinarily sensitive to the water supply. Changes in water resources will have ramifications that now can only be guessed at. As a system for generating understanding of the relationships between the physical, biological and socioeconomic environments, the Rio Grande Basin appears close to ideal. Exploring mechanisms for developing this understanding is the theme of this workshop and conference.

RIO GRANDE BASIN CONSORTIUM

As the Rio Grande Basin consists of many natural manmade systems, global climate change research in the region is necessarily multidisciplinary. Furthermore, it involves both theoreticians and practitioners. To enhance communications among a diverse group of players, avoid duplication of funding requests, improve chances of obtaining grants and coordinate a wide range of research efforts, some sort of umbrella organization or clearinghouse seems necessary.

Thus, the concept of a consortium of government agencies, universities and research organizations comes to mind. The specific makeup, structure and functions of such a body remain to be defined. Such items were topics for discussion throughout the workshops and conference and a specific focus of Workshop IV (see results and consortium update below).

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EVALUATION OF RIO GRANDE LABORATORY/CONSORTIUM APPROACHES--WORKSHOP I RESULTS

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INTRODUCTION

For both workshops I and II, participants met for an hour in one of five groups of approximately 15 people. Each group met in a separate room and was assigned a facilitator and a recorder. The conference planners composed the groups to ensure in each a wide representation of institutions. Discussions were taped and the recorders' tear sheets were collected.

In all workshops, the questions under discussion were based on two related assumptions: 1) that recent global studies are basically accurate in concluding that, due largely to anthropogenic influences, the composition of the earth's atmosphere is changing in a manner that will result in increasing deviation from historic weather patterns, if not long-term and relatively stable changes in climate, throughout the earth; and 2) that regional counterparts to the global studies are needed by scientists to provide finer, meso-scale, resolution of trends observed in studies based on global models and by public administrators and policy makers to provide information, relevant to their planning and decision functions, regarding possible local implications of climate change.

Workshop I focused on a proposal to treat the Rio Grande drainage basin as a regional unit, or laboratory, for long-term climate change research. Participants were asked to consider the strengths and weaknesses of this proposal and, provided strengths outweighed weaknesses, the possible benefits to be derived by developing a basin-wide consortium to address the proposal. The participants were not presented with a list of attributes of "the ideal candidate" for a regional climate study; neither were they given an alternative region with which to compare the region proposed. In Workshop I, then, the participants were simultaneously debating the questions before them and, more or less consciously, imagining a model region against which to compare the Rio Grande Basin.

Finally, it should be mentioned that nearly all the workshop participants reside within the proposed study area and, in their work, are concerned in various ways with natural resources. Thus, in discussing the workshop topic, the participants were considering their "home" region, one in which they have both professional and personal interests.

SUMMARY OF DISCUSSION

Participants in all five groups agreed that the physical, biological, and social characteristics of the Rio Grande Basin make it an exceptionally attractive subject for comprehensive climate study. Moreover, there was wide agreement that the basin's resources include a rich store of the kinds of archival data needed for such study and, as embodied in research facilities and personnel, an unusual capacity to conduct such study. For the most part, misgivings about the proposal rested not on its substantive merits—doubts about the basin's potential as a study area—but on concerns about institutional priorities and institutional inertia.

SUITABILITY OF THE RIO GRANDE BASIN AS A REGIONAL LABORATORY

Each group listed characteristics of the basin indicative of its potential strength as a regional climate research center. The basin profile produced by this exercise highlighted hydrologic unity; climatic, biological, and cultural diversity; multiple boundaries and corresponding "edge effects"; a dense base of relevant historical data; and a concentration of research institutions and resources. Discussion in the groups focused not so much on the independent "strength" of each of these factors as on their synergistic power in combination. For example, the fact that the basin exhibits diverse life forms might be far less compelling as a property of the "laboratory" were these various life forms not competing for water from the same system.

Hydrologic Unity

The hydrologic unity of the basin was noted by many participants as the fundamental measure both of its integrity as a "region" and its particular suitability as a "laboratory" in which to study precipitation-driven, hence climate-controlling, feedback mechanisms.

The following research implications of the basin's hydrologic unity were mentioned:

- That the Rio Grande's surface waters are fully appropriated and strictly allocated by three interstate compacts and an international treaty is advantageous for research purposes, inasmuch as small but sustained diminutions in surface flow might have relatively large social and economic consequences.
- New Mexico water laws, unlike those of other governments that have jurisdiction in the basin, recognize a hydrologic connection between certain ground and surface waters. Similarly, environmental protection laws and enforcement standards differ from state to state within the basin and between the US and Mexico. These variations in the law deserve ever more critical scrutiny as population growth in the basin increases pressure on land, water, and air resources.
- The mainstem of the Rio Grande has been long and heavily impacted by human activities and, in this sense, is like most rivers in arid settings. This shared feature with other dry regions (which, someone noted, include 55% of the earth's land mass) might permit generalization of research findings in the Rio Grande Basin to other climatically similar areas.
- Although the river's mainstem and many of its tributaries have been impacted significantly by human behavior, the basin contains a number of smaller watersheds that have been little affected by humans, comparatively speaking, and could serve as controls in research on the more heavily used streams. Some of the relatively unaffected watersheds are in protected areas (e.g., the Sevilleta and Jornada preserves in New Mexico and the international biosphere preserves in Big Bend and Mexico), which, again, enhances their value as controls in long-term comparison studies.

Climatic, Biological, and Cultural Diversity

The range of climatic zones it encompasses (see "The Rio Grande Basin," this volume), the number and variety of its biomes, and the distinct—and to some extent incompatible—values represented in its inhabitants' cultures were the most frequently mentioned examples of the diversity supported by the Rio Grande Basin. These layers of diversity were regarded by the workshop participants as both enriching and complicating the task of designing research that might reveal the interaction of physical, biological, and social entities.

Multiple Boundaries/"Edge Effects"

Consideration of the basin's "unity and diversity" led inevitably to discussion of its possible responsiveness to certain kinds of change, particularly change "at the margins," at the interface of population boundaries. Such "edge effects"—high reactivity at the periphery of a population's distribution—have been demonstrated in research linking the expansion and contraction of ecotones in the Sevilleta (middle Rio Grande long-term ecological research site) with the occurrence of El Niño and La Niña. The question of whether analogous effects might be observed at other kinds of boundaries to be found in the basin—jurisdictional, socioeconomic, and cultural for example—was regarded by some workshop participants as one of the most challenging questions that might be addressed by a coordinated basin-wide research effort.

Relevant Historical Data

As was repeatedly noted in the workshop meetings, there is a long historical record of climate-relevant data in the Rio Grande area as well as a large inventory of contemporary research ready to be expanded. Some discussants cited extant tree ring, flow record, soil moisture, and carbon dating data that might be used to help document cyclical climate patterns. Others mentioned that ice found in the lava tubes of El Malpais (only known ice record this far south) and the relict vegetation found in isolated and largely inaccessible areas of the basin can be used to reconstruct the climatic conditions of thousands of years ago. Still others noted the availability and potential importance of the Rio Grande pueblos' histories and of journal records dating to early Spanish explorers.

Research Community

In addition to offering abundant "material" for climate research, the Rio Grande region offers an unusual concentration of research expertise and resources. As several participants observed, the New Mexico research universities and the federal, state, and local agencies, institutes, and laboratories represented at the conference have counterparts in Mexico and in the two other basin states. New Mexico's two long-term ecological research programs at the Sevilleta Wildlife Refuge and the Jornada Experimental Range, likewise, have counterparts in other areas of the basin.

WEAKNESSES OF THE RIO GRANDE BASIN AS A REGIONAL LABORATORY

Most of the weaknesses mentioned in response to the question of the Rio Grande's suitability as a laboratory would apply to any area proposed as a climate study region. Some participants wondered, for example, whether macro- and micro-scale models could be integrated and whether regional effects could be separated from global effects. With regard to the latter issue, one participant suggested that population increases and shifts in the basin, together with corresponding changes in demands for water, might mask or exacerbate the effects of climate change, and in ways impossible to track. Similarly, another participant remarked that, given the highly variable flux in precipitation in the Rio Grande Basin, it might be more difficult here than elsewhere to distinguish long-term climate changes from shorter cycles.

Although most participants favored the idea of attempting to study the basin holistically, some said that the term "laboratory" has undesirable connotations (e.g., is demeaning to humans, makes them feel like microbes, and conveys the notion of "control") and should be dropped as a descriptor.

While everyone seemed to agree that the job of mounting a basin-wide coordinated research effort would be extremely difficult, some discussants, assuming the job was to be undertaken, suggested widening the study's scope to include not just water supply and quality issues (which had been the focus of most previous discussion at the conference), but also ozone depletion, acid rain, and hazardous waste disposal issues. One participant suggested, for example, that increasing reduction in the air quality in the eastern United States might generate pressures to build additional power plants in the southwestern states, which eventually would lead to severely degraded air and other changes in the Rio Grande area no less serious in their consequences than climate change.

BENEFITS OF REGIONAL LABORATORY/ CONSORTIUM APPROACH

Most of the workshop participants endorsed the concept of making the Rio Grande Basin a regional climate study center and the need, were the concept to be realized, to develop a basin-wide research consortium. Moreover, many agreed that, even without the specter of climate change as a goad, it would be "good business anyway" to consolidate and interpret current climate-related data with historical and paleo evidence, quantify existing trends in the basin, and initiate cooperative exchanges between academic and government agency researchers and between researchers and decision makers. In short, there was consensus that the effort to develop a "Status of the Basin" inventory and, possibly, a comprehensive spatio-temporal model of the basin would be repaid.

Other remarks supportive of the basin laboratory/consortium approach included the following:

- "This project could be a prototype for regional analysis. It could aid in validating and getting better resolution of global climate model data."
- "There is a need for an internal [to the region] peer-review group to assess the scientific merits of proposals before they are submitted to federal agencies."
- "[Research findings] could provide an objective basis for decision making and could help in developing a responsive decision-making process."
- "[Perhaps, through this effort,] it would be possible to minimize the adverse impacts and maximize the benefits of climate change within the basin."
- "The best thing that might come out of this is that it would bring together people and institutions that are not currently sharing information and other resources. It could facilitate interdisciplinary and interagency communication. At present, no one is 'putting it all together'."
- "The consortium could develop a clearinghouse that coordinates and categorizes existing information and makes it available in different forms for different groups. This would be helpful in informing the public about issues and about resource-sustainable practices."

IMPEDIMENTS TO REGIONAL LABORATORY/CONSORTIUM APPROACH

While the response of the workshop participants to the laboratory and consortium proposals was generally quite positive, a number of people expressed skepticism about the prospects for such endeavors. The impediments most frequently mentioned were as follows:

- Lack of short-term payoffs—Will a comprehensive basin model be immediately useful if the rate of change is slow? States have short-term agendas, due to changes in administrations every four years, and are unlikely to support investigation of a long-term problem.
- States now fight over water. Researchers and agencies fight over "turf." However are they going to cooperate?
- Climate change research cannot fly by itself; it will have to "piggyback" on other programs.
- Time and money—Who would pay? Two possibilities: develop a loose, informal consortium or a more organized, funded consortium.
- Current lack of a goal common to all who might be involved.

INFORMATION AND RESEARCH NEEDS

IDENTIFYING INFORMATION NEEDS--WORKSHOP II RESULTS

Michele Minnis, Natural Resources Center, University of New Mexico

The second workshop focused on the potential consequences of climate change in the Rio Grande Basin and on the kinds of information that would be helpful in preparing for, responding to, and, possibly, avoiding these consequences. Discussants were asked to consider, particularly, how climate change might affect the work of their own organizations. Here, as in Workshop I, the participants were not presented with a specific climate-change scenario but, instead, were encouraged to imagine the implications of the various scenarios that came to mind.

SUMMARY OF DISCUSSION

Discussion in Workshop II covered a broad range of topics but tended to center on water-related issues in the New Mexico portion of the Rio Grande Basin. In exploring water issues, the participants appeared to be guided by these questions: Assuming certainty of change in the water resource supply in the basin and tremendous uncertainty about the nature, magnitude, and timing of the change, how do we proceed? How do we make decisions about research and policy priorities? In view of the discussion in all five groups, the short answer to that question was: Take stock of where we are now. Examine current hydrologic reality and compare it with past hydrologic reality to develop a comprehensive working model of the basin.

Although the descriptions of a basin model differed from group to group, there seemed to be consensus that such a model would specify the water-balance characteristics of the basin over time, taking account of total yearly precipitation and seasonal distribution of precipitation, runoff/recharge relationships, and water loss through evapotranspiration. Moreover, the model would include the number, kinds, and distribution of water users and would track the implications of user demands on the resource in what one person termed "a cascading impacts analysis," i.e., an analysis that systematically proceeded from the hydrologic sphere into the spheres of plant, wildlife, and human social and economic behavior. The object of this approach would be to produce a framework of knowledge that could serve as a reference point for various climate-change scenario and policy studies and, in turn, one or a series of "state-of-the-basin" reports.

In addition to collectively sketching a general research scheme, the discussants considered related subjects: the need to expand existing data collection programs, facilitate interagency exchange of data, design data-management systems, involve policy makers in the project, and develop opportunities for public education.

CONSEQUENCES OF CLIMATE CHANGE

Temperature/Precipitation

Discussion of the potential impacts of climate change tended to emphasize scenarios involving directional shifts or increased variability in seasonal temperatures and in the distribution (both temporal and spatial) of annual precipitation in the basin. Several participants mentioned that changes in the seasonal distribution of precipitation might be problematic even if annual yield remained the same. To illustrate, one person noted that if most of the region's precipitation came in the form of torrential rains, as in one memorable Albuquerque storm two summers ago (eight inches of rain in an eight-hour period), much of it would be "unusable." Surface runoff would exceed recharge, and existing levies, which were designed for 100-year frequency floods based on different weather patterns, might prove inadequate.

Effects of temperature changes were envisioned as well. "If it gets colder, that will affect how economically we can grow our produce," said one person. "Temperature change would be followed by changes in wind patterns and, perhaps, changes in air quality," said another.

In some groups, the participants imagined the consequences of a net reduction in the basin's annual precipitation, or, in more colloquial terms, a "drying scenario:" greater fire hazard, decreased soil moisture and productivity, loss of plant cover and slope stability, increased erosion and dust lofting, increased sediment load in streams and corresponding decreased capacities in reservoirs. The following were noted as potential second-order impacts of prolonged drought in the basin: social pressure to eliminate irrigation channels ("put the water in pipes to conserve the supply"), increased mining of ground water ("from aquifers that are already overappropriated"), and an acceleration in the current trend to transfer water rights from agricultural to municipal uses.

A federal agency employee mentioned that if current precipitation patterns changed substantially in *either* a "wetting" or "drying" direction, the change would render current soil moisture/climate boundary maps obsolete and necessitate changes in his organization's land management practices. Recalling the dust bowl period, a colleague added "Most of us do not fully appreciate what a significant redistribution of vegetation occurred in the Great Plains during that time."

A workshop participant from a rural farming area observed that a lengthening of wet/dry cycles could be devastating for small-scale farming and livestock operations that support single families: "If some people lose that income, they'll end up migrating to the cities. If they're not well educated, they'll have trouble finding employment there and end up being a financial burden on someone."

In most discussion groups, there was some acknowledgement that sustained change or greater variability in current climate patterns would heighten tensions among social groups who represent competing values in natural resources. For example, Bureau of Land Management and Forest Service personnel mentioned that present controversies over grazing allotments on federal lands surely would intensify if the wildlife ranges on these lands were to contract due to drought. Pursuing this line of thinking, a number of people commented on the possible economic ramifications of substituting values in wildlife preservation for values in commercial timber and livestock production.

The possible results of climate-induced changes in land use were noted in several groups. In this connection, a City of Albuquerque employee remarked "We know that during the winter, 5-7% of the Rio Grande flow disappears between the north and south lines of Bernalillo County. We think [this water] goes into the ground as recharge. What I'm concerned about is that land-use changes upstream might degrade the quality of the water in our recharge."

Some participants imagined large-scale population shifts in response to climate-zone shifts. One person suggested the possibility of massive immigration to the Rio Grande Basin, were it to become cooler and wetter while other areas of the country became hotter and drier. According to some climate-change projections, it was noted, Dallas might have temperatures of over 100 degrees for as many as six months out of the year, while presently its highest temperatures—over 80 degrees—are confined to three and a half months of the year.

Energy Production and Demand

Anticipating fuel-consumption taxes and regulations designed to curb atmospheric warming, many discussants envisioned the effects of such policies on heating, cooling, and transportation costs in the Rio Grande Basin: "What will happen to coal-fired energy plants in the Four Corners area if they have to cut back in the power they can generate? What will substitute? Nuclear energy? Will New Mexico's uranium industry be revived? Will large areas of New Mexico be used for solar collectors?"

Others noted that taxing the use of carbon-dioxide-producing fuels would seriously affect industrial development and outdoor recreation in the basin. "This is a major concern for planners," one person remarked, "because a great deal of the cost involved in both the manufacturing and recreation industries is associated with transportation."

Comments in several groups highlighted the uncertainty in projecting future energy uses and demands in countries that are not now heavily industrialized. "The big question mark is the Third World," said one discussant, "So the fact that a large part of the basin is in Mexican territory would be critical in whatever work the consortium undertook. Will the Mexicans seek to raise their standard of living by the same route followed by the G-7 nations, or will they look to alternative energy technologies—photovoltaics, for example?"

GENERAL RESEARCH IDEAS

Need for Comprehensive Approach

Consideration of the possible consequences of climate change laid the ground for a discussion of specific research topics as well as schematics for a program of broad-band, ongoing research. One idea that emerged in every group's discussion was the need for an integrating mechanism—an organizing idea, a long-term goal, a model—that could facilitate the understanding of multiple interactions and feedback loops within the basin and in a manner that would be valuable to the scientific community and useful to policy makers at various levels in the public sector.

Awareness of the need for a comprehensive goal or research plan was shown in the following remarks, which were culled from discussions in different workshop groups:

- "We need to formulate a big research question that has a lot of individual research projects under it. But I don't think we've formulated that question yet. Maybe it's a scenario—'How would a 10% increase in temperature affect the Rio Grande Basin?'"

- "When you're talking about something as large as this, with as many people and as diverse interests as we're talking about, you need a framework that can support small groups of people with specific research objectives. That might be as far as we want to go in terms of what this consortium might do. It could provide a way of getting all these people together."

- "If we're trying to look at feedbacks, we need to develop a global picture of the basin, not so much to see it statically in a freeze frame but to see how one thing interacts with another—how short-term changes in the water supply, for example, affect other natural resources, the economy, air pollution, land use, etc."

- "We've got to deal with the scale problems—time and area. For example, we've got to structure research so that it addresses both long- and short-term issues."

- "If we do this right, we ought to be coming up with management strategies for social and economic changes that are likely to occur. The value of collecting [climate-related] information is so you have reference points for management decisions. The process [of coordinating data and policies] is what's exportable."

- You're not going to get a whole picture of what's going on in the basin unless you look at both the socio-economic situation—amount of people, types of industry, cultural differences, quality of life—and the natural resources situation—the health of the natural systems. Right now, there's nothing like this being done at a regional level. There's nothing that integrates data in an interstate/international context, in that layer between micro scale and global scale."

State-of-the-Basin Report

In every group, the discussants eventually arrived at the objective of producing something on the order of a state-of-the-basin report. The statements below are illustrative:

- "If this is a laboratory, then out of it must come results that people can use. Maybe it's a five-year report. But you need something that provides continuity to the whole program."

- What about a state-of-the-basin report? The idea came out of discussion about hydrology, but the report could include the state of the atmosphere and other things as well. It could be about natural resources, people, business, and laws. . . . It's appropriate to consider the social and economic state of the basin as well the natural resources, because they're interrelated. The socio-economic conditions have a marked effect on the natural resources."

- What we're talking about is somewhat like the state of the state report, but differently structured. There's a lot to be said for looking at a basin as a management tool for a lot of elements of society. That's what we're really getting at. The people who live in the basin probably have a lot more in common than they realize and, maybe, more in common with each other than with people living in the basins on either side."

SPECIFIC IDEAS FOR RESEARCH

Interpret Existing Data

There was wide agreement on the importance of interpreting existing data to estabish a baseline for more focused research. Generally, this baseline-development task might include: comparison of paleo, historic, and current hydrologic records;

documentation of traditions and values represented by distinct cultural groups within the basin; and longitudinal studies of ecological patterns (vegetation and wildlife), population trends, and the productivity of various economic sectors--agriculture (cattle and crop), manufacturing, tourism, and service.

The following specific research projects were proposed:

- examine the effects of the last glaciation;

- identify the causes of arroyo cutting in the late 19th century ("a very important change in geomorphology and land use that we do not thoroughly understand");

- investigate changes in microclimates due to overstocking/overgrazing (e.g., in the Penasco area—"What used to soak in now runs off.");

- combine historic rainfall, temperature, water and land-use records--concentrate on virgin flow areas as well as urban areas and note the effects of significant events (e.g., coming of cattle) and settlement patterns;

- attempt to locate "boundaries" in the record, places where the record departs from normal cycles and enters statistically abnormal areas ("We need some measuring stick so we can tell when we're entering a period of abnormality.").

Long-Term Monitoring Programs

Several participants underscored the need to initiate long-term, highly instrumented monitoring at the interfaces of biomes and in widely dispersed sub-basins. Others stressed the need to establish and inventory small, core research "areas" (geographic or socio-economic) in the basin. In discussing long-term monitoring projects, especially, but in other contexts as well, some participants noted the potential usefulness of remote satellite sensing and geographic information systems (GIS) technologies.

Experimental Programs

In addition to generating ideas for research focused on the needs of public agencies, the workshop discussions included a number of suggestions for "academic research," particularly research in which existing systems might be experimentally modified to observe results. The following quotations provide examples:

- "For starters, I think that what is really needed for the Rio Grande Basin is a comprehensive hydrologic model. Someone at NMSU is working on one for the state's fisheries, from the perspective of fish management and riparian management. The Bureau of Reclamation and the Corps of Engineers have some input-output models for their reservoirs. And the Geologic Survey, of course, has ground-water models for several of the basins. But, to my knowledge, no one is putting all this together."

- "One way of using the variety of people-caused changes to help understand possible climate-caused changes is to look at people-caused effects that we know about that may mimic the kinds of changes global warming might cause in the basin, to try to draw some conclusions about what we might need to respond to in terms of global warming. For example, the adjustment of the agricultural sector to the financial catastrophe of the early 1980s may tell us a lot about how farmers might adjust to regional wetting or drying trends."

ANTICIPATING INSTITUTIONAL RESPONSES

Every discussion group grappled with the subject of possible institutional responses to climate change. In most instances, consideration of this subject prompted questions for investigation rather than proposals for specific research projects. The following quotations indicate the range of concerns expressed:

- "What are the tradeoffs state and local governments will have to face vis-a-vis the priorities of various groups of constituents?

- "Why are policy decisions made the way they're made? We need a better understanding of the decision-making process."

- "Is there some way we can deal with the pollution we create locally to somehow compensate for, say, ozone depletion?

-"How can we institutionalize incentives for conservation and recycling, for spending less energy to produce new products?"

- "We need to identify impediments to conservation in the existing water rights permitting process. There are tremendous opportunities for conservation in domestic use as well, but we've got to have a water-rate structure that supports conservation."

- "Albuquerque's contract for San Juan/Chama water expires in 2025-2030. What then?"

- "Can we isolate the basin's contribution to global climate change and begin to mitigate possible adverse affects?"

- "How can we significantly reduce the total energy demand? How can we monitor and express that demand? Is there some way to plot per capita contributions to the greenhouse gases—what each person is putting into the atmosphere—along with per capita water consumption--what each person is drawing from the pool of water resources?"

DATA COLLECTION/USE

Across the five discussion groups, there appeared to be universal agreement that a basin-wide, long-term climate study program would need to make optimum use of data compiled in the past as well as data currently being compiled as a matter of routine. At the same time, there seemed to be a consensus among the participants that such a program could not succeed without 1) new data collection projects focused directly on climate change issues; 2) an increased willingness, at both the institutional level and the level of the individual researcher, to share data with others involved in the program; and 3) a well-conceived and well-maintained electronic data-management system.

Current Data Base

A number of discussants mentioned that data sets stored in and regularly updated by federal, state, and municipal agencies in the Rio Grande Basin contain information that would be essential to a climate study program centered in this region. As several people noted, however, these agency data usually are collected for specific administrative and regulatory purposes and thus, in many cases, are not summarized in formats appropriate to the needs of climate change investigators. Moreover, according to some participants, data that *would* be appropriate to such needs are not now being collected by anyone. In this connection, a USGS representative pointed out that, through his agency's extensive stream-gaging network in New Mexico, it is possible to monitor rainfall/runoff relationships in many but not all parts of the state. "It would be nice to have the option of putting gages in places where we could see more clearly what's happening in the natural system," he said, "but, at the moment, we don't have contracts or sources of funds that allow us to do that. For example, we have very few gaging stations in the drier, more southerly latitudes of the state. If the climate were to become drier and we needed background data from the drainage basins in the Gila, we'd have to play a big game of catch up."

Another participant mentioned the importance of continuing to monitor the older gaging stations—those 50 or more years in service—but said it may be equally important to reactivate abandoned gaging stations and establish new ones, including air quality gaging stations, in places that make sense in terms of climate change study but are considered irrelevant in terms of the missions of the agencies that operate the stations.

In one workshop group, it was noted that, although good historical water records are available in many locations, these records may not been carefully studied and correlated with other changes that have occurred in these locations (e.g., urbanization) during the data collection period.

Data Sharing

Many workshop participants indicated that the budget cuts recently experienced by many public institutions provide incentives for interagency cooperation and data sharing, but one participant noted an opposite trend: "My organization has come to view its data not so much as a public resource but as something to be sold to keep the [data collection] operations going. There's a big push for complete cost recovery through user fees. The idea of sharing data for the good of humanity or even to improve resource management in the region might not sit well with city councilors or administrators who are preoccupied with the bottom line."

In discussing the possibility of an electronic clearinghouse for data, some participants expressed concern about quality control—e.g., "If we put data into an open system, who's to say the data are accurate and representative?" Workshop participants from federal agencies, many of which have addressed the problems of organizing large data bases and making them accessible to the public, were asked if they could offer any rules of thumb. A USGS employee responded by stating, with respect to his agency's current study on evapotranspiration rates, that the study's conclusions will not be released until they have been subject to peer review, but that the constituent raw data are already available to people interested in doing their own calculations. Other participants, perhaps partly in jest, anticipated unpleasant side effects of consolidating and making public data that at present are more or less buried: "Computerizing the State Engineer's records might raise pressure to speed up the water rights adjudication process and, thereby, heighten social and political conflicts among water-rights claimants."

Data Management

Assuming institutional policies or practices that impede interagency data exchange could be overcome, several discussants cautioned that there still would be a great number of logistical problems to surmount in creating a basin-wide data system. The possibility of having such a system was attractive to many. One participant said, "If someone handed me one thing that would make my job easier, it would be a centralized water data base."

The director of the Sevilleta Long Term Ecological Research (LTER) Project mentioned that the 18 sites in the National Science Foundation-sponsored LTER Program have developed a data-management network that could be a helpful model were the Rio Grande Basin consortium to be established and undertake the creation of a centralized data base. He noted that each of the sites has identified the kinds of data it has available, the format the data are in, and the procedures for accessing the data over the LTER computer network.

The director also reported that different kinds of proprietorship are recognized in the LTER system. Some data sets are considered fundamental to all LTER programs, hence the property of the whole network. Where individual investigators have obtained the funding to collect certain data, however, these investigators are accorded proprietary rights to them. In a final comment on this subject, the director said, "If the consortium made improving data management and data-sharing capabilities a priority, that certainly would go a long way in recommending [its proposals]."

INSTITUTIONAL SUPPORT

With regard to the proposed development of a basin-wide consortium, the workshop participants appeared to be unanimous in their agreement on one proviso—the need for firm, long-term institutional support to guarantee continuity of the effort. Discussion of this issue ranged over several topics, most of which are touched on in the quotations below:

- "We elect officials every two or four years. While they're in office they learn to appreciate some of the relationships we've been talking about. But they leave office and, usually, their replacements have to start the learning curve from point one. What are effective measures for quickly educating newly elected decision makers on water law, water uses, and water conservation measures? What mechanisms might be set up in city, state and federal government to provide continuity from one administration to another?

- "We need to involve decision makers and planners in the research design process. If they help plan the research, they'll value the results and know how to use them."

- "The importance of continuity in this project cannot be emphasized enough. Institutions have as short an attention span as the public. Without institutional commitment—without a dedication of personnel and funds—the consortium idea won't work."

- "We need to convince administrators that if funds are tight this year, that's no reason to shut down a gaging station that's been operating for 50 years. That convincing will be easier if the data from that station are needed in a coordinated regional effort."

- "We need to make provisions for meaningful interim data reports. Research products need to show short-term, intermediate-term, and long-term possibilities—otherwise decision makers will not find them useful and will abandon the effort."

- "One of the things this consortium could do is provide good feedback about the tradeoffs implicit in data produced by research in the basin."

PUBLIC INFORMATION/EDUCATION

Many workshop participants, imagining the creation of a Rio Grande Basin consortium, expressed a need to develop information exchange not only among university-based researchers, public agency personnel, and political leaders but also between these groups and the public at large. One person noted potential hazards in trying to convey accurate information, in lay terms, about issues as complex and indefinite as climate change: "How do we avoid the Chicken Little phenomenon--scaring the hell out of people as we did with radon and asbestos? After five years of red alert people said, 'Something's wrong here, the sky hasn't fallen.' We've got to communicate our uncertainty up front, make clear what we know for sure and what we're inferring, what we're unsure about."

Other comments indicated possible subjects for public education as well as the communication difficulties involved:

- "How do we get all the costs of resource use taught to the users, so the people who are using water are paying all the costs—the conservation costs, the costs of piping, the external pollution costs? What kind of tax structure do you make? What kinds of incentives do you have? How do we internalize the costs of water use—and of air pollution?"

- "Perhaps changes in public perceptions and values can come about fairly quickly in the US, but we cannot expect other countries to follow suit. The Brazilians say, "When you quit cutting timber in the Pacific Northwest maybe we'll talk to you about not cutting the tropical rain forests."

- "The various social groups in the basin are like so many tribes. The ranchers are a tribe. The farmers are a tribe. The urban dwellers are a tribe. They've all got priorities and belief systems pertaining to water use and most of them assume they can continue indefinitely to use water the way they have been using it. If the water resource is going to change, particularly if it's going to decline in quantity and quality, these priorities will also have to change. Everybody will have to think more in terms of protecting and conserving the resource and in terms of sustainable uses."

- "We've got to be able to explain to people that population and economic growth is fine, so long as you can sustain it within the parameters you have. In many areas of the southwest our parameters are so tight we can't sustain the kind of population growth and water-use practices that other parts of the country can manage. We have to understand what our limits are and try to adapt ourselves to those natural limitations rather than try to make nature fit our priorities."

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DEFINING RESEARCH TOPICS--WORKSHOP III RESULTS

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INTRODUCTION

Following Workshops I and II, facilitators and recorders met with Paul Risser, vice president for research at the University of New Mexico, who led a lunch-hour work session to identify important research themes coming out of the morning workshops. These themes were reported after lunch to all workshop participants. Whereas participants were assigned to the morning sessions so that there would be an array of disciplines represented in each workshop, participants chose to attend the afternoon workshop in which they had the most interest.

The charge of the afternoon sessions was to develop fundable research projects which could be pursued by a coalition of agencies and institutions within the Rio Grande Basin having the most interest in a particular project. Research topics were the following: 1) the design and management of a shared data base, 2) the use of prehistorical and historical data, 3) the development of models and scenarios of climate change and subsequent social and economic changes within the Rio Grande Basin, 4) a "flagship" experiment using the entire basin as the research site, 5) maximizing the benefits and minimizing the costs of climate change; and 6) decision-making in the Rio Grande Basin.

SUMMARY OF DISCUSSIONS

The most common topic of discussion in all six of the afternoon workshops was one identified in the morning session as an impediment to the consortium approach—the need for a product that would be immediately useful to the users and managers of the Rio Grande's water. The basic notion was that a Rio Grande consortium should be dedicated to long-term monitoring, research, and management decisions about the slowly developing phenomenon of global climate change and its impacts on water availability. In order to attract funding for this effort, however, all agreed that it would be imperative for the consortium to produce "deliverables" that are immediately useful, but that are also initial steps in an ongoing coordinated research and management effort.

Another theme discussed in all workshops was that of funding. Many believed the consortium should try to tap national funding sources, such as the National Science Foundation, or private funding sources, such as the Ford Foundation, to produce the short-term deliverables which would establish the consortium as an entity. Direct funding from outside the basin could serve as seed money for initial consortium activities. Once the consortium was established, those controlling public funds at local and regional levels as well as national and international levels would see that funding consortium projects was an efficient way of promoting understanding and solving global climate change problems.

In all workshops it was agreed that if the consortium could develop a multidisciplinary approach to problem solving and a flexible model for decision making, these processes would be exportable to any region of the world where a resource is a magnet for a multitude of users.

An impediment to the regional approach identified in the morning sessions did not arise as a serious problem in the afternoon sessions. This is the problem of "turf" wars between countries, as well as among states, agencies, and individual researchers. To the contrary, the possible ultimate product of the consortium, as seen by participants of the decision-making workshop, was a political restructuring of the entire Rio Grande Basin, so that political divisions paralleled physical divisions within the basin.

DATA MANAGEMENT

Good database management can contribute to the creative use of extant, disparate data (prehistorical, historical, multidisciplinary), permit modeling of future change in all systems of the Rio Grande Basin (biological, social, economic) and permit modeling of appropriate response strategies both in the short- and long-term. If data are managed cooperatively: 1) duplication of effort is minimized, 2) money is more effectively used, 3) the Rio Grande Basin has an evolving repository of information with which to update models of changes and response strategies, and 4) data are more available than is now the case, and therefore, are more useful.

The central project proposed by this group was to design a data base that could be used by researchers and managers from many disciplines and at many levels. Clearly, any data base must have a GIS (Geographic Information System) component. The GIS is useful in producing "static" maps of data at a given time and place, but is also useful in producing "dynamic" maps in a series to model changes in time and space. Other projects were suggested as subsets of data-base design.

The data base should accurately translate information gathered by one discipline to forms usable in a different discipline. An example is the translation of rainfall pattern data collected by climatologists into appropriate sustainable agricultural strategies for rural water users' associations. An important goal is to make information translation easy for users.

One of the first steps to development of an extensive, multilayered data base might be experimentation to determine elements that need to be introduced into the data base to make it usable by disparate groups. Important issues are standardized data collection and input and standardized format for data output. Key issues are: 1) how will present and future baseline data be collected? 2) how will extant data be put into a standard format? 3) what is the most economical way to collect baseline data (from remote sensing to data collection by hand)? 4) how will quality assurance of the data be maintained?

An important approach is distilling variables from many disciplines to produce across-discipline key indicators of climate change. These key indicators would detect change early, easily, and cheaply.

The data contained within the data base should be used to project future data needs. One of the first products of the data base could be a "state-of-the-data" report, which would consist of information about what data is available and from whom it can be obtained. This report would be useful in identifying gaps and overlaps in the data and would lead to a data "wish list". The beginning of this task is found in Appendix D.

Another important step toward creating a shared data base would be the establishment of an electronic connection among those creating data and those wanting to use them. Data could be put into a relational data base hooked to a computer network. The connection could also be used as an electronic bulletin board. A rapid exchange of ideas between those generating data and those needing them to solve problems would influence the kind of data and the way in which they were collected, as well as create new uses for the data. The data base would serve as a source of data on which a model could be tested.

A potential funding source is the National Science Foundation Special Projects Program: Data Base Activities in Biological, Behavioral, and Social Sciences.

PREHISTORIC AND HISTORIC CONDITIONS

Some felt that it was not appropriate to fund a consortium to generate prehistoric records (paleoclimate, paleohydrology, paleoenvironment data) because there is already abundant information. These data should be organized in some uniform way so that they are accessible and user friendly. Sources of prehistoric and historic data are diverse: tree rings, pack-rat middens, layers of ice deposited in El Malpais caves, paleochannels in the floodplain of the Rio Puerco, diaries of conquerors, travelers, trappers, and miners, well-drilling records, livestock records, irrigation records, and photographs. Since the climate change of which we are speaking is induced by human activity, it was thought by some that it is useless to try to predict the future based on past climate change produced by natural phenomena. At minimum, people should explore historical rather than prehistorical data, because the former contains information about human activity in an area which may have contributed to change (i.e., logging forests has increased albedo, which influences the way a system receives energy). This reluctance to use prehistorical data was countered by the view that such records can locate climate change and produce information about processes. In this view, the two most important research issues pertaining to past data collections are: 1) whether these data can be used to predict the future, and 2) whether they help explain processes (the responses of systems to changes in components). Can we create a planning tool from information on past climate change in the Rio Grande Basin?

MODELING/SCENARIOS OF GLOBAL CLIMATE CHANGE

Participants in this workshop recommended projects that would answer the following questions:

1. What changes in water availability are likely?
2. What are the impacts of global climate change on ecosystems?

3. What are the impacts of global climate change on social and economic systems?
4. What is the impact of social and economic changes on water availability, water use, and ecosystems?

Most participants in this workshop were concerned with hydrologic modeling, some were interested in social and ecological modeling, and a few were involved in economic modeling.

A "state-of-the-models" report was suggested as a first product. Since a fair amount of natural resource modeling has been done in the Rio Grande Basin, it is important to know where these models are and how to put them to use. The next step would be to link physical, hydrologic and biological models with social and economic models to develop scenarios of change in natural resources and the impacts on society and the economy. Historical and prehistorical data could help verify models of physical change within the basin.

The difference between modeling a natural resource using a biological model versus using an economic model was highlighted in a discussion about water quantity and quality. Biologists maintained that modeling water availability could only be focused on water quantity, not quality. Economists maintained that both water quality and quantity have specific economic values and must be modeled together. It was observed that sociological or economic models might handle water quality issues better than physics or biological models.

A predictive and analytic "water-centered" model was recommended. The unit of time for the model should be a water year since most laws have to do with one year. The year could be subdivided into seasons. Additionally a water balance model is required. It is important to start with current conditions. Once the interaction among current conditions is understood, then components of the model could be changed to produce scenarios of change. Although energy is an important component of biological, economic, and social systems, it should be treated as a boundary condition rather than a central theme. Water is the endogenous part of the model, and energy is an example of an exogenous part of the model. Since there is a mechanism for determining water delivery in the basin, the most useful modeling effort is the prediction of how much water is entering the system. The Rio Grande Compact determines the delivery of water. An important component to model is precipitation changes. Modeling different scenarios for getting the water on the ground should be combined with extant models of the behavior of water from there. Two different models should be treated separately, before they are linked into the larger model: models of rainfed systems—forests, rangelands—and models of irrigated systems—acequias, agricultural models. There is a potential third model dealing with the behavior of riparian areas and wetlands. Both these areas are rainfed and depend in many places on irrigation. Models of rainfed systems deal with direct change in biological systems, models of irrigated systems deal with moving water around. The benefits from being able to model future changes within the basin is that sustainable management strategies can be developed.

An ultimate product is a unified model that incorporates all systems. Besides developing climate change scenarios, this model might be able to pinpoint "hot spots" in the legal and political systems, key decision points, and constraints. The impacts of change on margins could also be modeled—margins of society, of the economy, of cultures, as well as ecosystem margins (ecotones).

FLAGSHIP EXPERIMENT

A "flagship" experiment is a very large experiment that would stimulate a "fleet" of smaller experiments and studies in the Rio Grande Basin. The problem of long-term work on long-term changes in the basin was specifically addressed in this workshop. The flagship experiment suggested is a "state-of-the-basin" report or a Rio Grande Basin atlas. This atlas would contain state of the art information from researchers, managers, and users of the basin's natural resources as well as information concerning human populations—migration and emigration patterns, and so forth. The atlas would be updated periodically. The first atlas would be published in two years and would essentially be a comprehensive catalogue of all the parts of the various systems within the basin. The next atlas would appear five years later and would update the first, as well as predict future changes in the basin based on the baseline information of the first atlas and the change in baseline reported in the second. A third atlas would update the second and predict even more changes within the basin. A preliminary list of contents for the first atlas is: 1) land-use changes over time using satellite imagery; 2) water- use change with associated land use; 3) identification of water users and where water is used; 4) water distribution in the basin; 5) water availability; 6) climatic factors influencing water distribution; 7) political issues connected with land-use and water-use changes; 8) economic issues connected with change; 9) social issues connected with change; 10) the process of choosing what was included in the atlas; 11) the technical way in which one goes about analyzing data being used to prepare change scenarios; 12) the development of a series of important parameters to compare the Rio Grande Basin with a number of other basins; 14) a way of linking all entities in the basin to one another, information exchange and decision-making throughout the basin; 15) discussion of successes and failures in constructing the report; and 16) issues, resolved and unresolved, in developing a way to look at the entire basin.

The atlas has its most important value in that it would be a first step in developing basin-wide research and would be immediately useful to researchers, managers, and water users in the basin.

Several participants suggested that atlas users could define this product if it were the theme of a basin-wide workshop.

Another fundable project suggested by participants of this workshop is a comparison of the Rio Bravo in Mexico with the Pecos River in New Mexico. This would be a study of climate variability and climate-induced changes in the short-term (historical and current) and, in the long-term, a comparison of a tributary of the Rio Grande in a third-world country with a tributary in a developed country. Both rivers are in similar climatic regions, but the ways in which their basins are managed and used are very different. All the environmental, ecological, population, and social issues are so different that their comparison would be very powerful. What occurs in these basins profoundly affects what occurs downstream of them as well.

MINIMIZING COST/MAXIMIZING BENEFITS

This workshop group developed a basin-wide project that could also be considered a "flagship" experiment, and the realization of this project would create a framework for modeling the entire basin. The idea is to produce a "wiring diagram" of the entire Rio Grande Basin, stressing interactions among elements. The wiring diagram would provide a means to examine relationships, interactions, and feedbacks among elements of the Rio Grande Basin, in order to model future alternatives for management of the basin's resources.

The wiring diagram would provide the foundation for a dynamic model, for planning, and systematic understanding of how the basin works. It would identify gaps, show entry points for data, and identify data needs. It also would identify value needs and could be qualitatively predictive and educational. Such a diagram could be a proto-type of organization and understanding for other basins.

DECISION MAKING

The workshop group that focused on decision making wanted to develop a research proposal which would define who decision makers are, how they make their decisions, and the kinds of information sources on which they rely. The project would also identify information needs of decision makers. A second part of the project would be to see if decision makers would make different decisions if their information were different. The results of these two products would be immediately valuable and would lead to an ultimate long-term product: the development of a trans-basin authority based on the basin's physical boundaries. This trans-basin authority would cut across different governmental units at all scales and would consider the interactions of all the basin's systems in the face of global, or any other, climate change.

CONCLUSIONS

It is clear that there are several products which would be of immediate value in understanding, managing and using all of the systems of the Rio Grande Basin. It is also clear that these short-term projects could serve as stepping stones to longer-term experiments and projects to develop a truly integrated understanding of the Rio Grande Basin. The pieces of the puzzle have been defined: a basin-wide conference, a state-of-the-basin report, the development of a basin wiring diagram (depending on a sophisticated, multi-disciplinary data base), modeling scenarios of change using historical and prehistorical data to validate models, proactive planning to minimize negative impacts and maximize positive results of adjustments to climate change, and finally, the development of a trans-basin authority.

If these efforts are to be realized, there needs to be an umbrella organization for the numerous proposed projects and products. Two types were discussed: 1) a loose affiliation of entities organized around each topic, or 2) a small, centralized clearinghouse and action center which provided information and coordinated the efforts of entities organized around individual projects.

ORGANIZATIONAL
AND
POLITICAL PERSPECTIVES

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THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)--COMPOSITION, PROCESS AND ACTIVITIES

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INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) is an instrument of the United Nations (UN) acting through the governing bodies of the UN Environmental Programme (UNEP) and the World Meteorological Organization (WMO).

The IPCC's goal is to develop an internationally accepted strategy for addressing the various major problems which could result from human-induced climate change. Toward that end, there are now focused the efforts of 60 participatory nations including several hundred scientists and policy makers and many non-governmental and international organizations. Although there is no way at this point to determine if these efforts will result in a consensus, the scope of the undertaking establishes the IPCC as the major forum for attempting to reach one. Also, it reflects a broad recognition of the need for an orderly, international process to ensure that research, monitoring and impact assessments proceed in a rational manner and that intergovernmental agreement on the results of these assessments exists before legal or regulatory activities are instituted.

The IPCC was established in November 1988 through resolutions adopted by the governing bodies of UNEP and WMO and endorsed by the UN General Assembly in December 1988. These resolutions were based on recommendations arising from the Tenth World Meteorological Congress which was held in May 1987. At the first meeting of the IPCC, in November 1988, the panel agreed that its main tasks were to:

- assess the scientific information related to the various components of the climate-change issue, such as increases of major greenhouse gases in the earth's atmosphere and resultant modification of the earth's radiation balance;
- evaluate the environmental and socio-economic consequences of climate-change; and
- formulate realistic response strategies for the management of the climate-change issue.

To accomplish its tasks, the panel set up three working groups: I - Science, II - Impacts, and III - Response Strategies. These working groups were asked to build on past international and national assessments and draw fully on the expertise of existing international scientific bodies in undertaking this effort.

WORKING GROUP I - SCIENCE

Working Group I, chaired by the UK with Brazil and Senegal as the vice-chairs, is reviewing the available scientific assessments of climate warming with special emphasis being placed on:

- recent measurements of greenhouse gases and the new information on their chemistry and tropospheric lifetimes;
- a critical review of available climate data for detecting trends;
- evaluations of existing disagreements in model calculations of regional scale climate (regions are the monsoon region of the Sahel in Central Africa, the Great Plains of North America, the Mediterranean region and Australia. The results of those evaluations will be used in obtaining and interpreting model predictions of regional scale climate change in all other regions of the world);
- transient climate change calculations;
- new evaluations of sea level rise; and
- future requirements for climate research and observing systems for monitoring climate change.

Thirty international scientists are serving as lead authors of the Working Group I assessment report, aided by the participation of over 200 scientists from 30 countries. The report is expected to be particularly valuable to decision makers because:

- it will be an international scientific assessment;
- the scientific scope will be comprehensive;
- both natural and human-induced climate change will be considered;
- the focus on identifying gaps in the knowledge

and quantifying uncertainties will aid risk analysis; and
- it is linked to impacts and policy assessment.

The assessment report will contain an executive summary, prepared by the lead authors/scientists and written for general readership. It will summarize the major knowns and unknowns of the science, with the most policy-relevant scientific conclusions highlighted. The second draft is being peer reviewed and the final document is scheduled for submission to the IPCC this month.

WORKING GROUP II - IMPACTS

Working Group II, chaired by the USSR with Australia and Japan as vice-chairs, is focusing its efforts on the impacts of global climate change. The group has held two plenary meetings and a number of workshops on impacts since the IPCC began its work. A draft report that is now undergoing peer review covers impacts of potential climate change on:

- permafrost,
- ecological processes,
- human settlements,
- water resources,
- natural terrestrial ecosystems,
- world oceans and coastal zones,
- forests, and
- agriculture and land use.

The findings of this working group will be linked to those of both Working Groups I and III. The report prepared by the working group will contain an executive summary in the final IPCC report.

WORKING GROUP III - RESPONSE STRATEGIES

Working Group III, chaired by the US with Canada, China, Malta, the Netherlands, and Zimbabwe as the vice-chairs, was asked to assess response strategies to global climate change. The working group is concentrating on two broad areas of response strategies: limitation and adaptation. To address *limitation* strategies, two subgroups were formed, one to focus on the energy and industry sectors (including transportation) and the other on agriculture and forestry. The first is co-chaired by Japan and China and the second by the Federal Republic of Germany and Zimbabwe. To address *adaptation* strategies, two more subgroups were established. One of these, co-chaired by the Netherlands and New Zealand, is investigating coastal zone management and the other, co-chaired by Canada, France, and India, is examining resource use and management. All four subgroups of the Response Strategies Working Group (RSWG) are progressing in the finalization of their reports, with over 40 workshops and expert meetings held to collect contributions.

Energy/Industry Subgroup

The Energy and Industry Subgroup (EIS) is examining the role of the energy sector in greenhouse gas emissions and possible energy policy and technology responses to climate change. In support of the EIS report, several countries (Australia, Canada, France, the Federal Republic of Germany, Japan, the Netherlands, the United Kingdom and the United States) are preparing national case studies. Each will include a reference scenario and a policy scenario that examines the impact of various policy options in reducing greenhouse emissions. In addition, the United States and Japan are preparing a study that will examine the following to assess the global and regional outlooks: results of these assessments; the results of case studies of various developing countries; the analyses being conducted by the Department of Energy's national laboratories; and the results of global models.

Agriculture/Forestry Subgroup

The Agriculture and Forestry Subgroup (AFOS) held four workshops in late 1989 and early 1990. Workshops on problems of temperate and boreal forests were held in October 1989, in Germany and Finland, respectively, and one organized by the US Forest Services on tropical forests was held in January 1990, in Brazil. A fourth workshop on agricultural problems was held in the United States in December 1989.

Coastal Zone Subgroup

The Costal Zone Management Subgroup

(CZM) is preparing its report on six topic areas:

- extent and timing of sea level rise and associated climate-change effects;
- impact of sea level rise/climate change;
- problem identification;
- adaptive options/costs for coastal areas at risk;
- social, economic, legislative, institutional, and environmental implications of options; and
- funding mechanisms for adaptive options.

It is also preparing an inventory of information on technologies and practices for adapting to sea-level rise and a regional inventory of existing laws and policies concerning management of development in coastal areas.

In support of these studies, two major workshops have been conducted. One, held in Miami, Florida, in December 1989, focused on coastal zone issues in North and South America, Western Africa, Europe, the Baltic States, and the Nordic Countries. The other, held in Perth, Australia, in February 1990, focused on island and tropical countries.

Resource Subgroup

The member countries of the Resource Use and Management Subgroup (RUMS) have been drafting papers that address the management of water resources, salinization, desertification, forestry, agriculture, fisheries, animal husbandry, unmanaged ecosystems, and land use in general. "Theme" papers on biodiversity, food security and water resources have also been prepared by UNEP, FAO and the American Association for the Advancement of Science's Panel on Climate Change and Water Resources, respectively.

A workshop to discuss these papers and solicit additional ideas about the management of these resources took place in November 1989 in Geneva. This workshop had sessions oriented around three major themes: water resources, food security and biodiversity, with a focus on adaptive responses that improve the resiliency of resources toward future shifts in climatic regimes while ensuring socio-economic stability and growth.

US INVOLVEMENT IN THE IPCC

US scientists and policy makers are providing substantial support to the IPCC in virtually every aspect of the work of the science, impacts, and response strategies working groups. Specific contributions in the science working group are in the investigation of climate forcing trends (with Sweden), climate processes (with the FRG and the USSR), model simulations (with Canada, the UK, and the PRC), and model predictions (with the UK and Japan). The primary US contact point for the science working group is the executive secretary of the Committee on Earth Science, an interagency committee undertaking a significant research effort into global change.

With the Impacts Working Group, the United States is investigating the possible impact on agriculture, forestry, water resources (with Algeria) and the oceans and sea-level rise. The primary contact for this group is the National Climate Program Policy Board.

As the chair of the Reponse Strategies Working Group, the United States, through the State Department, plays the primary coordinating role. As with the other working groups, US experts are involved in all aspects of the work of the subgroups. Involvement in the working group is such that, at its meeting in October of 1989, over 30 representatives from some 15 executive branch agencies and offices, as well as Congress, were present.

FUTURE WORK OF THE IPCC

US efforts in the near term and those of the international community are focusing on completing the first assessment report of the IPCC for discussion at the Second World Climate Conference to be held in November of this year. The IPCC is moving quickly to complete this interim report, which should provide a detailed, comprehensive analysis of the state of scientific understanding of climate change and associated uncertainties, the impacts of climate change, and possible policy and technology strategies for responding to such change. It will also provide possible elements for inclusion in a climate convention and outline to the extent possible the primary issues that must be negotiated. The IPCC will also investigate quantitative emission target options to limit or reduce CO_2 emissions. Because work of this panel will provide essential background information for the climate convention, the US has strongly advocated that the energies and resources of the international community be devoted to completing this work.

SECOND WORLD CLIMATE CONFERENCE

The primary focus of the Second World Climate Conference, to be held in Geneva in November, will be to review the activities and achievements of the UN's World Climate Program (WCP) and serve as a forum for public exposure of the first report of the IPCC. The preliminary agenda of the Conference suggests that it will be divided into two phases. The first phase will emphasize the components, achievements and future activities of the WCP and the second phase the components, findings, and future activities of the IPCC. The expected outcome will include a conference statement and a plan for future actions.

The IPCC

The IPCC, during its third plenary session in February of this year, agreed that it should continue its work after the first assessment report of the IPCC is released this fall. Revisions may be made to its terms of reference if appropriate. Each working group has been asked to prepare a workplan for activities to be undertaken after the completion of the first assessment report. These workplans are to be discussed at the fourth plenary session of the IPCC in August. The IPCC may have a role in the negotiations of a climate convention. It may work towards the expansion and refinement of the topics addressed in the interim report and the completion of additional reports. Also, it may evolve into a more permanent organization. This matter will be a topic of further discussion at the IPCC plenary meeting in August.

Climate Convention

Negotiations of a framework climate convention are expected to commence soon after the submission of the IPCC's first assessment report. As part of its consideration of response strategies to climate change, the IPCC has begun to outline possible elements for inclusion in such a convention. Although consensus exists on a number of general issues, there remains significant disagreement on many other issues. An appropriate balance must be struck between developing a convention quickly and obtaining a good instrument with the widest possible acceptance.

There exists a broad consensus that a climate convention should generally follow the format of the Vienna Convention for the Protection of the Ozone Layer. The framework convention would lay down general principles and obligations and provide for a continuing assessment of the scientific aspects of climate change, its impacts, and response strategies. There is also broad agreement that the framework convention should contain provision for protocols to deal with specific obligations and that these protocols be negotiated separate from the convention.

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ENVIRONMENTAL EDUCATION --CHALLENGE FOR THE FUTURE

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Jeff is attending a Border Conference in Juarez so could not be here. But he has real interest in the work being carried out today. Global climate change is an issue he's been involved in over this past year. I want to give a Senate staffer's perspectives about what's going on at the national level, and how that relates to what you are doing.

As most of you know, global climate change has become an issue of international significance. It's interesting that there's quite a bit of debate at our national level. Most of you know of the controversy over whether or not enough science has been conducted. Do we know what the problems are? Do we know enough to recommend solutions? The administration has taken a cautious approach; that may change because of something that happened with the United Nations last week. An international global climate-change group of 130 scientists, put together by the UN and working together over the past couple of months, just came out with a report that makes it clear they take the threat of global warming very seriously and think something needs to be done. Last week Margaret Thatcher announced that she would support major reductions in carbon dioxide (CO_2) sources.

With the debate at the national and international level and around the country, everyone's a little anxious to see where we're going next. I think focusing on a region of the country, how climate change affects that region, and what we need to do to react to that is forward thinking. It will place the Rio Grande basin states well ahead of others seeking research dollars and solutions.

There are a couple of reasons that it's very timely. First, we just had Earth Day. Was it a one-day event or is it something that we'll continue to work on? I believe a lot of ground work was laid for public awareness of what affects their planet; global climate change is clearly the predominant issue there. Secondly, we have the Clean Air Act that the Senate spent seven weeks debating. That's more time than was spent on almost any other bill in the Senate's history. The House last week, in a record one-day consideration, reported on a Clean Air bill that now goes to conference. That bill includes effects of climate change. Finally, and probably most importantly, there is the national energy strategy. We have an Energy Secretary who, unlike his predecessors, has shown a keen interest in the subject matter and an awareness of national energy options. I think he is a credit to the office, but it's a tough topic. He has issues like Rocky Flats and WIPP, but he also is well-grounded in science. I think he provides us the best option for developing a national energy strategy that has some teeth and makes sense. There have been hearings throughout the country over the past two years on what components should be in this national energy strategy. The primary thrust is that energy efficiency and alternative energy sources need to be looked at first. That would go a long way in dealing with global climate change and CO_2.

I'd like to talk a little about what I think is the greatest difficulty we have in dealing with any of these climate-change issues: to get it into layman's terms. Whether it's tropical deforestation, ozone depletion or greenhouse gases, the standard man on the street has a tough time dealing with it. He may grasp that a temperature increase of a couple degrees over a decade can have significant ramification for him, but the reasons why this is taking place or the proposed solutions are not readily understandable. This past year Jeff has focused on educating the public, both officials and citizens, about what problems confront us. It has not helped that there has been a debate over whether or not there is a problem.

We've got to rely on the educational system to do that. Bingaman has laid out a plan which I think you could be very helpful with. Three years ago Jeff decided to put together Annual Student Seminars throughout New Mexico, modeled after Bill Bradley's initiative in New Jersey and David Boren's program in Oklahoma. The idea was to familiarize the best and brightest students in the state with public-policy issues and decision making. January marked the third year of Annual

Student Seminars. They attract students from all over the state. We have them in four different regions and spend all day on three major topics: arms control/ defense matters, education/health-care issues, and energy/the environment. As someone who has participated all three years, I've seen a very significant shift in interest among students. The first year I had to beg students to come into the environmental and energy workshop. This was just not something they were interested in. You couldn't keep them out this year. They're worried (maybe far more than their parents) because they're hearing a lot about it.

It was frustrating because teachers who accompanied these students admitted they were not prepared to teach current environmental issues. A lot of our schools have biology teachers who were not necessarily trained in biology. We're trying, in two different ways, to deal with this knowledge gap. The Annual Student Seminars provide a great deal more student awareness. The problem is that every principal can only send four to six students so we deal with very few students.

In an attempt to deal with the "lack-of-background" problem, which teachers have raised in earnest, we held our first Educators Conference in Las Cruces last month. We put together a small group of teachers who had expressed a real interest in environmental issues (those who had organized for Earth Day) and we let them design a program that they felt would be beneficial. We had a series of speakers; John Hernandez spoke on water issues that morning. We had between 80-100 teachers come on a Saturday morning. They didn't get credit, didn't get paid; there was no reason to show up except an interest in the issue. We thought that was a pretty good turnout for the first time. The second part of that program was workshops which the teachers designed. They divided up into grade levels and exchanged teaching methods. Probably the most important thing they dealt with was how do you get the climate-warming concept across; how do you explain that cutting down trees somehow, besides being unsightly, is not good for the environment? The ingenuity of the teachers was remarkable. Getting them together and exchanging ideas was by far the smartest thing we did. They created their own workbooks, which will be used throughout the state. These cover each grade level with lesson plans, experiments, hands-on demonstrations and ways in which teachers can get the topics across to students.

The kids themselves did special projects for this conference. Gaylord Nelson, the founder of Earth Day, attended as did Jeff. These kids did a great job, K through 3, especially. They're the ones who go home and tell their parents that they don't want to get plastic cartons anymore. We really need to develop that, and I think this teacher's conference was a good way to start.

Because that was so successful we are planning a similar undertaking here in Albuquerque in October. Last year we also held the Clean Air Summit, which drew attention to clean-air issues because Albuquerque was under sanctions. That was successful and we want to have it again, but the focus is on how climate change effects the local area.

We will be restaging the teachers' workshops. Now that we have these materials available we will be giving them to all teachers. We're meeting with the State Board of Education this afternoon along with the Planning Committee to plan for the October event. What we want to do is get the State Board of Education to recognize that environmental issues deserve some attention in each grade level. Right now curriculum planning doesn't require that they do this. It's important to build these issues into curriculum planning.

We're trying to be value-neutral. It's very easy to take a certain position one way or the other, but we don't want to do that. We just want to provide as much information as possible.

I just talked this morning with the chairman of Global Tomorrow, an international coalition of groups concerned about climate change with Rockefeller and Ford Foundation funding. This coalition has sponsored a series of workshops called Global Town Meetings around the country. One was held at the Smithsonian last month, and another in Eugene, Oregon two months ago. The workshop organizers have expressed a real interest in holding one here in Albuquerque to coincide with the event Jeff is planning. For this they would bring in internationally renowned and respected scientists to talk about climate change. We hope we're able to do that because that will bring some definite attention to not only the problems that we uniquely face here in the Rio Grande Basin but also to the general issue of climate change. There will be a senate hearing at the same time we will be having the Educators Conference and we will be doing student seminars to get more of the students involved.

We will also have a Senate Energy Committee field hearing on environmental education and climate change. Jeff is well positioned on this issue as he serves on the Armed Services Committee, the Energy and Natural Resources Committee and the Labor and Human Resources Committee, which deals exclusively with educational matters. So, through those three committees, we have the opportunity to influence funding or authorization of appropriations for issues we're talking about.

Let me review very quickly the Global Warming bill that the Energy Committee just reported. You are meeting to determine what areas of potential research a consortium should address here in the Rio Grande Basin. I think it's fair to say there is going to be money out there. There is clearly a commitment in the Congress to do something to deal with the issue in some effective way.

Let me just reel off some of the subtitles and the monies that have been authorized through the Senate bill. We think there's a good chance this will pass; we don't know what the House will do, but it usually provides a little more money. Most of these focus on the energy side,but you need to be aware of the whole range of issues. They include: gas turbines, $25 million; hydrogen, $45 million for the next three years; natural gas fleet conversions, $90 million; and natural gas recovery, $75 million. As we look for alternatives to high-sulfur coal, natural gas stands out. New Mexico stands to benefit greatly from that increased interest. Jeff sponsored the fleet provision of the Clean Air Act, to require the conversion of all government fleets as a way to start the incentive to get alternative fuels. We need to create a market; government fleets provide a way to do that. We are also looking into natural gas co-firing, which is using both coal and natural gas in the boiler to reduce the demand for high-sulfur coal. There is $30 million for natural gas heating and cooling systems; $45 million for energy efficiency research; and close to $60 million for ecological and environmental resource studies.

Jeff's pursuing a couple of other initiatives with Tom Bahr's very worthy help. One is the Arid Lands Research Center that we're trying to get established in Las Cruces. The focus would be research that is going on currently by federal agencies on arid lands. We see this as evolving into an international institute of study and research, through which a great deal of funding could pass for work on climate change and a variety of arid-land issues. Other states have similar institutes; our idea is to develop this one with more of a national and international scope. The bill directs the Secretary to assign a lead agency (we're not sure who that will be) and work closely with the land-grant institutions, such as New Mexico State. So we think we have a good chance of making it happen this year, which would be perfect timing given what is going on with climate change. Additionally, Jeff has introduced legislation to set up a national environmental education center here in Albuquerque through the Forest Service. We do not have an interpretive facility for Forest Service or public lands here in New Mexico. In fact, there is no center in the United States dedicated to environmental education. We think that has a good chance for passage; there seems to be a lot of support both in the New Mexico delegation and on the Senate Energy Committee, where it's being considered.

Finally, we'd like very much to work closely with your group once the workshops conclude and the conference is over. There are ways that Jeff can be helpful, especially by virtue of committee assignments. I think we're going to be coming to a lot of the federal agencies and trying to involve them in the educational effort. You all have some tremendous resources that the schools don't necessarily get to tap. Some of the agencies have programs with the schools but, in talking to teachers, especially here in Albuquerque, I've concluded that the schools are not availing themselves of them. We would like to help in that endeavor and, in terms of the October planning, it would be very helpful if you could provide us with some resources to help plan for the Senate Energy hearings. The idea frankly is that this would be the backdrop to push for whatever we need on the national energy strategy; that strategy will be finalized and out in draft in November or December. The Senate Energy Committee would be the only committee holding hearings at that time specifically focused on the strategy. Once the Rio Grande Basin focus emerges we could push at the start of the session (January) for a major research effort in that direction. So that's the purpose of the October initiative, to take advantage of the Energy Strategies release.

Jeff conveys his regrets for not being here, but looks forward to working with you, especially in October.

FUNDING PERSPECTIVES

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RESEARCH OPPORTUNITIES RELATED TO THE HUMAN DIMENSIONS OF GLOBAL ENVIRONMENTAL CHANGE[1]

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INTRODUCTION

Knowledge grows incrementally. Effective research answers specific questions. Only after related sets of questions have been answered can we effectively address the pertinence and significance of broader concepts. And when new concepts are proposed, our examination of their validity proceeds through the careful testing of focused hypotheses. Our pursuit of general knowledge occurs in the same way that one constructs a stained-glass window: the full beauty of the entire work can be appreciated only when each separate piece of glass is set precisely in place.

Scientific disciplines reflect our need for researchers to specialize. Many of us focus on specific phenomena or processes. Others, such as those in geography, are distinguished by the specific questions that they pursue across a range of phenomena and processes. Whether because of the nature of the topic or the distinctiveness of the approach, we often become so immersed in the paradigms and techniques of our own disciplines that we fail to observe what's going on in other disciplines. We also fail to note how our own work relates to research by other types of scholars.

To fully appreciate our own work and the broader range of scientific inquiry in which our research fits, we must periodically step back and look at wider-ranging issues. To paraphrase an old saying in hopes of making it more appropriate for a semi-arid setting, we need to examine the entire chaparral community as well as specific agave and yucca plants.

The social sciences frequently have borrowed from the natural and physical sciences, and they often have contributed their own insights and techniques in return. We need to recognize that the approaches that all scientific disciplines use are similar. The phenomena and processes on which different disciplines focus make the conduct of research quite varied. In a workshop session yesterday afternoon, Bob Woodmansee, a landscape ecologist from Colorado State University, almost described human activities as "harder" to study than were natural and physical processes. He caught himself when he realized that this statement might imply that the social sciences were "hard" rather than "soft" sciences, as they often have been characterized. Bob deftly changed his terminology and began referring to social and economic systems as "messy." Does that make the social sciences the "messy sciences?" Given the difficulties we have in generalizing about the complex ways that demographic, cultural, economic, political, legal, and other human factors function, that may well be one of the most apt and least value-laden adjectives we've been given.

It is precisely because different disciplines use different approaches to describe and explain phenomena and processes that cross-disciplinary contact should occur frequently. Through the strengths of other disciplines we can learn how to confront the weaknesses of our own. Through our observation of scientific methods practiced by other scholars we can identify new approaches to be used in our own inquiries. The value of frequent interdisciplinary contact is especially true when the phenomena and processes that different disciplines are studying are themselves entwined.

NEED FOR SOCIAL SCIENCE RESEARCH

The merit of continually broadening an interdisciplinary research agenda has been evident as we seek to describe and understand the myriad dimensions of global environmental change. Early in the 1980s, many scientists became more aware of a wide range of environmental conditions across the globe whose rates of change seemed to be accelerating. Among the apparent problems were warming temperatures, increased acidity in precipitation, depletion of atmospheric ozone,

[1] These statements are the personal opinions of the author and do not necessarily reflect the views of the National Science Foundation.

tropical deforestation, and extinction of biological species.

Initial inquiries into global environmental change were made in the natural and physical sciences. The first significant interdisciplinary contacts came when biologists and atmospheric scientists found they had much to say to each other. Earth scientists, oceanographers, and solar scientists soon joined in a network of scientists that sought to understand the myriad relationships among different natural and physical systems operating at global scales.

Circumstantial evidence pointed to human activity as a primary cause of changing natural conditions. Population growth, changing land-use and economic activity patterns, and increasing consumption of energy supplies and other natural resources were cited as the primary instigators of dramatic environmental changes. But early efforts to model global processes treated human factors largely as exogenous variables. The characteristics and magnitudes of human activity were merely parameters to be adjusted in different ways to see how natural and physical process models functioned in various scenarios.

In the last few years, however, recognition has grown that social scientists must also become actively involved in research on global environmental change. To fully integrate analyses of human activities into models of natural and physical systems, we must draw on the insights and look at problems from the perspectives of the scientists who are most experienced in research about people.

US GLOBAL CHANGE RESEARCH PLAN

This process has been reflected in development of the US Government's agenda for research on global environmental change. Individual agencies began to consider their own plans—with accompanying budget requests. As concern about global environmental change and the number of agency responses increased, the White House's Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB) charged the Federal Coordinating Committee on Science, Energy, and Technology (FCCSET; pronounced Fix-it) with coordination of agency planning efforts. Starting in 1988, the Committee on Earth Sciences of FCCSET established a Global Change Working Group to develop a research plan that coordinated the research initiatives of seven different agencies. The number of agencies involved in this process has since grown to nine. The working group's primary responsibility has been to develop an effective, integrated research agenda and to eliminate needless duplication of effort. As part of this process, OMB authorized development of budget projection extending five years into the future. This longer-range planning has fostered establishment of an integrated research plan, which first became functional with the Fiscal Year 1990 budget.

The US Global Change Research Plan specifies seven scientific elements:

1. Climate and Hydrologic Systems
2. Biogeochemical Dynamics
3. Ecological Systems and Dynamics
4. Earth System History
5. Human Interactions
6. Solid Earth Processes
7. Solar Influences

The order of the elements reflects the relative priority that they will be given. The FY 1991 budgeting process has resulted in a plan now under review by Congress. No major changes have taken place in the scientific priorities, and special emphasis is being placed on the potential policy-making utility of the basic research activities that will be undertaken and continued.

The development of the budget for FY 1992 is now in its initial phase. Among the items currently under discussion are the identification of three integrating themes to demonstrate the interrelationships among the various, seemingly diverse activities associated with the different science elements. Those integrating themes are the carbon cycle, the hydrologic cycle, and population dynamics. Throughout the last three years of budget development, social science slowly has been integrated into the research process. The ultimate goal of the federal government's research effort has evolved to be the more complete description and analysis of complex interrelationships among all relevant human, natural, and physical systems. A major use of these analyses will be to better understand and predict a wide range of policy alternatives.

NSF HUMAN DIMENSIONS OF GLOBAL CHANGE COMPETITION

The Division of Social and Economic Science (SES) at the National Science Foundation has seen itself as playing a crucial role in promoting and supporting the more active involvement of social scientists in research on global environmental change. In 1987 and 1988, the division funded some workshops to stimulate discussion on important issues and to provide initial recommendations regarding the development of a research agenda. In 1989, division leaders wanted to emphasize the need to conduct more basic research. They felt that the most effective arguments in favor of the integration of social science into the broad range of global environmental change research was to display the products of high-quality research, not merely to talk about what might be done. SES leaders, therefore, announced a special competition for proposals related to the Human Dimensions of Global Environmental Change (HDGEC). Six proposals were funded as a result of that initiative; collectively, these awards totalled more than $600,000.

In Fiscal Year 1990, we repeated the competition. As of June 1990, we are completing actions that will result in support for 19 proposals, using $1.2 million set aside in the division's budget. Individual research programs also are contributing to the support of a number of projects, and the US Agency for International Development is providing assistance for one project.

Looking ahead to FY 1991, the Bush administration has asked Congress to designate $2.5 million for the Human Dimensions of Global Environmental Change competition. In anticipation of an increase of that magnitude, we are increasing the competition's frequency, evaluating proposals received in both of the division's annual evaluation cycles. SES target dates are August 15 and January 15; any scholars interested in more information should contact any SES program officer for more details.

EXAMPLES OF PROJECTS FUNDED THROUGH THE HDGEC INITIATIVE

The range of projects that we are funding illustrates the myriad ways that social scientists can contribute to improve our understandings of the human dimensions of global environmental change. The following classification scheme is my own; I offer it merely to help you make sense of the diverse types of projects currently under way.

1. Research about human impacts on natural and physical systems:
   - An analysis of historical relationships between land use and natural vegetation in New England
   - An analysis of human activities as they have disturbed natural vegetation in Patagonia
   - An evaluation of the ways that environmental factors are considered in the development of mineral resources in Amazonia
   - An analysis of the role of small operators in the exploitation of Ecuadorian rainforests.
2. Research on human responses to changing environmental conditions:
   - A comparison of adaption strategies on US coastal islands
   - An assessment of individual perceptions of "chronic" versus "extreme" environmental conditions in southern California
   - An evaluation of the resiliency of different agricultural practices to drought and other changing environmental conditions in Mexico
   - Integration of environmental factors into general economic models.
3. Research on the roles and functions of institutions:
   - A comparison of native and colonial water rights as they affect the value and use of water in Hawaii
   - An evaluation of the role of science in the US as an institution defining issues related to global environmental change
   - An evaluation of the role of the media in shaping public opinions about global environmental change in the US and elsewhere.
4. Comparative case studies:
   - An assessment of human impacts on and responses to natural systems in nine regions where natural systems are especially sensitive to human-induced change
   - A comparative study of "social learning" of governments in six developed nations.
5. Explorations of ethical issues.
   - An investigation to develop the means to assess the long-term costs of global environmental change and obligations to future generations
6. Development of research techniques:

- Enhancement of remote sensing as a means of monitoring land-use and vegetation change in Brazil
- Explorations of ways to remove impediments to the effective use of geographic information systems (GIS) in the analyses of global environmental change. (Inquiries include analysis of accuracy and error in spatial data and improvements in the architecture of computer systems to accommodate very large spatial databases.)

7. Data collection:
   - Development of a comparative database of irrigation systems in more than 20 nations.

In addition to these projects funded by the NSF Division of Social and Economic Science and some of its constituent programs, representatives of all Global Change Working Group agencies have been exploring ways to integrate extant databases, especially those that deal with population, land use, and the flows of energy and materials through economic systems. NSF also is taking the lead in exploring an expansion of the concept of Long-Term Ecological Research sites to provide a means of systematically gathering social and economic data from a network of sites. We envision a set of Long-Term Regional Research Observatories, areas where consistent, longitudinal databases on a wide range of human-, natural-, and physical-system variables are maintained to permit comparative analyses of the complex interactions among these systems over time. We also envision these centers as sites for special multi-disciplinary inquiries.

WHAT CHARACTERISTICS WILL DISTINGUISH SUCCESSFUL RESEARCH ON THE HUMAN DIMENSIONS OF GLOBAL ENVIRONMENTAL CHANGE?

The range of projects we now are supporting through the Human Dimensions of Global Environmental Change initiative and the types of activities we are considering for the future emphasize the diverse ways that social scientists can participate in research on global environmental change. Despite this variety, there are a number of characteristics that I feel will distinguish the most successful research on this topic:

1. Research must be both basic and applied. The concepts of basic and applied research are not exclusive. Basic research is well grounded in and contributes back to increase our broader conceptual knowledge. Its conclusions are generalizable beyond the specific topic under investigation, and its methods are replicable in other settings. NSF's primary mission is the support of basic research that has these characteristics. At the same time, any basic research project should provide a ready basis for any number of specific, focused applications. In addition to more generalizable insights, research should provide increased information and better frameworks for addressing specific problems and for evaluating specific actions and policies. The ease with which academics and practitioners from a wide range of agencies and private firms worked together in the workshops yesterday highlights the potential for research on human-environmental interactions to benefit many different users.

2. Research should evaluate processes and phenomena across the globe. The need for detailed inquiries often forces us to conduct case studies, but we shouldn't focus our attention solely on those areas close to home. To truly understand the complex ways that culture, economics, and other human properties interact with natural and physical systems, we need to explore those properties in the myriad locations where they vary. Such research often will be most effective if it is done in collaboration with scientists in other nations.

3. Research should pay more attention to the role of location as a factor affecting the human dimensions of global environmental change. Too much research has been conducted as if all processes and phenomena operate in identical ways in all locations. Take it from this geographer—they don't. The development of geological information system provides an efficient and extremely powerful means of collecting, analyzing, and presenting spatial data. All disciplines offer valuable insights, perspectives, and techniques to address problems of global environmental change; I hope that geographers can play especially useful roles in helping integrate information and analyses that inherently must recognize the significant role of location.

4. Research must make stronger connections among analyses at different scales of inquiry. We need greater understanding of the ways that micro-scale activities of individuals (people,

biological phenomena, or physical phenomena) operate collectively through mesoscale (institutions, communities, nations, and the like) and up into macro-scale (regions or the globe as a whole) forms. The development of new capabilities and techniques to meet this goal will require greater collaboration among scientists within disciplines as well as more multidisciplinary work.

5. Research should focus on the direct links among different human, natural, and physical systems. The development of models (whether conceptual or mathematical) should consciously seek to explicate links among various systems. This may be one of our greatest challenges, because many models of human systems require far greater precision than they currently have. Continued work to improve models will require greater multidisciplinary collaboration. Despite the difficulties, however, we must make model improvement a primary goal because the payoffs from this effort are enormous. More precise and realistic models provide us with enhanced analytic capabilities, and they also will enhance our abilities to conduct more effective *a priori* evaluations of policies and other actions.

6. Research should also examine the indirect links among different systems. The initial emphasis for research on the human dimensions of global environmental change was on direct human-environmental links, but the recent transformation of eastern Europe shows how important indirect connections can be. As we learn more about the complex sequence of events that led to the political, economic, and social upheavals, we are learning that environmentally active "Green" parties played crucial roles in the opposition. And we are certain that with greater individual inputs into economic and political decision making, the residents of eastern European nations likely will demand more stringent pollution control measures, thereby reducing greenhouse-gas emissions. Or will an anticipated economic boom based in a capitalistic system result in increased emissions? The exploration of these types of indirect relationships will be essential to fully appreciate the complex interactions among human and other systems.

7. Research will require more "industrial-style" efforts rather than the "craftwork" projects in which social scientists usually have participated. The growing need for large-scale, multidisciplinary analyses encourages us to look to natural and physical sciences for models of how to conduct research. I'm not sure that we should seek publication of two-page journal articles with dozens of people listed as co-authors as the ideal to which we strive, but we certainly can benefit from examining how we might make greater use of post-doctoral fellowships, carefully coordinated sets of related research inquiries, and other approaches used extensively by other disciplines.

A FINAL CHANGE

In conclusion, I'm very optimistic about prospects for research on the human dimensions of global environmental change. The needs are great, but opportunities abound. The recognition of the value of truly multidisciplinary research has never been greater, nor has appreciation of the contributions that social scientists can make. We can realize this potential only if we act, so my final words are a call to social scientists: Don't wait! Assess your strengths, identify how you can participate, and then roll up your sleeves and start working.

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IMPACTS OF GLOBAL CLIMATE CHANGE AT THE NATIONAL AND REGIONAL SCALES WITH EMPHASIS ON THE SOUTHWEST

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INTRODUCTION

First I want to convince you that research into ecological systems is important not only for understanding what might happen in global change, but also what you might be able to do about it. Next I want to tell you 1) about EPA's role in the overall federal response to global change, 2) where some of the scientific research opportunities are, and 3) what EPA's scientific research agenda is.

To start I'm going to read from the report of the Ecological Systems Task Group of the Federal Global Change Research Program. It's a statement of why an investment in ecological research can make a difference.

> "A full scientific attack on global climate change requires understanding and predicting the dynamics of ecological systems. Ecological and biological processes regulate the cycling of important nutrients, especially carbon, nitrogen, and phosphorous species, and they influence the amount and rate of evapotranspiration, thus helping to regulate the physical climate system. At the same time, changes in the climate system, changes in ultraviolet B radiation, changes in chemical deposition and land-use conversion, all influence the health and distribution of ecosystems. Changes can occur rapidly, for example the seasonal course of phytoplankton blooms; or very slowly, for example the revegetation of land following the retreat of glaciers. Thus ecological systems form a bridge between the physical and biogeochemical aspects of the climate system and the influence of humans and human activities on the earth system."

Understanding these systems and their dynamics are therefore important from two very different perspectives. One from the controlling perspective, their influence on the water and energy fluxes and nutrient cycling, and secondly as resources that respond to global changes in ways that are directly important to human society. Documenting the current status of ecological systems around the globe will be necessary to demonstrate whether current hypothesis concerning carbon storage are correct. In addition, current species distributions and abundances and the quantitative nature of important processes such as carbon fixation, primary and secondary productivity, and decomposition rates, will be necessary if changes in these attributes or process can be detected. The natural variability in processes and species abundances and distributions must be documented carefully if the consequences about which we are concerned, largely on the basis of models, can actually be measured and shown to have happened and shown to be of importance to society. Understanding the processes controlling the response of ecosystems to global change is likewise necessary. Field measurements, field and laboratory experiments will be necessary in order to develop a quantitative understanding that allows the scientific community to interpret its observations correctly. Confidence in understanding these processes will enable the scientific community to convey a sense of confidence to policy makers who have to make decisions that are based ultimately on credible predictions of change and how society might respond. One hopes that as model development becomes more sophisticated the simulation of current process can be supplanted by model-based predictions of ecosystem response to and influence on global change.

From a policy-level perspective, the challenges are as daunting as from a scientific perspective. The global changes of the greenhouse effect, coastal pollution, and stratospheric ozone depletion, all produce physical and chemical stresses on ecosystems and biological resources. The regional, but very widespread changes such as acidic deposition, air pollution, and water pollution, introduce a range of chemical stresses. Regional but widespread changes in land use associated with increased clearing and deforestation produce direct losses of habitat that affect the viability of associated plant and animal species. For the greenhouse effect one must consider the very strong possibility of rapid changes in the climate system in the near future that will both be influenced by and influence ecological systems. The regional pollution issues, the responses of ecosystems are occurring now, and management responses need to be articulated now. For land-use changes, particularly habitat fragmentation and deforestation, there is nothing magic about this. There is no long series of cause and effect that needs to be elucidated: it is human activities that are already contributing to one of the biggest global changes ever known and that is the loss of species more rapidly than ever before recorded.

BASIC CLIMATE-CHANGE QUESTIONS

From a climate-system perspective there are three questions that people really care about. How fast and how much will the climate change? Who cares, especially on a regional scale? What can we do about it, if anything? Understanding ecosystem dynamics and the processes that control them play a role in all three.

How Fast and How Much?

The main perturbations in the carbon cycle for carbon dioxide (CO_2) are anthropogenic activities, combustion and land clearing. Industrial activities and the clearing of land, largely in the tropics, and subsequent combustion/biomass burning, is putting about 6 to 7 gigatons of carbon into the atmosphere every year, and about half of that is staying in the atmosphere. We do not know where the other half is going. It may be going into the oceans, and the possibility has been raised that it is actually going into the terrestrial biosphere, that it is being fixed in photosynthesis on the land. However we do also know that the terrestrial biosphere and the oceans are each cycling about a hundred gigatons of carbon per year. In other words, the combined fluxes of the terrestrial biosphere and the oceans are about thirty to forty times larger than the industrial perturbation. Well over half of the sources of methane are from biological sources, and the possibility that the terrestrial biosphere constitutes the missing sink of carbon is on the one hand comforting (it's nice to know where that carbon goes) and on the other hand very scary (the terrestrial biosphere is a limited place). If that is the sink, it's going to fill up, and what happens then is anybody's guess. One could conceivably see a very large positive biogeochemical feedback in the climate system that would lead to extraordinarily rapid rates of rise in the carbon dioxide concentration of the atmosphere. Small percentage changes in the very large fluxes between land surfaces or the ocean and the atmosphere could influence the carbon cycle a great deal. One important research response should be to understand biogeochemical and ecological processes that are regulating these carbon fluxes, to understand whether or not there is a large biogeochemical feedback awaiting us over the next several decades.

Who Cares?

Caring gets directly into the notion of impacts. From a research perspective understanding impacts is a very, very difficult thing to do, for obvious reasons. The climate models are not yet fully competent at giving us reliable regional scenarios of climatic or weather change. However, as the history of how plants or natural resources respond to climatic variation is over 100 years old, there are things one can do from a research perspective. We can certainly understand how natural resources have responded to climatic variation in the past. We're beginning to develop the capacity to model these changes. That gives us, at the very least a planning tool, some ability to predict in a scenario model what might happen, and to begin to formulate possible adaption responses to these changes.

The possible changes in precipitation and soil moisture are particularly relevant to this audience. If the mid-continental decrease in precipitation happens, then drought frequency and water management become more important issues especially in the West and Southwest than they are today, if that is imaginable. For those of us who grew up in the East, especially in New Hampshire where the notion of a few extra degrees doesn't sound like such a bad thing, the notion of managing water so familiar to Westerners is almost entirely foreign. I can remember only one time in the last 30 years when rationing water in New England was initiated; the droughts of the 1960's. That could become much more frequent, requiring a tremendous change in a region where water availability has never been an issue. That would require a dramatic change in how people think about resources there.

The impact of possible increases in drought on agricultural production, not only as regards what sort of agriculture is profitable in different parts of the U.S. but globally, is a major issue with truly-global implications. Equally important, if not so much in dollar and cents terms, certainly in how people view and care about the environment, are the possibilities of changes in ecosystem integrity, the growth or possible decline and breakup in forested ecosystems. We have seen the concern in forested ecosystems trigger major responses in political communities and scientific communities and other environmental issues, and this issue may very well do the same.

What Can We Do?

There are obvious short-term answers in terms of trying to promote energy efficiency or the use of alternative fuel sources. Even here the biological and ecological sciences will necessarily play major roles. If one of the trades that one wants to make is live carbon for dead—the use of carbon that is cycling rapidly through the system in place of fossil carbon that is cycled only slowly on geological time scales—then certainly, one would argue for increases in research on biomass conversion to fuels, and on better use and management of agricultural soils and forested systems to conserve and sequester carbon.

EPA'S PERSPECTIVE

The Environmental Protection Agency is perhaps not quite unique in the federal program on global change, but it is certainly one of the few agencies that has both strong policy and science missions. Within EPA it's important to know that these have separate identities, but that an overall agency-level response depends both on input from the economists, social scientists and policy analysts as well as from the natural and physical scientists. So one has the notion every day in EPA about what is economically possible and viable and what the options for responses are. At the same time, from the science side, one has a reality check: what really can be done and what are the geochemical consequences of taking or not taking a possible option. So response from EPA is motivated from both of these independent tracks.

Policy

From the policy side of EPA, and this is a major emphasis within our own agency, there are two main thrusts. The first is on implications—the economic, social, and regulatory implications of climate impact: how will we have to manage water in the future? Part of a major study that the agency did at the request of the Senate on the effects of climate change in the US showed that in California the strong possibility existed, if the scenarios were to be believed, that there would be water shortages and managing water in California would be much more difficult than it already is.

What coastal management policies will have to change for protection against sea-level rise; and how might those coastal management policies, whether they involve building a sea wall or changing regional zoning laws, run up against the administration's "no net loss of wetlands" policies? This is currently an unanswered question, but one that's quite important if wetlands are blocked from migrating as sea level rises.

What kinds of agricultural and economic practices might have to be changed in order to be productive in a climatically different world? These are the sort of speculative analyses on impacts that are needed if planning is going to give us any notion about what kind of responses are going to be necessary.

The second major thrust of the policy response in EPA to global change is on the economic, social and regulatory impacts of "mitigation strategies"—where mitigation is not seen as how do we make things better in a world that is certain to change, but what sorts of interventions are economically and politically feasible to reduce the rate of change and reduce the sorts of social adaptation to residual change. Various activities are underway. One of the most important, both domestically and internationally, is a series of analyses that have been done jointly with the U.S. Department of Agriculture and several international groups on economic aspects of reforestation and deforestation. There are good economic reasons why deforestation is such a problem in the world. One wants to understand that and try to see if there are economically viable ways to slow that process.

Another important area is increased energy efficiency: what are the obstacles and what can be done to remove those obstacles? Also, what are the opportunities for new technologies in energy production, with more use of renewables, solar energy, and possibly hydrogen. Finally, where are the opportunities, both domestic and foreign, for such things as a framework convention and how might that be conducted?

On the science side, EPA's history is a bit different for global-change activities. Our programs in climate-related issues are relatively recent, only about three-and-a-half years old, but have been growing steadily. They were initiated about the same time that the Federal government brought its coordinating body together. This is the Federal Coordinating Committee on Science, Energy and Technology (FCCSET—pronounced "Fix-it") which operates in the office of Science and Technology Policy. In the beginning of our program we spent a tremendous amount of effort on two studies that had been requested of us by the Senate: one on potential effects of climate change in the US and the other on potential policy options for stabilizing the atmosphere (how one might influence the concentrations of the major greenhouse gases in the atmosphere).

Role in Global Change

As our program has doubled in size for the past three years, we have gone through our own evolution in looking for EPA's niche in the federal structure. We think that niche is understanding the role of the terrestrial biosphere in global change in terms of how fast, who cares, and what can we do about it. You will see that this does not preclude investigation into the anthropogenic, energy and industrial sides of the equation, to determine how fast change might occur. The main focus of our research program will be on measurements and experimental studies of carbon dioxide and methane fluxes in order to not only quantify what's happening now, because the actual number of such measurements in the world is pitifully small, but to understand enough about environmental controls on those fluxes (the responses to temperature, to rainfall, to soil moisture, to increasing atmospheric concentration of CO_2), to determine what might happen over the next thirty to fifty years as a function of variability in the climatic systems. Are we looking to take the two possible extremes—carbon dioxide fertilization effects will overwhelm adverse changes in productivity, or a large positive feedback due to increased methane flux and carbon dioxide fluxes to the atmosphere will overwhelm whatever energy policies or practices might be adopted? I think we do not know the answer to that, but research into the terrestrial biosphere is critical to finding it.

In terms of who cares, that depends on the kinds of effects and impacts that occur. Our primary interest will be in how to model the movement of ecological systems. Which species of vegetation (trees, grasses) really are the most sensitive to climatic variability? What weather processes control germination, seedling establishment and dispersal? How might their growth patterns change and will we be able to predict what a different world might look like?

From the standpoint of what can you do about it, there are two components. One is directly in the tradition of EPA as an agency that sponsors research on the technological side of the energy economy. One needs to have better a characterization of the human and industrial sources of methane for example. We know the industrial and combustion sources of carbon dioxide fairly well. For methane the story is considerably different. There is leakage of natural gas from distribution systems both domestically and abroad that should be better quantified. The design of buildings and industrial motors for energy efficiency and more effective use is in its infancy. We see an important catalytic role for EPA to play in technology development, much as it did in catalytic converters, for using landfill methane emissions. Landfills turn out to be an important and possibly vastly underrated source of methane both in the US and globally. We are now establishing a project that would look at using some of this methane in fuel cells. We've also been quite interested, along with the Department of Agriculture and the Department of Energy (DOE), in the use of biomass for fuel and we'll probably introduce a couple of pilot-scale projects as demos for the developing world. As the Developing World industrializes and the demand for energy grows, that puts incredible demands on both fossil and biological resources. One wants to have technologies in place that can be transferred; that won't happen without a research investment.

From the biospheric perspective the notion that planting trees for carbon is good and has been around for a long time. What's not been around for some time is the notion that there may be a lot of other things that one can do that are possible in a management situation that would improve our ability to store and sequester carbon in natural systems more effectively than we do now. In a sense, what we would like to do is revive the notion that managing for carbon is one of the criteria that land managers should have for how they look at their resources when they make management decisions for agricultural soils, for forest soils. We'd like to look very, very carefully at opportunities not only for reforestation but for promoting agroforestry on a larger scale than it is currently practiced, for using biomass as an energy source on a larger scale than it is currently practiced, and for doing an intensive research program on where the land is available for doing this domestically and abroad. We'd like to know what kinds of plant species are appropriate, how they might be grown and whether future climatic conditions will allow them to be grown in places that are currently suitable. We would like also to enter into a partnership with federal agencies in the US and other nations that can start to promote the use of these research results.

Another area of our program is, in effect, synthesis. It's a common pattern in the scientific community: the most important thing to do is to publish your work that's true, it's the only real measure of scientific progress that anyone has ever devised. In a sense it is a bit like democracy, every other measure that you can think of is worse. But it is folly to think that scientists are the clients for our research decisions in the US. Ultimately, it is the people who must make legislative decisions about where the government is going to spend money. It's folly to think that either legislators or their constituents are going to pore through journals to find the results that will make a difference in the decisions they make. We think that is important enough to produce a series of scientific assessments, from our own and other people's work, to attempt to convey the research results to both our scientific colleagues and to policy audiences, and really say two things: what we know, i.e., what we have found out about these areas; and secondly, why you should care about it, i.e., why it is important to you, why this impacts the decisions that you are being called on to make.

Research Opportunities

Now I promised to wrap up with a notion of where the research opportunities are and I'm going to divide these up into three categories: *great*, *improving*, and *reasonable*. In the *great* category I think you will see EPA make a very strong push to understand the role of the biosphere in global change, both in terms of how it regulates global change, how it impacts the carbon cycle in particular, and how ecosystems respond to global change. Research opportunities will *improve* in the area of what may occur for vegetation and natural resources and what the implications might be for resource management. For technology development and transfer the opportunities will be *reasonable* although compared to the kinds of initiatives that are being requested of the DOE, they will have a much smaller role, perhaps more of a catalytic role than a major hardware development role.

CONCLUSIONS

I'd like to end by reminding us all that global climate change is not a new issue. I went back to look at old ecology textbooks from college, and there it is, usually in the last chapter, entitled "Human Influences on Ecosystems." The texts commonly say, "We don't know where CO_2 in the atmosphere is coming from nor where it's going." They also include methane, deforestation, etc. So this issue has been here for thirty years! It is perhaps a measure of society's reluctance to acknowledge this that has led to the state of newspaper headlines in the last several years. The issue also is not going to go away. There are other global change issues that may yet turn out to be as important and that we really cannot ignore: desertification, urbanization, land-use changes, and the loss of species diversity. In fact, the loss of species diversity is occurring on scales that make a mere 25% increase in carbon dioxide concentrations look like a pittance. We're losing species on the earth more rapidly than ever before recorded, and we can't lose sight of this. The same social forces are contributing to these changes. They have similar widespread social consequences that require study. They require both scientific research and policy-level responses on the part of governments. The plural is important here because it's not just us. These problems require global responses.

EPILOGUE

Proceedings, The Rio Grande Basin--Global Climate Change Scenario, 1990, WRRI Rept M24

WHERE DO WE GO FROM HERE? -- WORKSHOP IV RESULTS

Eleonora Trotter, Biology Department, University of New Mexico and
Michele Minnis, Natural Resources, University of New Mexico

INTRODUCTION

After a morning of presentations open to workshop participants as well as the public, conference attendees divided into three groups to address three ways to create a Rio Grande Laboratory: the development of 1) a basin-wide conference; 2) a Rio Grande Basin Consortium; and 3) an information-transfer and public-education plan.

CONFERENCE WORKSHOP

It was decided that if the Rio Grande Basin Laboratory was going to evolve there had to be a basin-wide conference to involve research scientists, resource managers, and resource users from the upper Rio Grande as well as the lower Rio Grande Basin. No other river in the world forms a boundary between an underdeveloped and a developed country. Therefore, cooperative research, management and decision-making possibilities are unique. The Rio Grande is a unifying physical and biological entity between two countries and among several states.

Although the river has been divided into political and management subunits, it is becoming more and more necessary to consider the river and its drainage basin as a whole entity once again. As one participant put it: "as compacts and state boundaries begin to fall, and as water rights become transferable from any one part of the basin to any other, . . . it becomes extremely important for a person in one part of the basin to know what is going on in another part of the basin."

Focus

This group agreed the present meeting identified research, management, and decision-making projects related to climate change that could be uniquely addressed in the Rio Grande Basin. Participants concluded that the focus of the next meeting should be to develop a "state-of-the-basin" report. The ultimate product of this meeting would be an integration of questions, projects, data, and information, into the first volume of the Rio Grande Atlas (the state-of-the-basin report). At this meeting ongoing projects and research and management needs would be presented. Proceedings of this conference could be used to create the state of the basin report which would be updated at regular intervals (2 years, 5 years). Subsequent meetings would present results of collaborative projects generated at the first meeting. Modeling basin phenomena based on extant data to predict future behavior of, for example the interaction of El Niño Southern Oscillation precipitation effects with a rise in temperature, will be a future meeting theme.

Goals

Conference workshop participants suggested the following goals:

1) to gather together extant information data, projects, and models in the Rio Grande Basin concerning the biological, social, and economic systems within the basin;
2) to inform decision-makers and the public-at-large regularly about projects within the basin concerning responses to a changing environment.
3) to focus efforts not only on global climate change, but also on immediate problems arising from human migration into the Rio Grande Valley from the north and south, and the subsequent concentration of large human populations in urban centers such as El Paso and Juarez.
4) to transfer research results to decision-making and management groups.
5) to educate the public about the impacts of demographic and environmental changes in the Rio Grande Basin arising from global climate changes as well as increasing numbers of people.

One participant noted that we should not come to the end of the basin-wide meeting without tangible results that suggest solutions to biological, social, and economic problems in the basin. Water quality and human demographics are of critical interest. The doubling of the population of the Basin expected in the next 15 years will exert a tremendous demand on Rio Grande water.

Structure

Participants suggested that the basin-wide conferences consist of two parts. The first would be a series of presentations on extant work in the basin to share information about physical, biological, social, economic and political systems within the basin. This first part could be open to the public.

The second part would be to use information to design future projects to answer specific questions about response to environmental change. As one participant pointed out, it is of primary importance that everyone understand the different perspectives of those involved in different activities.

Location

Chamisal, an island in the middle of the Rio Grande between Juarez and El Paso administered as a National Monument by the National Park Service, was suggested as a site for this conference. This choice was made in part to symbolize the importance of cooperative effort within the basin, especially on both sides of the border created by the river. It was thought that this site would be accessible to both Mexican and US participants, who might otherwise have to face a foreign travel limitation.

Date

The original suggestion of a time for a meeting was January 1991. However, this is an ambitious project and requires getting funding and organizing at a larger scale than did the present conference. Therefore, until funding is obtained, a specific date has not been set.

Funding

Various potential sources of funding were suggested:

1) agencies and institutions sponsoring the meeting financially in some way (directly or by paying for some aspect of the meeting and its product) would be able to send a specific number of representatives without paying a registration fee.
2) other people whose agency or institution did not contribute would pay a registration fee; $195 was suggested.
3) a contingency fund would be solicited from some organizations (such as the State Department, US Information Agency (USIA), the United Nations, Man in the Biosphere, Boundary Water Commission) to fund travel for any person who could not come because of lack of funds.
4) politicians. Such a conference, fostering inter national cooperation to study and to manage one physical entity like the Rio Grande, might find support and help in obtaining funding from our representatives in Congress.
5) special interest groups. American Rivers, a nationally based organization for the protection of rivers might help to fund a project to treat the Rio Grande as a whole river again. Other special interest groups might be The Nature Conservancy, Sierra Club, and the Wilderness Society.
6) As there have been programs of exchanges of judges and lawyers between Mexico and the United States, agencies of the two governments might be persuaded to sponsor this conference as an additional exchange activity between countries.
7) Both the National Aeronautics and Space Administration and the National Oceangraphic and Atmospheric Agency (NASA and NOAA) were suggested as funding sources. If more emphasis were placed on air pollution, another problem of the Rio Grande, NOAA might find the conference attractive.
8) Ten years ago in 1981 there was a meeting on Padre Island to discuss transboundary resource management. This meeting might be considered a followup to the Padre Island meeting, and the same source of funding as for that meeting might be available for this meeting. Certainly the list of participants could be used to locate key participants for the Rio Grande Basin meeting.

Organizational Strategies

Practically speaking, all acknowledged that the organization of an international two-and-a-half day conference is a staggering task, a logistical nightmare, but well worth doing. A suggested strategy for this international meeting is to make it a smaller and focus on identifying and inviting key people. These should not be solely those who would normally represent their agency or institution at such a meeting, but also technical people who deal with the day-to-day work of understanding, managing and making decisions about the water in their section of the Rio Grande. It was also suggested that a team be formed in every state on both sides of the border consisting of a research person and a management person. These people would be responsible for suggesting key participants. It was suggested that there exists networks between universities, between agencies, and between other agencies which should be used to generate a list of potential participants.

Bob Woodmansee agreed to be one contact person for Colorado, Chuck DuMars will be a contact person for Mexico, and Bruce Thomson will be a contact person for Texas. A preliminary list of people and institutions not present at this conference to be sent information are:

1) Dr. Jurgen Schmandt, University of Texas at Austin—In 1990 and 1991 Dr. Schmandt sponsored two conferences on global climate change. The first centered on Texas, the second focused on regional units and their response to climate change.
2) Larry MacDonald, Natural Resource Law Center, Boulder, Colorado.
3) Al Utton, School of Law, University of New Mexico, Albuquerque, NM. He has much experience with trans-boundary problems.
4) The University of Monterey in Mexico which runs the Mapimi ecological research site, and universities in each of the Mexican states bordering the river.
5) Members of the International Boundary Water Commission.
6) Howard Applegate, University of Texas at El Paso, who has written six excellent articles on air quality in Juarez.
7) Randy Charbonaux, director of the Center for Research in Water Resources at the University of Texas, Austin, a geohydrologist working on inflow from Texas below Fort Quitman.

The group discussing the conference decided to stay together and continue to develop the conference. Whether the conference occurs depends on developing a structure for the Rio Grande Basin Consortium.

CONSORTIUM WORKSHOP

In earlier workshops, participants decided that there should be a consortium of different entities for several reasons. The most pragmatic reason to work together, of course, is the ability to get more money to operate if agencies and institutions can demonstrate that the work they are doing individually ties into a multi-faceted effort. Any money given to one participant has the potential for more return if several participants are working together. In fact, one person suggested that money for projects go through the Consortium first and then to each project. If money travels this direction, then double administrative costs are avoided and each participating agency actually gets more money to use for research or management development.

Avoiding redundancy of effort (data collection and interpretation in particular), is another pragmatic reason to develop multidisciplinary, interagency projects. A third reason is that information transfer from basic research to application, or vice versa is much more rapid if basic researchers and "practitioners" are working on the same problem. This requires a clear understanding of the assumptions of each group in order to make translation accurate, as has been mentioned previously.

It was pointed out that one had to have faith in the consortium to make it work. The assumption of establishing a consortium is that participants are going to get a great deal more out of it than what they put in. Indeed, 99% of the development of the consortium is going to come from using old, rather than new money. Since this is the case, agencies and institutions need to work together to create a multidisciplinary "umbrella" organization. Individual competition for dollars at this stage would mean less money coming into the basin in the long-run. Once the organization is functioning, then necessary, internal competition will be good for the quality of the work. Another participant likened the development of a consortium to the parable of the loaves and fishes. Everyone has more to share than any one of us would think possible. Sharing creates a better allocation and use of resources.

Structure

A framework for the organization was introduced. Every successful organization is divided into "Enablers" (Funding sources), "Doers" (those that get the job done and produce a product), and "Users" (those who put the products to use). The "Leadership" takes the central position among these elements. The Enablers work with the Leadership to give purpose, authorization to do work, and the resources with which to operate. The Leadership focuses on problems to solve. Doers analyze these problems, get the job done, and produce results and products for the Consortium. Products are translated into usable form by the Leadership for the Users. Enablers, the Leadership, Doers, and Users are all involved in developing a mission and goals for the organization. There is information flow among all these components in any direction.

Leadership is going to be critical. A dynamic leader provides vision, and the entrepreneurial skill to accomplish the vision. This is a fine definition of a leader for a simple structure, but the leadership of an organization of entities working on physical, biological, social, economic, and political systems of the Rio Grande Basin, and the interaction of these systems, does not seem to call for a simple structure. No one person will have a complete grasp of all the issues involved in a multi-institutional organization. One suggestion was some form of multiple leadership, although a reported attempt at this disintegrated when faced with a periodic review process.

Another question dealt with is how to create a stable funding base for the Rio Grande Basin Consortium out of the multiple, unstable funding bases of the different participants. In an earlier workshop all agreed that in order to work, the consortium had to be stable in increments of 5 to 10 years. A participant suggested that defining the problems the consortium was to solve would help to define the structure of the organization, which would also define the kind of leadership necessary.

The groups discussed what "doers" should accomplish. These were the people who acquired, interpreted, and archived data. This function includes both extant data coming from different places in very diverse forms which have to be standardized for all users. The doers will accomplish synthesis; that is, they will develop new ideas from extant information about how to view the systems of the Rio Grande, how to manage these systems in the future. Synthesis of extant information will help us move into the future. The doers and the leadership of the consortium will be responsible for education, translation, demystification, and simplification of knowledge and information acquired. The users of information can exert a strong influence on all components of the Consortium, but are especially powerful when their votes withhold operating funds from the Consortium. Additionally, it is morally correct to provide information to the public about how to act and react to change.

Another model proposed as that of the Waste Management Education and Research Consortium which was set up and funded by the Department of Energy (DOE) last year at a budget of 5.3 million dollars/yr. Members of this consortium are the three major universities and the two national laboratories in New Mexico. The charge of this consortium is education and research in the area of different waste management technologies, with an emphasis on radioactive, hazardous, and mixed wastes, associated with DOE labs, water production associate with the oil and gas industries, and from agriculture. Part of the reason this consortium was funded is that it could demonstrate a strong management team composed of one director, the managers of three different divisions directly under the director, and with parts of each division answerable to the manager of that division. These were 1) research, including physical, biological, social, economic, and modelling; 2) a data center which was the clearing house for data as well as the compiler of it. This division was also responsible for education, training, and dissemination of information; and 3) a policy center where information from research and the data center is used to decide how to implement policy. This consortium exists external to the participating institutions and derives its funding from one, stable source—the DOE. The Rio Grande Basin Consortium presents a much more complex situation with 20 different federal, state, and local agencies and institutions, as well as individual citizens, so there is no one source of stable funding, or a centrally focused structure.

The discussion then turned to another fundamental issue—how large can a group be and be functional? The enablers, those who buy into the consortium idea, cannot be available all the time making decisions. Those who buy in have to buy in with their trust that the leadership team will get the work done. Once the agencies and institutions have bought in, then there should be a steering committee or advisory committee formed. This committee makes general decisions such as what the mission and goals of the organization are, but the Director and staff take responsibility for the functioning of the consortium. Creating a small management team is a good investment in efficient use of funds moving through the consortium.

Another way of enabling the consortium to do its work was suggested by an agency representative, who felt that "funds are not enough." Agencies could be actively involved through a key person from each agency on the leadership or "doer" team. A person could be assigned to work with the consortium a lot more easily, in some cases, than money could be a line item in each agency's budget. Keeping the consortium working requires not only funds but expertise. As a workshop participant put it "you can accomplish a tremendous amount and still keep the federal agencies and universities working together . . . if you enabled the consortium with part of a key person's salary." Certain agencies can release people to serve in an organization in the consortium. This suggestion is excellent as long as the agencies releasing people to work in the consortium are not those who "need something to do." The consortium will demand dedication.

Funding

Tony Janetos, of the Environmental Protection Agency, shared information about what EPA is looking for when considering various groups to fund. Several characteristics make some organizations more attractive than others:

1) There is a management team in place that really does take the responsibility for getting things done, and for settling internal differences of opinion on how money should be allocated. The management team should be paid by local institutions and agencies. This support should count as matching funds.
2) The organization has a real problem to work on, and if the problem is regionally based then the region really has to be the one which would provide answers to that real problem. An example is the Mountain Cloud Chemistry Program in the Southeastern mountains. These mountains experience acid rain and offer an excellent place in which to study its deposition. An example of a project EPA turned down is one that claimed it was working on problems concerning global climate change, but could never make a convincing argument as to why it was uniquely qualified to look at this problem.
3) The quality of the investigators is of utmost importance. If the best research scientists and resource managers are not convinced that a consortium effort is important, then it is not worth applying for funds.
4) The people who decide how to spend the money are not necessarily the same people who will be the doers. These doers in the consortium (scientists, policy analysts, resource managers) have superiors outside the consortium. If the external bosses see that a first quality team of doers has been put together, this will encourage them to do their part to enable the consortium to act.
5) Going after multiple sources of funds is very wise. Even though there is supposed to be a billion dollar budget for research on global climate change, two-thirds of that goes to NASA, a good deal of it inside NASA is for building equipment; there is very little money for ecological research. Most of the new money in the federal research budget is going to marine sciences, and the atmospheric sciences. EPA would look extremely favorably, therefore, on any project that could develop matching funds from other state and federal agencies.
6) The federal agencies now have forums in which a group presents its project to all the interested agencies at once, rather than one at a time. These agencies can then discuss multiple funding.

Agency/Institute Input

Part of the discussion centered around what each entity has to give to the consortium. The US Army Corps of Engineers has large data bases covering long time periods, and also has experience in modeling. The US Forest Service now has a global climate change initiative with a coordinator for the Southwestern Region whose expertise is in air quality. The New Mexico State Engineer Office offers data and existing models which could be reevaluated with the focus of global climate change. Members of the State Bureau of Mines volunteered that the mining industry is threatened by any organization or research which suggested that they change or suspend their activities. The Bureau of Reclamation is creating land information systems using GIS. New Mexico has been chosen as a pilot project. The BLM is developing an Arid Lands Research Center that would be interested in paying for and sharing data with any other agency. New Mexico Engineering Research Institute at the University of New Mexico is developing a Center for Global Environmental Technologies, funded at 1.5 million. This center is devoted to new technologies. Funding is coming from the Air Force, Navy, FAA, and EPA. As various groups offer their contributions, a need for a mechanism to collect and transfer these resources of each agency is apparent.

An ugly issue that is always part of developing a multidisciplinary consortium is the issue of competition, whether this is between similar consortia or among members of one consortium. There is bound to be resistance within member institutions. Every agency has groups that will be threatened by the creating of a consortium that is bigger than their structure. This needs to be acknowledged immediately, and openly. Rules within the consortium pertaining to competition for scarce resources should be laid down immediately and clearly so that everyone knows them.

INFORMATION TRANSFER WORKSHOP

Conference participants who attended this workshop addressed two questions: how to improve communication between researchers based in different institutions but engaged in related work, and how to inform various publics about the issues with which the proposed Rio Grande Basin Consortium would be concerned.

Between Researchers

One of the problems considered by the discussants was that of scientists and/or practitioners who are professionally concerned with similar or related research subjects but, because they work in different institutions or fields of specialization, are unaware of their common interests and, thus, of the possibilities for collaboration or data exchange. As a step toward correcting this state of affairs, the conference organizers composed two questionnaires—one concerning water resource data, the other climate change research—which the participants were asked to complete and return. Results of both surveys are included as appendices to this volume.

One member of the discussion group mentioned that the consortium might expand the service rendered through these questionnaires by operating as a central repository of information concerning various climate studies and related data-generating activities underway in the Rio Grande Basin. Another group member proposed that, in time and with appropriate funding, the consortium might support a small staff for this archival function. At each of the institutions participating in the consortium, key contact people might be identified to act as the consortium clearinghouse reference sources for their organizations.

A related idea put forward was that the consortium establish a Rio Grande Basin computer bulletin board on TECHNET or another "net" to which a majority of consortium members had access. Such a bulletin board could be used for posting inquiries about needed data or announcements of requests for proposals, new studies undertaken, and newly available data. Consortium member agencies that were not tied into TECHNET or unable to afford its membership fees could arrange with agencies or universities that are TECHNET members to have access to it. Informing consortium participants of the existence of various networks and the means to use them was suggested as another service the consortium clearinghouse might provide.

Workshop discussants involved with the work of the recently formed New Mexico Geographic Information Systems (GIS) Task Force mentioned this organization's capacity to produce basemaps that could be extremely useful in the consortium's work, particularly, for example, in assembling an atlas of the basin.

A suggestion endorsed by the entire discussion group was that the consortium put out a quarterly newsletter informing members of its activities. One participant proposed that the newsletter attempt to address both professional and lay communities.

Public Education

Addressing the subject of public education, a workshop participant representing the Albuquerque Environmental Health Department remarked: "More and more, government agencies are realizing how critical it is to involve constituents in policy decisions. It's expensive and time consuming, but absolutely essential if you want to ensure citizen support for tax-sponsored projects designed to serve the public interest." This person also reported that the City of Albuquerque, planning its groundwater protection program, allocated $200,000 (10% of the total budget) to public involvement efforts.

The group members considered a variety of activities the consortium might initiate or support through a public education sub-committee. Among the ideas suggested, the following seemed to be regarded as most promising:

- Include in the consortium membership representatives of existing environmentally-oriented organizations or citizen activist groups.

  As one of the discussants noted, several of these groups already produce newsletters and sponsor public education programs which could serve as outlets for information about consortium business as well as, perhaps, vehicles for inviting lay volunteers to conduct surveys or participate in other data collection or processing tasks. Potentially interested organizations mentioned during the workshop included: the League of Women Voters, the Native Plant Society, the American Association of University Women, the Sierra Club, the Garden Club Federation of America, the Wilderness Society, the Cattlemens' Association, New Mexico Citizens for Clean Air and Water, the American Lung Association, the Conservation Voters Alliance, the Southwest Research and Information Center, and the New Mexico Hazardous Waste Management Society.

- Create a speakers bureau of consortium members who would be interested in making presentations to public interest, neighborhood, church, and other groups about issues raised by the possibility of climate change, their own research, or other subjects.

- Design an exhibit or other presentation that could be used by consortium members or volunteer associates in visits to elementary school classrooms or, possibly, loaned to local libraries, museums, or shopping malls.

  One of the workshop discussants noted that several of the concepts explained by speakers in the morning conference session could be presented in a graphic format on story boards in a stationary display. For instance, as individual participants noted, such displays might spotlight climate change hypotheticals ("what if . . .") or suggest "Things You Can Do to Reduce Air and Water Pollution."

- Work with Albuquerque Public Schools' (or another community's) environmental studies coordinator to design and integrate into elementary and middle school curricula small-scale studies of water, air, and land resources. These studies might include data collection and analysis projects such as those described in *Albuquerque's Environmental Story* and a similar book for young readers recently produced in Las Cruces.

- Initiate and maintain contacts with science writers from local newspapers and meteorologists from local television stations.

SUMMARY

This workshop opened up the complexity of determining which consortium structure would be most effective for the Rio Grande Basin in the long-run. Although participants recommended some basic components, it was acknowledged that the structure of the consortium depended on defining the projects with which it would deal. Effective leadership, consortium structure, and projects within the venue of the consortium have, of course, an influence on each other. It was generally agreed that a Consortium Steering Committee should be formed of representatives of each agency and institution, but especially of volunteers from the three Saturday afternoon workshops: Consortium Structure, Basin-Wide Conference, Education and Information Sharing. It was proposed that the group organizing the present conference should be the nucleus for the leadership team. It was decided that 1) members of the steering committee and the leadership team would investigate different successful structures and present them to the steering committee for consideration; 2) that a professional person with experience in management structure be consulted about the kind of structure that would fit the needs of the consortium.

THE RIO GRANDE BASIN CONSORTIUM—UPDATE

Eleonora Trotter, Biology Department, University of New Mexico

INTRODUCTION

At the end of the June workshop-conference, possible structures for an organization were discussed which could facilitate communication, data sharing, collaborative research, education, and decision-making among agencies, universities, municipalities and other entities within the Rio Grande Basin. The charge of this organization was to carry on the work started at the meeting to consider the Rio Grande Basin as an integrated biological system responsive to both global scale as well as to regional and local scale change. This organization was to include not only those striving to understand the physical and biological systems of the Rio Grande Basin, but also those concerned with the social and economic systems of the basin. No formal organizational structure was decided upon at the June meeting. Instead, an ad hoc steering committee was formed to develop an organization which is now called The Rio Grande Basin Consortium (RGBC). The purpose of this paper will be to describe the structure and activities of the Rio Grande Basin Consortium which have evolved since the meeting on the Rio Grande Basin and climate change scenarios. This paper will also list possibilities for this organization in the future.

CONSORTIUM STRUCTURE

The Rio Grande Basin Consortium steering committee consists of members elected by participants in workshops which discussed 1) consortium structure, 2) a basin-wide conference, and 3) education and outreach. Other members of the steering committee have been drawn from the organizers of the workshop/conference and from the original group of Faculty Scholars at the University of New Mexico who first developed the concept of the Rio Grande Basin as a research laboratory in which to study global climate. Finally, those indicating a strong interest and a demonstrated dedication to the development of a consortium have also been included in the interim steering committee. The workshop on consortium structure agreed that James R. Gosz (Principal Investigator of the Sevilleta Long Term Ecological Research Site, UNM) should be the chairman of the interim steering committee. Members of the committee are listed at the end of this chapter.

An ad hoc executive committee was also formed at the suggestion of the consortium Structure Workshop to perform the daily work of the consortium, as well to prepare for and to call to order meetings of the entire steering committee. This executive committee consists of Jim Gosz, chairman, Eleonora Trotter (research assistant professor, Department of Biology, UNM), Executive Director of the RGBC, and several other steering committee members at the University of New Mexico. UNM committee members can meet rapidly to give immediate attention to problems, as well as to take advantage of opportunities for the consortium, such as calls for proposals.

The full interim steering committee of the Rio Grande Consortium met for the first time in September 1990. At the suggestion of the workshop on consortium structure, a consultant with experience in developing appropriate structures for organizations was asked to lead a discussion on the mission and goals of the consortium and the development of organizational structure which would best support the mission and goals. Dr. Barbara Coe, visiting professor, UNM, Public Administration, led the discussion. Dr. Coe's specialty is in the organization of multi-agency collaborations. At the September meeting the interim steering committee agreed to become the steering committee of the RGBC. The ad hoc executive steering committee was asked to continue as constituted to do the daily business of the consortium, to develop projects for the consideration and approval of the full steering committee, and to call meetings of the full steering committee. As projects were developed, "teams" of those interested in that project would be formed. This simple, rather informal structure seemed to reflect immediate needs for organization. The full steering committee discussed a mission and a goals statement prepared by the executive steering committee. It was agreed that the mission and goals would be reworked as a result of this discussion and presented for approval at the next meeting of the full steering committee.

Dr. Coe's observations of the RGBC are summarized here.

1. The RGBC is an extremely dynamic group, and accomplished much at the first steering committee meeting by establishing a mission statement and deciding on a workable structure for present needs. Differences in levels of commitment to a collaborative organization were evident and are normal in multi-organizational groups, where they are more extreme than in single groups. In fact, membership itself will be extremely dynamic as other commitments pulled members away from the consortium and individual projects drew new members in. Different funding levels of member groups will also create dynamic change in commitment and membership. The establishment of an ad hoc structure around proposals as they materialized is logical and appropriate, as are memoranda of understanding between groups for each individual project, as the needs of each agency varies.

2. The question of representation on the steering committee will have to be addressed eventually. A committee should be no bigger than 20 to preserve the effectiveness of its decision making. On the other hand, there are more than 20 different entities within the basin which may become part of the consortium. One possibility is to rotate representation on the steering committee among the membership of the consortium to keep the size of the steering committee workable.

3. At some point in its development the consortium will have to establish formally an executive committee, a chairman/woman, and an executive director by election or by appointment.

4. It is very important for the effectiveness of the consortium that an equal number of researchers, managers, and decision-makers be represented on the steering committee. A suggestion from the workshop on consortium structure was for actively participating agencies to release key people to serve on the consortium steering committee. Part of those agencies' contribution to the consortium could be a salary to pay for participation in guiding consortium business.

5. In a multi-entity organization symbols of the organization such as a logo and letterhead, as well as formal agendas, detailed minutes of meetings, and informative newsletters are more important than in single organizations to the continued existence of the consortium. Concrete products, such as a proceedings of the June meeting and high visibility projects, for instance, are very important to institutionalize the organization.

CONSORTIUM PRODUCTS AND ACTIVITIES

The Rio Grande Basin Consortium steering committee has met three more times as of the publication of these proceedings (November 1990, and January and February of 1991). The first newsletter preceded the September meeting. A meeting in March is also planned. The steering committee has approved the mission statement and consortium goals stated below. The committee has decided to review and approve proposals which are consonant with the mission and goals of the consortium. Each proposal will include a statement that it has been approved by the steering committee, assigned an RGBC number, and a copy of the mission statement and consortium goals. Presently, there are four proposals approved by the steering committee. The following is a report of the achievements and plans of the consortium.

Products

1. These proceedings of the June 1990 meeting "The Rio Grande Basin: Global Climate Change Scenarios" is the first product of the consortium. It is being sent to all those attending the meeting, and is available through the Water Resources Research Institute, New Mexico State University, Las Cruces, New Mexico.

2. The consortium has published one newsletter in September 1990 reporting activities of the consortium.

Approved Projects

1. *National Park Service Proposal.* Bandelier National Monument and El Malpais National Monument in collaboration with the Sevilleta Long Term Ecological Research Site (one of 18 linked long-term ecological research sites funded by the National Science Foundation) applied to become a part of the National Park Service Global Climate change Program. This proposal as ranked among the top six of proposals reviewed by the National Park Service. Although the monuments are small they, in concert with the Sevilleta LTER,

will provide an array of biological sites which are likely to be extremely sensitive to global change. Four biomes collide within the state of New Mexico. The Sevilleta contains all these whereas El Malpais is within the Great Basin biome and Bandelier is within the Piñon-juniper woodland biome. A rich array of comparisons and contrasts among these sites can be made.

Because of high rating, the El Malpais and Bandelier will sponsor a workshop to write a Global Change Plan and approximately 10 pre-proposals involving these sites. Full proposals of a subset of the pre-proposals will be selected for funding in 1993. Weather patterns, plant physiology, and ice formation are areas of sensitivity to climate change at El Malpais. Bandelier has an unparalleled record of human use through time, and its fire history has been correlated with Pacific weather patterns. The Sevilleta has evidence of long-term human use, populations of organisms sensitive to climate change and well-documented weather patterns.

2. *Chino Mines Grant Fund*. The Water Resources Research Institute (WRRI) at New Mexico State University solicited proposals to develop training programs for environmental scientists, or to use innovative techniques to solve environmental problems such as the problem of ground water contamination in the state of New Mexico. A proposal was submitted to compare the functioning efficiency of a standard septic drain field and an alternative biofilter (marsh plants growing in a lined gravel bed) at the individual residence to cluster housing scale. These two systems will be fed by the same septic tank attached to the new Sevilleta LTER field station. It is hoped that information gained through this experiment will be useful to those wanting to install such systems, as well as to those developing regulations for this type of human effluent treatment.

3. *Database Planning Proposal*, National Science Foundation.

A proposal to design a database which could be used in common by the diverse agencies, institutions, and political entities in the Rio Grande Basin is being submitted to the National Science Foundation by the Department of Biology, Sevilleta LTER, University of Washington. The design of a database which is developed to be used by those of different disciplines (physical and biological, social and economic), as well as by different research, management, and decision-making groups has not, as far as is known, been attempted. The Rio Grande Basin presents a great richness of information upon which different groups could call to understand interrelated phenomena (biologist, social, political) within this region. The database proposal is stressing the concept of taking information from many separated sources (Geological Survey, Bureau of Reclamation, the Army Corps of Engineers, Langmuir Laboratory, Sandia and Los Alamos Laboratories, and many others) to make it possible for any one user to integrate information from data sets.

4. *Regional Response to Global Climate Change*. A meeting sponsored by the Houston Area Research Center, Houston, Texas, March 3-6, 1991.

James R. Gosz (Sevilleta LTER, UNM), Eleonora H. Trotter (RGBC, UNM) and Sarah Kotchian (Environmental Health, City of Albuquerque) represented the Rio Grande Basin Consortium at this important international meeting. A liaison with the Houston Areas Research Center group was discussed. A proposal is to study four counties in Texas that border the Rio Grande to determine how global warming may exacerbate and/or alleviate the natural, social, and economic problems in the Lower Rio Grande Valley. The RGBC has had a preliminary discussion with Dr. Allen Jones of HARC and a collaboration between the two groups promises much for integrated research and decision-making within the entire Rio Grande Basin. Among potential results of this collaboration is the possibility of sponsoring a basin-wide conference in the future which would include Colorado and Mexico as well. Other proposals and projects pending are reported in the next newsletter.

During the November RGBC steering committee meeting, when the Mission Statement and Consortium Goals below were approved, a committee member pointed out that the goals are ambitious but that such goals will sustain the consortium for many years.

INTERIM STEERING COMMITTEE

F. Lee Brown
Co-Director, Natural Resources Center
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RIO GRANDE BASIN CONSORTIUM DRAFT MISSION STATEMENT

The Rio Grande Basin Consortium is a coalition of scientists, administrators, practitioners, citizens, institutions, and agencies within the Rio Grande Basin. The consortium addresses the current and future status of the Basin resources by:

1. improving understanding of the Rio Grande Basin though the development of new knowledge about environmental, social, economic processes, and their interactions;

2. sharing the knowledge broadly and effectively to allow strengthening of decision-making processes; and

3. fostering interdisciplinary, interagency, and international cooperation.

CONSORTIUM GOALS

1. To be a clearinghouse of information on the environmental, social, and economic systems of the Rio Grande Basin.

2. To facilitate the exchange of multidisciplinary data in order to understand the various systems within the basin and their interactions.

3. To create and maintain an active network among consortium participants to:

   a) identify links between people and projects,
   b) demonstrate well-integrated, multidisciplinary efforts to improve the quality and usefulness of research,
   c) increase the cost-effectiveness of activities, and
   d) increase funding levels for basin projects.

4. To provide forums in which participants can interact, such as

   a) basin-wide conferences,
   b) workshops, courses, and publications,
   c) newsletters.

5. To develop ways to translate knowledge gained from research, administration, and application into understandable terms for the use of people from the rich diversity of cultures in the Rio Grande Basin.

6. To create and guide activities promoting sustainability of the resources in the Rio Grande Basin, respecting and valuing information from the different biological and physical systems as well as from people of different social and economic systems, past and present.

7. To promote social and economic responsiveness to environmental change, recognizing the interrelatedness of these systems.

8. To export a model of interrelated research, management, education, and social action to other regions experiencing environmental, social, and economic change.

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APPENDIX C

RESULTS, QUESTIONNAIRE I
GLOBAL CLIMATE CHANGE AND YOUR WORK[*]

A questionnaire on global climate change efforts and impacts was distributed to everyone invited to participate in the workshops. This provided a pre-conference assessment of involvement and concerns. Respondents represent 15 government agencies, universities and other organizations or offices.

The survey was short, consisting of only 4 questions:

1. Does your current work focus on or concern climate change?

2. Do you know of any climate change-related work currently being sponsored by your organization?

3. Are there aspects of your work that would be substantially affected by sudden and/or sustained changes in the basin's climate?

4. From your perspective what are the two most important research issues related to climate change in the Rio Grande Basin?

ABBREVIATIONS USED

ABQ = City of Albuquerque
ACE = Community Acequia Associations
BLM = Bureau of Land Management
BUREC = Bureau of Reclamation
CORPS = U.S. Army Corps of Engineers
ELBUT = Elephant Butte Water Users
GCC = Global Climate Change
HED/EID=Environmental Improvement Division
IHS = Indian Health Service
IWR = Institute for Water Research
LTER = Long-term ecological research
MINES = NM Bureau of Mines
NMSU = New Mexico State University
NMTEC = NM School of Mining & Technology
RGB = Rio Grande Basin
NPS = National Park Service
SENBING = Senator Bingaman
USFS = Unit U.S. Forest Service

Numbers in parentheses indicate number giving that response, if more than one.

1. DOES YOUR CURRENT WORK FOCUS ON OR CONCERN CLIMATE CHANGE?

ABQ
- Sharing information on climate change and exploring policy changes
- Requirements of cottonwood propagation
- Recharge Estimates
- Public education-hazards of climate change
- Water rights, resources--long-term implications if GCC
- No (3)

ACE
- Water rights, planning, conservation management--community acequias

BIA
- Agriculture, range, and soil taxonomy perspectives

BLM
- Effects of GCC on endangered species habitat
- Weather prediction, vegetation alteration, incidence of fire
- No direction issued in BLM from Washington
- Change in watershed conditions as results of climate change
- No

BUREC
- Water operations--Rio Grande, San Juan, Pecos
- Increase/decrease in precipitation--forecasts of

[*] Eleonora Trotter prepared questionnaire and compiled results

water accounting
Stochastic variations of weather and hydrology
No

CORPS
Flood control reservoir projects in the RGB
Frequency and amount of flooding important to hydrologic design
Regulation of Corps reservoirs in drought and wet
Computer model for optimization and reallocation

ELBUT
Management of water for irrigation

HED/EID
Airborne pollutants contribution to potential climate change

IHS
Effects of climate change drinking water from ground water

MINES
Geologic hazards--subsidence, fissuring, slope instability
Paleorecharge rates, paleoclimate, paleohydrology

NMERI
Limit emissions, recycle/recovery, alternative to CFCs

NMSU
Aerosol transport and diffusion models to predict rainfall
Research in hydrology, environmental engineering
Weather and ecosystem changes
RGB fisheries modeling, surface runoff, rainfall simulation
Experiments on responses of vegetation and soil to drought and rain
No

NMTEC
Siting of hazardous waste management based on information from past
Indirectly: acid rain and NOx chemistry
Long-term variability in weather not clear
Constructing water balance fluctuations, past 20,000 yr. Stable isotopes
No

NPS
Global Climate Change Program Committee, research

SCS
Soil moisture work for classification of soil series in RGB
Plant adaptations to environmental changes

SENBING
No response

SNL
Impact on predictions of ground water for 10,000 yrs--hazardous waste
Exploring policies, technologies to mitigate climate change
Weather variability-atmospheric transport and diffusion climatology
No

UNM
Paleoclimate reconstruction--lacustrine and marine sediments
Climate control of processes affecting nutrient cycling, etc.
No (2)

USFS
Relationship of watershed management and forest ecology
Water quality, development, augmentation, rights
Wildfires; water augmentation through vegetation management
Effect of atmospheric pollution on aquatic and terrestrial ecosystems
No

USGS
Geochem and isotope tech to study past recharge/flow ground water
Changes in surface ground water, well levels, recharge to basins
Regional flood frequency, streamflow, reservoir contents
Groundwater flow models to predict effects of scenarios
Water resources, data collection, interpretation

2. DO YOU KNOW OF ANY CLIMATE CHANGE-RELATED WORK CURRENTLY BEING SPONSORED BY YOUR ORGANIZATION?

ABQ
Air quality
Long-term biological study of Rio Grande Valley State Park
Meteorological
Groundwater quality and flow
No (6)

ACE
No

BIA
Depth-to-water surveys, rangelands; soil temperature/moisture--Jicarilla Reservation
BLM
LTER NMSU--Jornada desertification model northern Chihuahuan Desert
No (5)
BUREC
Sponsorship of this workshop/conference
Global Warming Coordinator (2)
With U of C, Advanced Decision Support System--basin modeling
CORPS
Completing Drought Contingency Plan for RGB
Corps IWR participating in international study on GCC
No (2)
ELBUT
Conservation methods for "on-farm" use
HED/EID
No, but maybe other work in EID
IHS
No
MINES
Quaternary geology, hydrology and environmental Geology (2)
NMERI
No
NMSU
Monitoring climate, especially spatial variation of rainfall and runoff
Instrumentation in remote areas
No (4)
NMTEC
Use stable isotopes in vadose-zone water. See above
Probabilities of sudden changes must be evaluated
No (3)
NPS
In Dept Interior GCC Working Group, in Washington, DC
SCS
Plant testing at Plant Materials Center--Los Lunas
Water management and leaching of pesticides
SENBING
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UNM
Faculty Scholars
El Nino/La Nina Southern Oscillation effects on precipitation in the Southwest (4).
USFS
Forest/atmosphere; Interaction Priority Program
No (4)
USGS
Several projects
Nationwide program on this topic
Research sites will supply input to GCC models (2)
Climate change studies by major basins in U.S.
No

3. ARE THERE ASPECTS OF YOUR WORK THAT WOULD BE SUBSTANTIALLY AFFECTED BY SUDDEN AND/OR SUSTAINED CHANGES IN THE BASIN'S CLIMATE?

ABQ
Spread of exotic tree species; decline of natives
Need for more cooperative efforts, assessment of risk
See above
Recharge studies; water rights
Insect disease vector population dynamics; ground-water recharge
Changes in ecosystems requiring education
Change in water quality and shortage of supply
No
ACE
No
BIA
Agriculture and range management
BLM
Fates of endangered and threatened animals and plants
Management of large acreages
Runoff timing, water quality, quantity, soil loss
Frequency, location, severity of fires
Mine reclamation-revegetation or open pit reclamation design
Revision of resource management for public lands in NM
BUREC
Rehabilitation and maintenance, reservoirs, water accounting
Water supply and demand
Water supply and usage
Surface hydrologic conditions

CORPS

Will require more coordination with other agencies

Increased pressure to reallocate reservoir storage

Overwhelming of levees and dams based on previous information

All facets of flood and drought control would be affected

ELBUT

Effect of droughts in cropping patterns

HED/EID

Climate change directly related to air quality

IHS

Long-term results of changing groundwater levels

MINES

More pressure on ground-water resources, especially irrigation

Geologic hazards change with change in precipitation and temperature

NMERI

No

NMSU

All aspects of agricultural research

Basic research to develop sustainable management if climate changes

Meteorological parameters would change

Management of water resources and water quality

Change in water flow and vegetation

NMTEC

Studies of thunderclouds, lightning, precipitation would be affected

Increasing variability in data base

Water flow, erosion, sedimentation, distributary stream and riparian species

Effects on groundwater and soilwater hydrology

NPS

National Parks in southwest might cease to exist

SCS

May delay release of certain species tested here

Soil moisture could change demanding correction in series

SENBING

No response

SNL

See 1

Both work and play

Weather forecast--large variability now

Would play larger role developing renewable resources

UNM

Physical and biotic interactions between floodplains and streams

Min-Max deviation without change in means causes change in cycling

Water markets affected by water availability

No

USFS

Water demand and availability--most water from forests

Timber species changes

Response of vegetation to flooding and drought

Forest water yield, instream flow, forest productivity

No response

USGS

Distribution and amount of surface and groundwater use

A change in trend could make tenuous predictions misleading

Increase in one program of research

Groundwater investigations--water supply

No

4. FROM YOUR PERSPECTIVE WHAT ARE THE TWO MOST IMPORTANT RESEARCH ISSUES RELATED TO CLIMATE CHANGE IN THE RIO GRANDE BASIN?

ABQ

Potential vegetation changes

Recover historic data; systematic collection of climate data

Sustained water supply

Local air quality. Which local actions seen on global scale?

Quantity of water and population density, agriculture and commercial economies

Scientific rigor: elimination of "pop science" aspect

Role of Rio Grande cottonwoods--CO_2 uptake

Relation of river, vegetation, wildlife, insects, humans

Predicted substantial changes in precipitation

Geographic Information System (GIS) role in supporting environmental research

Interactions of local and global air quality

Public understanding of human impacts on ecosystems

No response (3)

ACE

Use of GIS in research and planning

Impact of drought cycles especially if long-term

BIA

Vegetation changes

Temperature and moisture of soil

BLM

Ecological modeling under various change scenarios

Short- and long-term social and economic im-

pacts of GCC
Water quality
Water quantity
What ecological processes/feedback perpetrate desertification?

BLM

Evidence for human-induced climate change or periodic change?
Developing regional monitoring program
Vegetation change
Contribution of natural coal burns to "greenhouse effect"
Agricultural production
Fossil fuel use within the basin
Documenting existing land use, vegetation and soils

BUREC

How does climate change affect water supply?
How does climate change affect agriculture?
Impact on agricultural irrigation
Agriculture, silviculture, forestry, rural/urban habitats
Quantity, timing, quality of water supplies
Surface water supply
Impact on water supply
Groundwater recharge and depletion

CORPS

Optimizing use of reservoirs
Change in ppt patterns and amounts?
How will change affect basin residents (including wildlife)?
How will the climate of the Rio Grande Basin be affected?
Impacts on sediment transport
Rapidity of change in precipitation patterns and amounts?
Rainfall and snowpack
Will there be enormous environmental losses to sustain human use?

ELBUT

Long-range predictions to determine surface water allotment
Alternatives to water storage—evaporation from reservoirs

HED/EID

Regional air quality modeling and link to global models
Study local, regional, global changes in atmospheric data

IHS

Infiltration rates of water
Precipitation patterns--frequency and intensity

MINES

How climate has changed and impact on hydrologic regime?
How long between change in precipitation and temperature and impact on hydrologic system
Use of geologic record—effects of past climate changes
Keeping GCC a moderately scientific problem

NMERI

Release of CFCs
Release of Halons

NMSU

Associated changes in water quality
How to detect climate change?
Water availability
Change in precipitation/runoff regimes
How will it affect agricultural systems?

NMSU

Migratory birds on Rio affected—impact outside basin
How will it affect native plant systems?
Impact of climate change on water consumption
What parameters would respond most to climate change (precipitation/temperature)
Long-term predictions of water availability
Interrelationships of rainfall variability, vegetation, soils, etc.
Change in vegetation/desertification

NMTEC

Distinguish climate change from normal variability?
Elevated temperature—change nature and dynamics of all ecosystems
Will climate change lead to more or less rainfall?
Holocene, Pleistocene evolution of river valley systems
Better characterization of Holocene climatic record
Prediction of climate change (2)
Better characterization of ground water—surface water relationships
Change in hydrologic cycle—effects all ecosystems
No response (2)

NPS

Leverage funding by collaboration—state, local, national
Assessment of past and present climatic shifts

SCS

Chemical and physical changes in soils
Vegetative responses
Chemical and physical changes of soils
Vegetation responses

SENBING

Understanding global, regional and local impacts
Watershed protection; baseline information of past and present

SNL

Flow rates through unsaturated zone change?

Water availability and quality—Southwest not meant for such large populations

Quantifying potential impacts

Enhanced hydrostatic stability of air effects air quality

Synergistic relationship between climate, hydrology, ecotone?

Indications of and rate of GCC

Formulating responses

UNM

Present position in time spectrum of natural climate change

Effects on potential evapotranspiration

Education—all levels to live with less

Natural and social consequences of reduction of water?

Hydrologic consequences of climate change in basin?

Estimates of past climatic variability

How to develop cooperation among all users to conserve water

UNM

Effects on temporal-spatial distribution of precipitation

USFS

Buffering of climate in Rio Grande Basin. Are thresholds changing?

Change in biotic communities—diversity, habitat, ecotones

Resulting changes in watersheds

Water quantity

Water quality

Do changes in microclimates change climate of basin?

Predictive models for regional effects on hydrologic variables

Direction of forest vegetation change

No response (2)

USGS

Trends in groundwater supply

Effects in high mountain areas?

Water supply change

Is there global climate change?

Quality and quantity of surface and ground water

Changing the water budget—increased evapotranspiration

Demands change

Future impoundments in the upper Rio Grande

No response (2)

APPENDIX D

RESULTS, QUESTIONNAIRE II
WATER-RESOURCE DATA BASE[*]

A questionnaire on water data collected in the Rio Grande Basin was distributed to each person invited to attend the June 1 workshops. These 101 invitees represented 11 federal agencies, the 2 national laboratories, 3 Indian groups, 7 state agencies, the 3 major universities, as well as various politicians and water-use organizations. Although only 15 questionnaires were returned, they represent the major water-data-collection organizations in the state.

A follow-up phone survey addressed three things not easily covered with the matrix format of the questionnaire. These include 1) length and continuity of the record, 2) access form for computerized data and 3) availability of a list of publications. Results were compiled and respondents were given the opportunity to edit the summaries.

A blank questionnaire and questionnaire responses, including results of the phone survey, are presented on the following pages. Results are arranged alphabetically by organication. Specific questions regarding data available from any of the organizations should be directed to the contact indicated. Consult the explanation below for the meaning of abbreviations used in the summaries.

EXPLANATION

Frequency - collection interval: **bm** = bimonthly, **d** = daily, **h** = hourly, **irreg** = irregularly (usually on event basis), **m** = monthly, **q** = quarterly, **w** = weekly, **y** = yearly

Record - length/continuity of data base: **c** = continuous, **s** = single measurement or set of measurements at a site, **v** = length and/or continuity vary with location, **y** = years

Format - style of data base: **c** = computerized, **s** = some, **w** = written

Published - availability of information in published form: **i** = internal report or publication issued by organization, **o** = released through outside literature, ***** = publication list available

Accessibility - availability to the public: **f** = floppy disk available, **ip** = only if published, **p** = computer printout available, **s** = some

Interpreted - extent to which data are interpreted: **occas** = occasionally

Use - purpose of collecting data: **AMP** = for annual monitoring program, **CBWS** = for closed basin water salvage study, **DB** = for data base, **F/RU** = for fisheries, **GS** = for grazing studies, **GWS** = for ground-water studies, **IEA** = for irrigation efficiency analysis, **ISC** = for irrigation scheduling, **ISU** = for irrigation suitability, **MA** = for management, **MO** = for modeling, **NADP** = for National Atmospheric Deposition Program, **PS** = for problem solving, **R** = for research project, **RA** = for river assessment, **RS** = for recharge studies, **RTWC** = for real-time water control, **SEO** = for State Engineer Office, **SDWA** = for Safe Drinking Water Act requirements, **SS** = for stream standards, **USGS** = for US Geological Survey, **VRGW** = for vegetation response to ground water studies, **WA** = for water accounting, **WRA** = for water-rights administration, riparian-use studies.

Aquifer Properties include porosity (P), hydraulic conductivity (K), transmissivity (T) and yield (Y).

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[*] William Stone prepared questionnaire and compiled results.

WATER-RESOURCE DATA BASE

Contact David Schatersman Organization Bureau of Land Management

Title Hydrologist Address P.O. Box 1449

Phone 505-988-6231 Santa Fe, NM 87504

	Frequency	Record	Format	Published	Accessibility	Interpreted	Use
Meteorology							
Precipitation	d	v	c	all	all-p,f	always	NADP
Precip. chem.	m	v	c	all	all-p,f		
Evaporation							
Transpiration							
Other							
Surface Water							
Runoff							
Discharge	d	v	c	all	all-p,f	always	USGS
Diversion							
Water use							
Sed. load							
Chemistry							
pH							
Spec. cond.							
Total solids							
Hardness							
Other							
Soil Water							
Infiltration							
Moist. content							
Suction							
Chemistry							
Age							
Other							
Ground Water							
Water-level depth							
Water-level elev.							
Pumpage							
Water use							
Aquifer							
Aquifer prop.							
Recharge							
Chemistry	q	v	w	no	no	seldom	SDWA
Age							
Other							

WATER-RESOURCE DATA BASE

Contact Mike Hamman Organization Bureau of Reclamation
Title Water Operations Branch Chief Address P.O. Box 252
Phone 505-766-3381 Albuquerque, NM 87103

	Frequency	Record	Format	Published	Accessibility	Interpreted	Use
Meteorology							
Precipitation	d	v	w,c	i,part o	all-p,f	always	WA
Precip. chem.							
Evaporation	d	v	w,c	i,part o	all-p,f	always	WA
Transpiration							
Other (temp.)	d	v	w,c	i,part o	all-p,f	always	WA
Surface Water							
Runoff							
Discharge	d	v	w,c	i,part o	all-p,f		
Diversion	d	v	w,c	i,part o	all-p,f		
Water use	d	v	w,c	i,part o	all-p,f		
Sed. load	irreg	v	w,c	i	ip	always	RA,M
Chemistry	irreg	v	w,c	o	ip	always	WA
pH							
Spec. cond.							
Total solids	d	v	w,c	o	ip	always	WA
Hardness							
Other							
Soil Water							
Infiltration							
Moist. content							
Suction							
Chemistry							
Age							
Other							
Ground Water							
Water-level depth	d	v	c	i	ip	always	CBWS
Water-level elev.	d	v	c	i	ip	always	CBWS
Pumpage	d	v	c	i	ip	always	CBWS
Water use	d	v	c	i	ip	always	CBWS
Aquifer	irreg	v	c	i	ip	always	CBWS
Aquifer prop.	y	v	c	i	ip	always	CBWS
Recharge	y	v	c	i	ip	always	CBWS
Chemistry	d	v	c	i	ip	always	CBWS
Age							
Other							

WATER-RESOURCE DATA BASE

Contact Carl Popp
Title Professor of Chemistry
Phone 505-835-5227
Organization Chemistry Department
Address NM Tech
Socorro, NM 87801

	Frequency	Record	Format	Published	Accessibility	Interpreted	Use
Meteorology							
Precipitation							
Precip. chem.	d	v	w,c	part	all-p	occas	R
Evaporation							
Transpiration							
Other							
Surface Water							
Runoff							
Discharge							
Diversion							
Water use							
Sed. load							
Chemistry	irreg	v	w,c	part	ip-p	occas	R
pH	irreg	v	w,c	part	ip-p	occas	R
Spec. cond.							
Total solids							
Hardness							
Other							
Soil Water							
Infiltration							
Moist. content							
Suction							
Chemistry							
Age							
Other							
Ground Water							
Water-level depth							
Water-level elev.							
Pumpage							
Water use							
Aquifer							
Aquifer prop.							
Recharge							
Chemistry							
Age							
Other							

WATER-RESOURCE DATA BASE

Contact Douglas Earp
Title Geohydrologist
Phone 505-768-2600

Organization City of Albuquerque
Address P.O. Box 1293
Albuquerque, NM 87103

	Frequency	Record	Format	Published	Accessibility	Interpreted	Use
Meteorology							
Precipitation							
Precip. chem.							
Evaporation							
Transpiration							
Other							
Surface Water							
Runoff							
Discharge							
Diversion							
Water use							
Sed. load							
Chemistry	q	lyr,c	w,c	no	all-p	usually	DB
pH	q	lyr,c	w,c	no	all-p	usually	DB
Spec. cond.	q	lyr,c	w,c	no	all-p	usually	DB
Total solids	q	lyr,c	w,c	no	all-p	usually	DB
Hardness							
Other							
Soil Water							
Infiltration							
Moist. content							
Suction							
Chemistry							
Age							
Other							
Ground Water							
Water-level depth	m	3yrs,c	w,c	no	all-p	usually	DB
Water-level elev.	m	3yrs,c	w,c	no	all-p	usually	DB
Pumpage							
Water use							
Aquifer							
Aquifer prop.							
Recharge							
Chemistry	q	3yrs,c	w,c	no	all-p	usually	DB
Age							
Other							

WATER-RESOURCE DATA BASE

Contact Mike Riley
Title Special Project Coordinator
Phone 505-526-8391
Organization Elephant Butte Irrigation District
Address 530 S. Melendres
Las Cruces, NM 88004

	Frequency	Record	Format	Published	Accessibility	Interpreted	Use
Meteorology							
Precipitation							
Precip. chem.							
Evaporation	d	v,d	w	i	all	always	IS
Transpiration	d	v,d	w	i	all	always	IS
Other							
Surface Water							
Runoff							
Discharge							
Diversion	d	14yrs,c	w	i	all	always	IEA
Water use	d	14yrs,c	w	i	all	always	IEA
Sed. load							
Chemistry							
pH							
Spec. cond.							
Total solids							
Hardness							
Other							
Soil Water							
Infiltration	d	1yr,c	w	i	all	always	IS
Moist. content	d	1yr,c	w	i	all	always	IS
Suction	d	1yr,c	w	i	all	always	IS
Chemistry							
Age							
Other							
Ground Water							
Water-level depth							
Water-level elev.							
Pumpage	y	14yrs,c	w	i	all	always	IEA
Water use	y	14yrs,c	w	i	all	always	IEA
Aquifer							
Aquifer prop.							
Recharge							
Chemistry							
Age							
Other							

WATER-RESOURCE DATA BASE

Contact David Lightfoot
Title LTER Data Manager
Phone 505-646-3921
Organization Jornada LTER
Address Dept. of Biology, NMSU
Las Cruces, NM 88003

	Frequency	Record	Format	Published	Accessibility	Interpreted	Use
Meteorology							
Precipitation	d	20yrs,v	w,c	part o*	all-p,f	occas	R
Precip. chem.	d	20yrs,v	w,c	part o*	ip-p,f	occas	R
Evaporation	w,m	20yrs,v	w,c	part o*	all-p,f	occas	R
Transpiration							
Other (temp.)	h,d	20yrs,v	w,c	part o*	all-p,f	occas	R
Surface Water							
Runoff	irreg	v	w	part o*	ip	occas	R
Discharge							
Diversion							
Water use							
Sed. load	irreg	v	w	no	ip	occas	R
Chemistry	irreg	v	w	no	ip	occas	R
pH	irreg	v	w	no	ip	occas	R
Spec. cond.	irreg	v	w	no	ip	occas	R
Total solids	irreg	v	w	no	ip	occas	R
Hardness							
Other							
Soil Water							
Infiltration	irreg	v	w	no	ip	occas	R
Moist. content							
Suction	irreg	v	w,c	no	ip	occas	R
Chemistry							
Age							
Other							
Ground Water							
Water-level depth							
Water-level elev.							
Pumpage							
Water use							
Aquifer							
Aquifer prop.							
Recharge							
Chemistry							
Age							
Other							

WATER-RESOURCE DATA BASE

Contact William P. Winn | Organization Langmuir Lab
Title Director | Address NM Tech
Phone 505-835-5423 | Socorro, NM 87801

	Frequency	Record	Format	Published	Accessibility	Interpreted	Use
Meteorology							
Precipitation	d	v	w	no			R
Precip. chem.	d						R
Evaporation							
Transpiration							
Other (temp., wind, etc.)	d	7yrs,d (summers)	sw,sc	no	ip	occas	R
Surface Water							
Runoff							
Discharge							
Diversion							
Water use							
Sed. load							
Chemistry							
pH							
Spec. cond.							
Total solids							
Hardness							
Other							
Soil Water							
Infiltration							
Moist. content							
Suction							
Chemistry							
Age							
Other							
Ground Water							
Water-level depth							
Water-level elev.							
Pumpage							
Water use							
Aquifer							
Aquifer prop.							
Recharge							
Chemistry							
Age							
Other							

WATER-RESOURCE DATA BASE

Contact Keith Yarborough
Title Physical Scientist
Phone 505-988-6870

Organization National Park Service
Address P.O. Box 728
Santa Fe, NM 87504-0728

	Frequency	Record	Format	Published	Accessibility	Interpreted	Use
Meteorology							
Precipitation	m	v	w,sc	no	all-p	occas	PS
Precip. chem.	m	v	w,sc	no	all-p	occas	PS
Evaporation	m	v	w,sc	no	all-p	occas	PS
Transpiration							
Other (wind)	m	v	w,sc	no	all-p	occas	PS
Surface Water							
Runoff							
Discharge	d,m,y	v	w,sc	no	all-p	occas	PS
Diversion							
Water use	d,m,y	v	w,sc	no	all-p	occas	PS
Sed. load	m	v	w,sc	no	all-p	occas	PS
Chemistry	m	v	w,sc	no	all-p	occas	PS
pH	m	v	w,sc	no	all-p	occas	PS
Spec. cond.	m	v	w,sc	no	all-p	occas	PS
Total solids	m	v	w,sc	no	all-p	occas	PS
Hardness	m	v	w,sc	no	all-p	occas	PS
Other (toxics)	m	v	w,sc	no	all-p	occas	PS
Soil Water							
Infiltration							
Moist. content							
Suction							
Chemistry							
Age							
Other							
Ground Water							
Water-level depth	m	v	w,sc	no	all-p	occas	PS
Water-level elev.	m	v	w,sc	no	all-p	occas	PS
Pumpage							
Water use	m	v	w,sc	no	all-p	occas	PS
Aquifer							
Aquifer prop.	m	v	w,sc	no	all-p	occas	PS
Recharge							
Chemistry	m	v	w,sc	no	all-p	occas	PS
Age	irreg	v	w,sc	no	all-p	occas	PS
Other							

WATER-RESOURCE DATA BASE

Contact William J. Stone
Title Senior Hydrogeologist
Phone 505-988-6231
Organization NM Bureau of Mines
Address Campus Station
Socorro, NM 87504

	Frequency	Record	Format	Published	Accessibility	Interpreted	Use
Meteorology							
Precipitation	irreg	v	w,c	no	all-p	always	RS
Precip. chem.	irreg	v	w	no	all-p	always	RS
Evaporation							
Transpiration							
Other							
Surface Water							
Runoff							
Discharge							
Diversion							
Water use							
Sed. load							
Chemistry							
pH							
Spec. cond.							
Total solids							
Hardness							
Other							
Soil Water							
Infiltration							
Moist. content	irreg	s	w,c	i	all-p	always	RS
Suction							
Chemistry	irreg	s	w,c	i	all-p	always	RS
Age	irreg	s	w	i	all-p	always	RS
Other							
Ground Water							
Water-level depth	irreg	s	w,sc	most i*	ip-p	always	GWS
Water-level elev.	irreg	s	w,sc	most i*	ip-p	always	GWS
Pumpage							
Water use	irreg	s	w,sc	most i*	ip-p	always	GWS
Aquifer	irreg	s	w,sc	most i*	ip-p	always	GWS
Aquifer prop.	irreg	s	w,sc	most i*	ip-p	always	GWS
Recharge	irreg	s	w,sc	most i*	ip-p	always	GWS
Chemistry	irreg	s	w,sc	most i*	ip-p	always	GWS
Age							
Other							

WATER-RESOURCE DATA BASE

Contact David Tague/William Bartels Organization NM Env. Improv. Div.
Title Surface Water/Ground Water Address 1190 St. Francis Drive
Phone 505-827-2822/827-2981 Santa Fe, NM 87503

	Frequency	Record	Format	Published	Accessibility	Interpreted	Use
Meteorology							
Precipitation							
Precip. chem.							
Evaporation							
Transpiration							
Other							
Surface Water							
Runoff							
Discharge							
Diversion							
Water use							
Sed. load							
Chemistry	irreg		c	no	p	occas	DB
pH	irreg		c	no	p	occas	DB
Spec. cond.	irreg		c	no	p	occas	DB
Total solids	irreg		c	no	p	occas	DB
Hardness	irreg		c	no	p	occas	DB
Other (nutri-ents, metals)	irreg.		c	no	p	occas	DB
Soil Water							
Infiltration							
Moist. content							
Suction							
Chemistry							
Age							
Other							
Ground Water							
Water-level depth							
Water-level elev.	irreg	v	w	no	all	seldom	SDWA
Pumpage	irreg	v	w	no	all	seldom	SDWA
Water use							
Aquifer							
Aquifer prop.							
Recharge							
Chemistry	irreg	v	w	no	all	occas	SDWA
Age							
Other							

WATER-RESOURCE DATA BASE

Contact Tom Morrison
Title Water Resource Engineer
Phone 505-827-6135

Organization NM State Engineer Office
Address Bataan Memorial Bldg.
Santa Fe, NM 87503

	Frequency	Record	Format	Published	Accessibility	Interpreted	Use
Meteorology							
Precipitation							
Precip. chem.							
Evaporation							
Transpiration							
Other							
Surface Water							
Runoff							
Discharge							
Diversion							
Water use	5yr	15yr	w,c	i*			GWS,M,PS, RA,WA,WRA
Sed. load							
Chemistry							
pH							
Spec. cond.							
Total solids							
Hardness							
Other							
Soil Water							
Infiltration							
Moist. content							
Suction							
Chemistry							
Age							
Other							
Ground Water							
Water-level depth	5yrs	v	w,c	part*	all	occas	GWS,M,WA, USGS/DB
Water-level elev.							
Pumpage	y	v	w,c	part*	all	occas	GWS,M,WA, WRA
Water use							
Aquifer	irreg	v	w	no	all	occas	GWS,M,WRA
Aquifer prop.							
Recharge							
Chemistry							
Age							
Other							

WATER-RESOURCE DATA BASE

Contact Dick Kreiner
Title Chief, Reservoir Control
Phone 505-766-2639

Organization US Army Corps of Engineers
Address P.O. Box 1580
Albuquerque, NM 87103-1580

	Frequency	Record	Format	Published	Accessibility	Interpreted	Use
Meteorology							
Precipitation	d,m,y	v	w,sc	no	all-p	occas	R,DB
Precip. chem.							
Evaporation	d,m,y	v	w,sc	no	all-p	always	WA
Transpiration							
Other							
Surface Water							
Runoff	d,m,y	v	w	no	ip	occas	RTWC
Discharge	d,m,y	v	w,c	no	ip-p	always	RTWC
Diversion	d,m,y	v	c	no	all-p	always	WA
Water use							
Sed. load							
Chemistry							
pH							
Spec. cond.							
Total solids							
Hardness							
Other							
Soil Water							
Infiltration							
Moist. content							
Suction							
Chemistry							
Age							
Other							
Ground Water							
Water-level depth							
Water-level elev.							
Pumpage							
Water use							
Aquifer							
Aquifer prop.							
Recharge							
Chemistry							
Age							
Other							

WATER-RESOURCE DATA BASE

Contact Charles Mullins
Title Biologist
Phone 505-883-7877

Organization US Fish & Wildlife Service
Address 3530 Pan American, NE - Suite D
Albuquerque, NM 87107

	Frequency	Record	Format	Published	Accessibility	Interpreted	Use
Meteorology							
Precipitation							
Precip. chem.							
Evaporation							
Transpiration							
Other (temp.)							
Surface Water							
Runoff							
Discharge							
Diversion	irreg	30yrs,v	w	i	all	occas	FIRU
Water use	irreg	30yrs,v	w	i	all	occas	FIRU
Sed. load							
Chemistry							
pH							
Spec. cond.							
Total solids							
Hardness							
Other							
Soil Water							
Infiltration							
Moist. content							
Suction							
Chemistry							
Age							
Other							
Ground Water							
Water-level depth	irreg	v	w	i,o	all	occas	VRGW
Water-level elev.							
Pumpage							
Water use							
Aquifer							
Aquifer prop.							
Recharge							
Chemistry							
Age							
Other							

WATER-RESOURCE DATA BASE

Contact Deborah Potter Organization US Forest Service
Title Program Leader - WSA Address 517 Gold Ave, SW
Phone 505-842-3143 Albuquerque, NM 87102

	Frequency	Record	Format	Published	Accessibility	Interpreted	Use
Meteorology							
Precipitation							
Precip. chem.							
Evaporation							
Transpiration							
Other (visibility)	d	v	c	i	all-f	occas	DB
Surface Water							
Runoff							
Discharge							
Diversion							
Water use							
Sed. load							
Chemistry	irreg	v	c	i	all	occas	M
pH	irreg	v	c	i	all	occas	M
Spec. cond.							
Total solids							
Hardness							
Other							
Soil Water							
Infiltration	irreg,y	v	w	i	all	occas	GS
Moist. content	irreg,y	v	w	i	all	occas	DB
Suction	irreg,y	v	w	i	all	occas	DB
Chemistry	irreg,y	v	w	i	all	occas	DB
Age							
Other (permeability)	irreg,y	v	w	i	all	occas	DB
Ground Water							
Water-level depth							
Water-level elev.							
Pumpage							
Water use							
Aquifer							
Aquifer prop.							
Recharge							
Chemistry	irreg	v	w	no	all	always	SDWA
Age							
Other							

WATER-RESOURCE DATA BASE

Contact Roy Cruz
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Organization U.S. Geological Survey-WRD
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	Frequency	Record	Format	Published	Accessibility	Interpreted	Use
Meteorology							
Precipitation	d,irreg	v	c	i,o	ip-f,p	occas	GWS,R
Precip. chem.	m	v			ip-f,p		
Evaporation							
Transpiration	irreg	v			ip-f,p	occas	GWS,R
Other							
Surface Water							
Runoff	d,m,y	v	c	i,o	f,p	occas	MA,R
Discharge	d,m,y	v	c	i,o	f,p	occas	MA,R
Diversion	d,m,y	v	c	i,o	f,p	seldom	MA,R
Water use							
Sed. load	d	v	c	i,o	f,p	occas	ISU,MA,R, SDWA,SS
Chemistry	bm,q	v	c	i,o	f,p	occas	ISU,R,SDWA,SS
pH	bm,q	v	c	i,o	f,p	occas	ISU,R,SDWA,SS
Spec. cond.	d,bm,q	v	c	i,o	f,p	occas	ISU,R,SDWA,SS
Total solids	bm,q	v	c	i,o	f,p	occas	ISU,R,SDWA,SS
Hardness	bm,q	v	c	i,o	f,p	occas	ISU,R,SDWA,SS
Other							
microbiology	bm,q	v	c	i,o	f,p	occas	ISU,R,SDWA,SS
temperature	d,bm,q	v	c	i,o	f,p	occas	ISU,R,SDWA,SS
Soil Water							
Infiltration	m,irreg	v	c,w	i,o	ip-f,p	always,occas	AMP,R
Moist. content	m,irreg	v	c,w	i,o	ip-f,p	always-occas	AMP,R
Suction	m,irreg	v	c	i,o	ip-f,p	always-occas	R
Chemistry	irreg	v	c,w	i,o	ip-f,p	always	AMP,R
Age							
Other							
Ground Water							
Water-level depth	d,m,y, irreg	v	c,w	i,o	s,ip-f,p	occas-seldom	AMP,DB, GWS,MO,
PS,SEO,U							
Water-level elev.	d,m,y, irreg		c,w	i,o	s,ip-f,p	occas-seldom	AMP,DB, GWS,MO,PS, SEO,U
Pumpage	irreg	v	c,w	i,o	ip	occas	GWS,MO
Water use	m,irreg	v	c,w	i,o	ip	always-occas	GWS,R,MO
Aquifer	irreg	v	c,w	i,o	ip	occas	GWS,R,MO
Aquifer prop.	irreg	v	c,w	i,o	ip	always	GWS,MO
Recharge	irreg	v	c,w	i,o		occas	GWS,R,MO
Chemistry	irreg	v	c,w	i,o	f,p	occas	DB,GWS,SEO, R,RS
Age	irreg	v	c,w	i,o	ip-f,p	occas	GWS,R,RS
Other							