IMPACT ASSESSMENT BY ANALOGY:
COMPARING THE OGALLALA AQUIFER DEPLETION
AND CO$_2$-INDUCED CLIMATIC CHANGE

Michael H. Glantz
Environmental and Societal Impacts Group
National Center for Atmospheric Research
Boulder, Colorado 80307

and

Jesse H. Ausubel
35 Claremont Avenue
New York, New York 10027

September 1982
IMPACT ASSESSMENT BY ANALOGY.

Michael H. Glantz
and
Jesse H. Ausubel

ABSTRACT

This paper presents a comparison of two long-term, gradual, cumulative environmental changes with potentially severe societal consequences for the American Great Plains: the depletion of the Ogallala Aquifer and a possible global warming induced by increasing carbon dioxide (CO₂) in the atmosphere. While these two environmental issues (one actual and one potential) have been addressed separately in the past, there are compelling reasons to consider them together. A most important reason is that both have implications for the amount of water available for sustained agricultural production in this region. Also, linking such issues could enable us to learn, on the basis of how society responds to one issue, how it might respond to others.

The first section discusses the logic and possible value of reasoning by analogy. The second section describes the two cases, identifies similarities and differences, and suggests a possible convergence between the Ogallala and CO₂ issues. The third section examines categories of potential societal responses for these issues.

The authors conclude that because studies of possible responses to the Ogallala depletion are more advanced, they may shed light on responses to a hypothetical CO₂-induced climatic change. Portions of the Congressionally mandated $6 million High Plains Study that analyzed the Ogallala depletion for its impacts on the national, regional, state, and local economies, could provide useful first approximations of how farmers and other decisionmakers might respond to a CO₂-induced change in the regional water balance. They also conclude that it may be timely to take these two issues, and other long-term, gradual, cumulative environmental issues that have been expressed analogically as analogies with CO₂ (e.g., acid rain, air pollution, and soil erosion) and consider an overall framework in which responses can be considered and evaluated. Finally, it is important to look at them together because their effects on society may converge, if present trends in exploitation of the aquifer continue and if speculation about the CO₂ issue and its impacts on the region prove to be correct.

Paper submitted for publication. Please do not quote without permission of the authors.
Introduction

This paper compares two long-term, gradual, cumulative environmental changes with potentially severe societal consequences for the American Great Plains: the depletion of the Ogallala Aquifer and a possible global warming induced by increasing carbon dioxide (CO$_2$) in the atmosphere. While these two environmental issues (one probable and one potential) have been addressed separately in the past, there are compelling reasons to consider them together. Both have implications for the amount of water available for sustained agricultural production in this region. Linking such issues could enable us to learn, on the basis of how society responds to one issue, how it might respond to others. The linkage also shows the need to identify the combined regional effects and societal responses to these problems. As Pittock and Salinger have suggested for the CO$_2$ issue, "It is the regional effects of such a global warming which will largely determine the social and economic consequences" (1). Assessing these environmental issues together suggests that researchers and policymakers should formalize their "casual" analogies by undertaking more rigorous comparisons and making their assumptions about the analogy explicit (2).

The paper is divided into four parts. The first section discusses the logic and possible value of reasoning by analogy. The second section describes the two cases, identifies similarities and differences, and suggests a possible convergence between the Ogallala and CO$_2$ issues. The third section examines categories of potential societal responses for these issues. A final section offers conclusions and recommendations.
1.1 **Reasoning by analogy**

Reasoning by analogy is by no means a newly discovered endeavor but has been one of the traditional tools of the art of discourse. Mathematical models might be regarded as a formalized version of analogy, in which extended, elaborate comparisons are often drawn between logico-mathematical structures and the behavior of natural, hypothetical, or human systems. The purpose of this paper is more modest; we claim merely that certain issues are amenable to comparison, both in general and in detail, that the elements of such comparisons should be made explicit, and that the similarity of properties may be enlightening and useful for assessment and could possibly have some predictive value.

1.2 **Economy of Effort**

Use of analogy in the study of the impacts of climate on society was proposed by participants in the Working Group on Impacts at the World Climate Conference (3). There were at least two reasons for suggesting such an approach. First, it is important in climate-related impact assessment research to absorb the lessons of the past in order to ensure progress as one climate impact study follows another (4). Large impact assessment studies are now underway on the CO₂ issue, and it is important to assure that those undertaking these efforts be made aware of, and exploit, experiences gained during the past decade in climate impact assessment as well as in other areas of research that may have a bearing on the CO₂ issue. For example, there are undoubtedly similarities in structure, function, and methods of research between current CO₂ efforts and recent efforts to examine, for example, the potential consequences of
climatic changes brought about by stratospheric supersonic flight or chlorofluorocarbon releases to the atmosphere or the consequences of drought in the Sahelian region of West Africa.

Secondly, there are several environmental issues that may have strong similarities with regard to societal effects—for example, CO₂, acid rain, depletion of the ozone layer, soil erosion, and depletion of ground water. Efforts must be made to share research experiences so that in each case the impact assessment will not have to be undertaken as if it were the first time one had faced this genre of environmental problem.

To these two reasons for using analogy may be added a third. A comprehensive assessment can be extremely expensive. By contrast, reviews of past, similar experiences are generally quite inexpensive. They enable us to avoid duplication and to begin further studies from a higher level of sophistication and with a greater awareness of the successes as well as the pitfalls of climate-related impact analysis.

A workshop on the effect of a CO₂-induced warming recommended comparisons with previous warm periods in history.

Appropriate case studies might include the late Roman Empire (300-600 AD), Iceland in the Middle Ages (1100-1400 AD), Western and Central Europe (14th Century), North America during initial European colonization (1500-1650), or the U.S. High Plains from 1870 to the present (5).

However, as acknowledged by the report, differences between periods may outweigh their similarities, and thus raise doubt about the value of historical analogies.

Comparing two contemporary environmental changes may raise fewer a priori questions. To provide an example, we propose to compare the
regional effects of water depletion in the Ogallala Aquifer with those resulting from a climatic change induced by CO₂ loading of the atmosphere. First we will identify similarities in the two issues and show that they share enough important characteristics to justify further discussion. On the basis of this comparison, we will try to determine if responses of decisionmakers, from farmers to national policymakers, to the one issue might be similar to responses to the other.

2.1 The Ogallala Aquifer Depletion

The Ogallala Aquifer is a geological formation of water-bearing porous rocks which underlies parts of eight states in the American Great Plains, stretching about 800 miles from north to south and about 400 miles from east to west (Figure 1).
The depth of the aquifer from the surface of the land, its rate of natural recharge, and its saturated thickness vary from region to region (6). The aquifer provides a major source of water for agricultural, municipal, and industrial development in a large section of the Great Plains. It is particularly valuable in the dry climate of that area, where the rainfall is highly variable, with runs of wet or dry years sometimes occurring.

Exploitation of the aquifer has varied through time as well as from place to place. It began at the turn of the century in the southern part of the High Plains but did not become extensive there or in other parts of the Great Plains until farmers were faced with an extended drought at a time when technological developments had reduced the costs of tapping the groundwater (7,8). The first major impetus to exploitation of the aquifer was the drought of the 1930s, when many dryland farmers resorted to groundwater to reduce their vulnerability to uncertain rainfall. Once drilled, the wells tended to remain in operation, even after the drought was over.

Since World War II, reliance on groundwater in the region has increased steadily, stimulated by drought in the 1950s, new irrigation technology, cheap energy for pumping, and higher prices for food, feed grains, and cotton. Tens of thousands of wells now dot the region above the aquifer. A large, new agricultural economy has developed because irrigation farming provides much greater economic returns per unit area than was possible with dryland farming. In addition, an extensive feedlot industry has developed in this region, supplying by 1977 about 38 percent of the national total production of grain-fed beef (9).
The hydrologic results of this sharp increase in the use of water from the aquifer have been major. The withdrawal of water has greatly surpassed the aquifer's rate of natural recharge (e.g., 10, 11). Because the saturated thickness and rates of withdrawal and recharge vary spatially, and because the lateral movement of the water in the aquifer is exceedingly slow, some places overlying the aquifer have already depleted their water supply as a source of irrigation; in others rising costs of energy have made it either uneconomic to rely on groundwater or have prompted farmers to conserve. On the High Plains of Texas, for example, where the aquifer is the main source of irrigation water, drawdown has been viewed as critical since the early 1950s (12). Other parts of the Plains, especially Nebraska, have more favorable saturation thickness and recharge rates and are not so vulnerable (13). Reinforcing this difference is that "present laws concerning ground water vary from no statewide regulatory controls in Texas to full authority of the State Engineer to control ground water extractions in New Mexico" (9, p. I-4).

In 1976, Congress expressed its concern about the water resource situation in the High Plains by authorizing a $6-million, five-year study (Section 193 of Public Law 94-587):

In order to assure an adequate supply of food to the nation and to promote the economic vitality of the High Plains Region, the Secretary of Commerce...is authorized and directed to study the depletion of the natural resources of those regions...presently utilizing the declining water resources of the Ogallala aquifer, and to develop plans, to increase water supplies in the areas and report thereon to Congress.... In formulating these plans, the Secretary is directed...to examine the feasibility of various alternatives to provide adequate water supplies to the area...to assure the continued economic growth and vitality of the region... (9, p. I-5-I-6)
The year 2020 was selected as the date toward which to project. In addition to this study, a $5.5 million study was commissioned for the U.S. Geological Survey "to provide (1) hydrologic information needed to evaluate the effects of continued ground-water development; and (2) computer models to predict aquifer response to changes in ground-water development" (13).

Several draft reports on impact studies on the Ogallala are already available (9,14). The High Plains Study Council, composed of the Governors of the six states involved in the study, is expected to present recommendations to the U.S. Congress by February 1983. The final report of the High Plains Study is likely to show favorable conditions for agriculture until 2020 in most areas of the aquifer. By 2020, however, most of the marginal lands will have been put into use and there will be little additional land after that time to bring into production in order to offset the loss of the land removed from irrigation because of the depletion of the aquifer elsewhere in the region.

2.2 Carbon Dioxide and Climatic Change

Carbon dioxide is a trace gas that is important in regulating the climate of the earth. Human activities are increasing the concentration of carbon dioxide in the atmosphere. These activities include deforestation and various other land uses that lead to combustion of wood and oxidation of organic materials in soils, but by far the most important contribution is from the burning of coal, oil, and gas. Projections of continuing growth in population and economic activity imply increasing levels of CO₂, if a substantial share of global energy is extracted from fossil fuels, especially from the abundant supplies of coal. Such projections predict a
doubling of pre-industrial levels of atmospheric CO₂ within the next 50-100 years (15-18).

While there is little doubt that carbon dioxide traps longwave radiation, thus warming the atmosphere near the surface of the earth, there is substantial uncertainty about what the climatic consequences of increased CO₂ would be. Many numerical models of the atmosphere suggest an increase in global average annual surface temperature of about 2-3°C with a doubling of CO₂ (18,19). The earth would then be as warm as it appears to have been during any period in the last 100,000 years (20). The temperature increase would not be distributed uniformly among regions: if there is a 2°C warming near the equator, there might be a 5-10°C warming (annual average) near the poles. Very little can be said with confidence, however, about redistributions of rainfall that might occur. Moreover, the estimates are based on equilibrium responses of climatic models to very large fixed increases in CO₂.

Numerical models of the climate system suggest that, given an increase of CO₂ in the atmosphere, precipitation will increase in the tropics whereas the midlatitude rainbelt will shift northward. With higher evaporation rate due to higher temperatures in these areas in North America that presently provide water for irrigated agriculture, these areas will grow drier (21).

The modeling results, which must be qualified by substantial uncertainty, are supported by findings in paleoclimatology, whose data are likewise tentative. As can be seen in figure 2, reconstruction of the climate of the Altithermal (about four to eight thousand years ago),
a period for which paleoclimatological evidence suggests that warmer atmospheric temperatures may have occurred on a hemispheric scale, shows that a drier band existed in the midlatitudes of the Northern Hemisphere (22, 23).

Scientists have also plotted temperature and precipitation patterns that occurred in the Northern Hemisphere during the ten warmest Arctic winters and summers in the twentieth century (24) as well as departures for annually averaged conditions only (25). A short period of instrumental records makes it difficult to define quantitative scenarios for longer periods (i.e., decadal), so we look at ensemble averages of individual years. If the characteristics of these ensembles (i.e., sets) of individual years prove to be realistic indicators of long-term changes, then these particular observed climatic data could suggest what the effects of a CO$_2$-induced global warming might be. Figure 3 depicts the
summer precipitation anomalies that occurred during the ten warmest Arctic summer seasons (26). For example, the chart suggests drier conditions in the Great Plains correlating with warmer Arctic summers and, by inference, with a warmer earth.

It is not clear whether anthropogenic effects have been detected in present climatic statistics. However, if model estimates are reasonably correct, those effects should appear unambiguously in the next 10 to 20 years (e.g., 27-29). As CO\textsubscript{2} continues to increase, the consequences for climate should emerge more distinctly, and the consequences in agriculture, water supply systems, and many aspects of human life and the environment are likely to manifest themselves with increasing intensity. Of course, the consequences of the changes in climate and increases in atmospheric CO\textsubscript{2} could be beneficial as well as harmful. Indeed, CO\textsubscript{2} is essential for plant
life, and increasing CO₂ could have a positive effect on food supplies by increasing photosynthetic rates for some plants (30). The numerous possible beneficial or detrimental effects and their distribution over regions, industries, and population groups are beginning to be explored in a systematic way.

Although the consequences of increasing CO₂ and climatic change are unknown, numerous policy groups have begun to take an interest in the question (e.g., 31-34). The Department of Energy is conducting a multi-year research program and evaluation of the problem, and the National Academy of Sciences has recently completed a review (18). In addition, CO₂ is attracting the attention of an increasing number of physical scientists (for bibliographies on the CO₂ issue see 35-37), as well as social scientists (e.g., 38-42).

2.3 Similarities, differences, and convergence

Do the CO₂ and Ogallala issues have enough in common to justify an analogy? They share several important characteristics, most notably a long time scale. Both issues are expected to become serious within the next 50 years (as the Ogallala becomes largely depleted in some areas and the climate presumably departs from the range within which it has remained for the past tens of thousands of years) and to become increasingly critical through the next century. Both issues also become gradually more serious. The drawdown of water and the burning of fossil fuels are essentially continuous and have been steadily increasing; they are not comparable to a sudden dam burst or the dumping of toxic wastes, in which the potential problem is connected to a small number of identifiable, discrete events.
Moreover, both issues are cumulative and difficult or costly to reverse. Each foot of drawdown of the Ogallala brings the total depletion closer. Similarly, a portion of each year's CO₂ emissions adds to previous accumulation, and the ability of the Earth to withdraw carbon from the atmosphere is not growing as rapidly as our capacity to add to it. Implementation of policies to recharge the Ogallala or reduce atmospheric CO₂ concentration can be effective only over a long period, so that if policy action is postponed for many years, the only option may be to accept the environmental changes and to adapt.

Another parallel is that both issues are affected by our tendency to opt for short-term gains from the use of large amounts of water or energy without considering possible long-term costs. Finally, cheap fuel can aggravate both issues; if it is expensive to buy fossil fuels or pump water, the problems may grow at a slower pace.

In some characteristics, the two issues show weaker similarities or differences. Both the CO₂ increase and the Ogallala depletion have features of a potential "tragedy of the commons." A tragedy of the commons occurs when a resource which is freely available to all is so heavily used that the resource is exhausted or degraded (43,44). It is worth noting that the histories of various local, regional, and subnational commons (e.g., grazing lands, river systems, fisheries) offer excellent lessons in the variety of responses by human institutions to changes in resource supply and demand. In the case of CO₂, all countries share the atmosphere and its capacity for disposal of waste; if many nations emit large amounts of CO₂, they, along with others, may end up with climates quite different
from the ones they have today. The Ogallala, like CO₂, is an issue which becomes serious if many users behave in the same way.

However, the consequences are not necessarily distributed or shared in similar fashion. Nations which burn the most coal may or may not suffer the most adverse consequences, although climate studies do suggest that the USSR, China, and the United States, the countries with the largest coal reserves, will probably all experience some drying. Their actions could well impose large costs on some others.

In contrast, there is much strong local cause and effect with the Ogallala. Although its depletion could have secondary but nonetheless dire effects on food importing members of the international community, the Ogallala is, in fact, a national problem. The heaviest users of the aquifer are quite likely to suffer the most immediate adverse consequences. The flow within the aquifer is not so free or fast that the consequences will spread evenly or rapidly. CO₂ also presents greater possibilities for benefit, for example, due to increased photosynthetic productivity (45) than the Ogallala depletion, though judicious farmers might gain from the adversity of others. Both issues do require widespread action to make most responses effective. The nature of economic markets means that even careful behavior by an individual farmer or nation to gain insulation from the issue will meet limited success.

While the degree of "commonality" in the CO₂ issue is greater, so is the degree of uncertainty. It is highly speculative how much CO₂ will be emitted; how the climate will change; what the impacts on society and the environment will be; in what context of national and global events the
climate-induced changes will take place. In contrast, rates of drawdown of the Ogallala aquifer, degree of depletion, depth from surface, saturated thickness, and recharge rates are to a large degree measurable or calculable, although predictions into the future, here too, are fraught with uncertainty. The effects of drawing water from the aquifer are relatively direct and identifiable, while it may be arguable for a long time what might be the impacts of climate change on society and whether those impacts are attributable to CO₂.¹

In one important aspect, with regard to their ultimate societal consequences, the two issues may converge. If, as inferred, one of the effects of increasing the level of CO₂ will be to increase the frequency, duration, and severity of droughts in the Great Plains, this in turn will lead to reduced recharge of and increased demand on the Ogallala Aquifer.

It is worth noting that there is a major difference in the ways the "drying out" of the Great Plains might occur. The Ogallala issue is essentially driven by increasing or unabating water demand. A CO₂ dying out of the Plains would be essentially driven by a decreasing water supply. However, since both lead to reduced water availability, the convergence or reinforcement of the two could create an extremely difficult resource management problem.

¹It is interesting to note that efforts to evaluate the costs of impacts of climatic change and the Ogallala depletion have gone in a similar and perhaps challengeable direction: the CIAP study (46) and parts of the Camp Dresser and McKee study (9) (among others) employed economic models not designed to estimate costs of altered agricultural activities in the long term. The CIAP study arrived at global cost estimates by aggregating and extrapolating questionable, geographically specific, partial equilibrium models for prices, crop yields, and temperatures (47). Camp Dresser and McKee employed an econometric model to project decades into the future, though such models are designed for short-term phenomena (up to a few years) and are dubious even then (14,48).
3.1 Comparing Societal Responses

In order to compare possible societal responses to the depletion of the Ogallala and to CO₂-induced climatic change, it is necessary to define categories of response and give examples. Discussion of such responses has been underway for several years in the natural hazards literature (e.g., 49). Cultural anthropologist Michael Thompson has suggested recently (50) a categorization of individual and group strategies in terms of relative emphasis on management of resources (supply) versus management of needs (demand). The response categories employed below come from the CO₂ impacts literature. There are several reasons to take the categories from the CO₂ literature. Most importantly, they appear to be applicable to the Ogallala case. Secondly, it is convenient to begin with categories which appear to have been effective with one of the issues already.

Responses to CO₂-induced impacts have been categorized in several ways. Meyer-Abich, for example, wrote about prevention, compensation, and adaptation (51); Corbett wrote of prevention, mitigation, and compensation (52); Schelling discussed prevention and adaptation (53); Kellogg and Schware discussed at length averting and mitigating strategies (54); Lave and Ausubel presented in the same article adaptation and prevention, adaptation and adjustment, amelioration and mitigation (55); finally Lave and Ausubel noted in the same report additional categories of available social reactions to: (1) prevent, finesse, or control the rate of disturbances (i.e., causes) or (2) to remedy, ameliorate, or adapt to the effects of the disturbances. These conflicting, often overlapping, meanings associated with the same strategic category when discussed by
different authors (and sometimes the same author in the same paper) clearly indicate the need to develop a more consistent set of terms to describe possible responses to a proposed CO\textsubscript{2}-induced regional climate change. We will use the terms prevention, compensation, and adaptation, as defined by Meyer-Abich (51) and illustrated extensively by Robinson and Ausubel (56).

The three responses are broad stretches on a continuum which ranges from dealing exclusively with the causes of the environmental change to dealing exclusively with the consequences of the environmental change. Prevention refers to strategies which attack the problem at its origin, that is, strategies which reduce the production of CO\textsubscript{2} or reduce the consumption of water from the Ogallala. Compensation refers to strategies which allow the production of CO\textsubscript{2} or extensive use of Ogallala water but try to compensate for it; for example, by reforestation which would absorb CO\textsubscript{2} or by importation of water to recharge the aquifer. Adaptation refers to strategies which allow the environmental changes to occur (a change in climate, reduced water supply) and involve becoming attuned to the new regime. Examples of the three responses may well involve factors which could be ascribed to more than one category. They are classified here according to the authors' perceptions about whether they are predominantly preventive, compensative, or adaptive.

3.2 Prevention

Prevention with respect to the Ogallala issue translates into an attempt to conserve present water levels in the aquifer. Conservation might, for example, require limiting withdrawals to an amount equaling the
natural recharge, an impractical measure that would essentially eliminate use. Conservation could also include: farming practices that are conducive to the retention of soil moisture (such as stubble mulching, minimum tillage, fallow, and crop rotation); cultivation of crops that consume little or no irrigation water (such as gopherweed, kenaf, Jerusalem artichoke); shifting from high water-use irrigated crops to relatively lower water-use crops (for example, from corn to wheat, or from sugar beets to sunflowers); the use of irrigation only as a buffer during periods of severe moisture stress; acceptance of lower yields for conventional crops by using less water and fertilizer; reduction of the number of cattle dependent on feed; and so on.

Institutional tactics would include tighter regulations or higher prices for water withdrawals. Lending institutions, such as the Federal Land Bank, could encourage conservation through loan practices that would discourage farmers from developing new irrigation facilities or expanding existing ones.

Prevention would be the most difficult (and drastic) option for the Texas High Plains area because of the extremely low recharge rate and relatively low saturated thickness of the aquifer in that region, and because of the region's dependence on Ogallala water. This strategy might be implemented (in theory) if, for example, it was believed that the value to society of the groundwater in the future would be much greater than it is at present. Prevention would require policymakers to repeatedly weigh present short-term economic benefits against long-term future benefits. Prevention seems an unlikely response for this reason and because there may
be few farmers today who would willingly end their dependence on water from the Ogallala and revert to dryland farming and ranching. Many of the farmers in the High Plains of Texas, for example, do not really have a choice concerning their dependence on irrigation. Their land was purchased at a price reflecting irrigated land values and their annual payments preclude any option that diminishes gross returns. To other farmers it would mean a return to dependence on variable rain without irrigation as a buffer.

With respect to CO₂, prevention means evolving a system which uses less fossil fuel. On the one hand, conservation might be used to reduce energy demand. On the other hand, energy sources which produce less CO₂ could be emphasized. Development of hydroelectric power could be subsidized; greater encouragement could be given to solar technologies for heating, generation of electricity, and production of fluid fuels for transportation; biomass fuels, which balance creation and absorption of CO₂, could be substituted for certain fossil fuels. Alternatively, one could rapidly expand both conventional nuclear power and more advanced forms, such as breeder technology. An additional strategy would be to encourage exploration for and exploitation of natural gas which emits less CO₂ per unit energy than do other fossil fuels.

At least in theory, a variety of institutionally oriented tactics could be directed towards prevention of CO₂ emissions as well. For example, higher taxes might be introduced for CO₂-emitting fuels; carbon residuals permits could be required; standards for ambient CO₂ could be established; and principles of assigning legal liability for damages on
account of climatic change could be accepted. Tactics outside the energy economy might also be effective. For example, slowing down expansion of agriculture into forested lands and improving land use practices could reduce emissions.

Several experts have argued that prevention strategies, whether based on law, regulation, price mechanisms, or rationing, are unlikely with respect to CO₂ (38,51,54,57). Shifts away from fossil fuel would require international cooperation but some nations are apparently willing to gamble on the possibility of benefits from CO₂-induced climate change. The energy alternatives continue to appear costly and/or risky themselves. Because of the long lead time needed for building new energy systems, significant decisions would probably be required well before statistical evidence about climatic change is convincing and well before signs of widespread degradation become attributable to CO₂ increases. Finally, the long time span and gradual nature of the issue do not match the political process, which tends to be myopic and focused on problems that appear to require more immediate political attention (58). On the other hand, strong arguments can be made for the benefits of shifting to renewable energy sources and improving efficiency of water use. Conservationist views of the aquifer and the atmosphere as sacrosanct domains may also provide impetus for adoption of prevention strategies.

3.3 Compensation

In the Ogallala case, a compensation response would be a commitment to maintain the level or rate of development of the economic activities which depend on the aquifer's water supply. One way to maintain the supply would
be to recharge the aquifer artificially. This could be accomplished by importing water into the region and by land management practices designed to increase the natural rate of recharge. (Such strategies are sometimes referred to as technological or engineering fixes.)

A second approach would be to maintain the present level and style of agriculture in the region, but not necessarily with the water in the Ogallala itself. The most obvious strategy would again be to import water. Interstate water importation schemes for various parts of the United States have been suggested for several decades with varying degrees of seriousness. Studies of interstate transfers have also been included as part of the High Plains Study; the U.S. Army Corps of Engineers received $800,000 to complete a feasibility study for transfers suggested in Figure 4 (59).

Routes A through D were sized to import sufficient water to restore and maintain irrigated lands projected to go out of production during the next 40 years, even if voluntary water conservation measures are undertaken (59).
However, political opposition to interbasin water transfers is often very strong. For example, in the charge given to the Army Corps of Engineers, both the Mississippi and the Columbia Rivers were placed off limits as possible sources of water to be transferred to the High Plains regions to offset the depletion of the Ogallala. Another strategy frequently suggested to compensate for diminished water supply, resulting either from the Ogallala Aquifer depletion or from CO$_2$-induced climate change, is weather modification (precipitation enhancement). This strategy also evokes strong political opposition (often local) from competing interest groups, not to mention skepticism from within the scientific community as to its feasibility.

Several compensation strategies have been proposed with respect to CO$_2$. The one most frequently mentioned is reforestation: decreasing atmospheric carbon dioxide by planting millions of trees which would transfer carbon to the biosphere. Strategies have also been proposed which are focused on different reservoirs and processes in the carbon cycle. It is theoretically possible to absorb carbon dioxide into soil carbon banks, by growing short-lived plants for conversion to humus, which would be stored in artificial peat bogs. Biological transfer to the deep oceans is also a theoretical possibility; supplying phosphates and nitrates to surface waters could fertilize growth of those marine organisms that produce carbonate shell structures and these would eventually sink and either dissolve in the deep ocean or settle safely on the ocean floor. Physical transfer to the deep ocean is conceivable as well; pipelines might, for example, gather CO$_2$ from power plants and deliver it to points
in the oceans where currents would carry it down to deeper layers where it would remain for centuries. Another compensation strategy would involve using solar- or nuclear-generated electricity to extract carbon from the atmosphere and convert it to a liquid hydrocarbon. As in the case of the Ogallala, there are proposals for "climate management" in which other factors in the climate system (clouds, albedo) would be manipulated to compensate for CO₂-induced climatic changes, if the physical and political obstacles can be overcome. Finally, large-scale water schemes, ranging from interbasin transfers to iceberg importation, have been mentioned for CO₂.

Doubts are often expressed about the effectiveness and practicality of compensation strategies for CO₂. Lack of mechanisms for international cooperation and pressures for use of the biosphere for food, firewood, and fiber limit opportunities. And once the level of atmospheric CO₂ becomes very high, the strategies might not be feasible on a worthwhile scale. Yet, such compensation strategies should not be ruled out; the scale and diffusion of many of today's technologies were scarcely imagined a generation ago, and it is in about a generation that the compensation strategies might become necessary alternatives.

3.4 Adaptation

If one chooses neither to prevent an issue from arising by suspending the cause, nor to compensate with countermeasures to suspend the undesirable effects, the remaining choice is to allow the effects to take place and let society adapt. Of course, adaptation may involve anticipatory as well as ex post facto actions.
Several adaptive responses to the Ogallala depletion are already being pursued or considered for implementation either by individual farmers and communities or by states and federal agencies. For example, on a local or state basis, once effects of the Ogallala depletion begin to be felt, policymakers may encourage economic diversification to minimize dependence on the aquifer. At the farm level adaptation could mean acceptance of lower well yields, lower crop yields, shifting to different crops (often of lower value), more efficient irrigation practices, less irrigated acreage, lower overall agricultural production, and ultimately relocation or a change to economic activities not necessarily related to agriculture.

Unequal distribution of costs may be a reason that adaptation is a likely response. The effects of mining the Ogallala will initially be local because the rate of flow of the groundwater is exceedingly slow and not all places in the Great Plains will suffer the same consequences at the same time from similar rates of withdrawal. In Texas, the Plains region is highly dependent on aquifer water and depletion would have a major impact on local communities, as well as on the state’s economy. For Colorado, on the other hand, where there is much less dependence on Ogallala water, it was suggested by that state’s High Plains Study Team that the economic effect of depleting its portion of the aquifer would be of the same magnitude as closing a large military installation or factory (59). Nebraska, with land that could be put into production (the Sand Hills) and with a relatively high recharge rate and deep saturated thickness, is in a more favorable position than other states above the aquifer with respect to future availability of groundwater. These geographic disparities and
variations in effects of mining the aquifer suggest local adaptive responses, rather than a comprehensive interstate compact governing rates of use of Ogallala water.

Suggested adaptive responses to the CO$_2$ issue in the Great Plains, cited in the CO$_2$ literature, encompass, in fact, several of the preventive, compensatory, and adaptive responses to the Ogallala depletion, thereby showing the need for more consistent use of these terms. One description of adaptive response to a CO$_2$-induced warming in the Great Plains goes as follows:

Methods to mitigate Plains irrigation abandonment include centralized planning of ground water and surface water use beginning immediately; maintenance of present-day underground water levels; careful rationing of water to back up a change in the present irrigation areas to effect a mixed irrigated/non-irrigated agriculture. Additional water is brought from non-Plains basins, even as far away as the Great Lakes and Canadian North. A small percentage of the increased personal income in the United States is used to ensure greater support for Plains food production, both dry and irrigated.

To maintain wheat in the Plains, several techniques are used: planting of drier/hotter tolerant varieties of wheat and sorghum; no-till practices; increased herbicides and pesticides; crop-growing geared to long-range weather forecasts, cycles, and cumulative soil moisture (S.M.I.) indices.... Occasional failures are balanced by increased wheat growing in what is at present the Corn Belt and in the East. Businesses and farmers are given incentives to move to the increasingly useful Canadian North.

To mitigate desertification in the Great Plains the following are introduced, in addition to improved wheat practices: careful management of native, drought-resistant grasses with production capacity in each area geared to soil-moisture levels; institution of timely and effective soil conservation practices throughout the Plains, with no setbacks like those of the mid-1970's; a soil-bank reserve program; shelter-belt planting and windbreaks; new tree species suitable for the Southern plains (sic); and snow supply management (55, p. 119).
While adaptive responses would also occur in relation to forestry, fisheries, and so forth, Meyer-Abich argues that qualitatively the basic forms of adaptation to climatic change are migration, reeducation, and industrialization (51). Change in agricultural productivity, which is one of the basic results of climatic change, is followed by corresponding adjustments in population density (migration) or by increasing agricultural or other economic activities (reeducation and industrialization).

For a variety of reasons, Meyer-Abich also concludes that adaptation, whether innovative or passive, is most likely to be the predominant societal response. Adaptation has these advantages:

- does not require an agreement on long-term goals but is rather flexible when goals and values are changing;
- does not require long-term international cooperation but allows a maximum of self-determination in evaluating costs and benefits;
- allows the appropriation of positive externalities of climatic changes, if there are any;
- allows one to confine oneself to the least marginal action at present;
- allows deferment of expenses most distantly into the future;
- is the line of least resistance with respect to present patterns of interest and incentives.

These categories of response to the societal implications of a CO₂-induced global warming show how people might react to such an environmental situation, but give no indication of the reasons and motivations behind their responses. Many authors, in several disciplines, have sought to investigate why individuals and groups make decisions regarding environmental change the way they do (e.g., 60-64). This is an important area of research related to but beyond the scope of our paper.
4. Conclusions and recommendations

We have attempted to show that environmental issues might be compared for the purpose of learning from how society responds to one issue about how it might respond to others. To make such a comparison as concrete as possible, we took two contemporary environmental issues centering on changes that could adversely affect the net moisture that would be available to crops, i.e., the water balance, and have pointed out similarities and differences between these two environmental changes. We have selected a specific region, the American Great Plains, as the focus for comparison. One of the environmental issues, a CO$_2$-induced climatic change, remains more hypothetical than actual. The other issue, depletion of the Ogallala Aquifer, is already a serious problem, with growing adverse consequences projected to occur in the next century. Potentially serious effects of both changes could occur at about the same time, in the middle of the 21st century.

Three points emerge from our comparison.

1. Responses detailed for one issue may offer scenarios for responses to other issues. In particular, because studies of possible responses to the Ogallala depletion are more advanced, they may shed light on responses to a hypothetical CO$_2$-induced climatic change. Portions of the High Plains Study (9), which analyzed the Ogallala depletion for its impacts on the national, regional, state, and local economies, could provide useful first approximations of how farmers and other decisionmakers might respond to a CO$_2$-induced change in the regional water balance. More thorough review of the High Plains Study would determine which components of the study might contribute to the identification of potential CO$_2$ impacts.
2. Categories of response can benefit from more consistent definition and may be applicable to more than one issue. We have attempted to reduce the confusion that surrounds categories of responses to the impacts of a CO₂-induced climatic change. Having chosen three categories taken from the CO₂ impacts literature—prevention, compensation, and adaptation—we placed in those categories specific suggested responses to the potential impacts of a CO₂-induced warming. These categories (which are not necessarily mutually exclusive) also provide a useful framework for actual and possible responses to the Ogallala Aquifer depletion.

It is interesting to note that while there is richer detail in the assessments of the Ogallala issue, there appears to have been more consideration of conceptual frameworks for the CO₂ issue. It may be timely to take these two issues, and other long-term, gradual, cumulative environmental changes that have thus far been expressed only as casual analogies with CO₂ such as acid rain and air pollution (65) and soil erosion (66) and to develop an overall framework in which responses could be identified and evaluated.

3. The CO₂ and Ogallala issues should be considered jointly. To date, these two issues have been assessed separately in the scientific as well as policymaking communities, as contemporary but unrelated environmental changes that could affect agricultural production in the American Great Plains. The separation is partly a result of the jurisdiction between the Department of Energy, directing CO₂ research, and the Department of Commerce, involved with regional economic development. Yet, in addition to the potential research benefits of comparing these
issues, it is important to look at them together because their effects on society may converge, if present trends in exploitation of the aquifer continue and if speculation about the CO₂ issue and its impacts on the region prove to be correct. Impacts that have been suggested for these environmental changes separately could combine to make a difficult situation a much more desperate one. Moreover, policies judged expensive for one issue might seem more affordable as responses to a combination of both (and perhaps other) issues. Finally, by combining the assessment of these two issues, allusions to the long-term stability of regional climate (such as the following) would receive the critical scrutiny that they deserve:

Key resources of land and climate, well suited to large agricultural enterprises, remain but the Region is faced with a simultaneous decline in water and the energy resources to support such enterprises (9, Preface) (emphasis added).

In sum, the development of credible comparisons and analogies appears to be a fruitful as well as inexpensive means of advancing climate-related impact assessment research for a variety of important environmental issues.

Acknowledgments

We would like to express our appreciation to the Weyerhaeuser Foundation for their encouragement and financial support for the Great Plains Planning Workshop and for research activities related to the topic of assessing climate-related impacts by analogy. We would like to thank the workshop participants who were instrumental in redirecting the focus of our research and to the many colleagues who read the manuscript and
provided critical reviews and suggestions. We would also like to thank the Aspen Institute for Humanistic Studies and Dr. Walter Orr Roberts, Director of the Food and Climate Program of the Aspen Institute, for his support. Finally, special thanks are extended to Maria Krenz for her editorial help during the many stages of this paper and for her assistance in organizing the workshop.
References


5. U.S. Department of Energy, Workshop on Environmental and Societal Consequences of a Possible CO₂-Induced Climate Change, Annapolis, MD, April 2-6, 1979, p. 92.


7. W.D. Bittinger and E.B. Green, You Never Miss the Water Till... (Water Resources Publications, Littleton, CO, 1980).


14. Camp Dresser and McKee, Congressional Briefing on the Six-State High-Plains - Ogallala Aquifer Regional Resources Study (Camp Dresser and McKee, Austin, TX, 1981).


47. H.K. Margolis, paper presented at the AAAS/DOE Workshop on Environmental and Societal Consequences of a Possible CO₂-Induced Climate Change, Annapolis, Maryland, April 1979.


52. J.G. Corbett, paper presented at the AAAS/DOE Workshop on Environmental and Societal Consequences of a Possible CO₂-Induced Climatic Change, Annapolis, Maryland, April 1979.

53. T.C. Schelling, Letter memo from the Ad Hoc Study Panel of the Climate Board on Economic and Social Aspects of Carbon Dioxide Increase to Dr. Philip Handler, President, National Academy of Sciences, April 18, 1980.


55. L.B. Lave and J. Ausubel, paper presented at the AAAS/DOE Workshop on Environmental and Societal Consequences of a Possible CO₂-Induced Climatic Change, Annapolis, Maryland, April 1979.


