The Ogallala Aquifer and Carbon Dioxide: Comparison and Convergence

by

MICHAEL H. GLANTZ, Ph.D.(Pennsylvania)
Head, Environmental and Societal Impacts Group, National Center for Atmospheric Research, P.O. Box 3000, Boulder, Colorado 80307, USA

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JESSE H. AUSUBEL, M.I.A., M.B.A.(Columbia)
Special Assistant to the President, National Academy of Engineering, Washington, DC 20418, USA.

INTRODUCTION

The issues of the depletion of the Ogallala Aquifer by irrigation activities and a possible global warming induced by increasing carbon dioxide (CO_2) in the atmosphere, have been addressed separately in the past. This paper suggests reasons to consider these two environmental issues together. Our hypothesis is that there may be sufficient similarities between the two issues, such that studying the possible evolution of one of them could shed light on the other. Moreover, either one of these environmental changes (one of them actual and the other projected) could have serious consequences for agricultural production in the US Great Plains—surely one of the world's greatest food-exporting regions.

If these changes were to take place as many authorities are currently predicting, their combined effects on regional water-supplies (and therefore on agricultural output) could prove to be severe. Moreover, linking such issues will also suggest that policy-makers as well as research workers should move away from making 'casual' analogies, and instead move towards the use of more formal ones, by making their assumptions about those analogies explicit (Martino, 1975).

Also explored in this paper is whether analogy may be a generally fruitful and efficient tool for environmental impact assessment. Reasoning by analogy is based on the simple proposition that if two or more things agree in one or more respects, they may agree in yet other respects. Analogy is one of the traditional tools of the art of discourse. Indeed, mathematical models might be regarded as a modern, formalized version of analogy, in which extended, elaborate comparisons are drawn between logico-mathematical structures and the behaviour of natural systems.

There are several reasons for suggesting the use of analogy for issues such as CO_2-warming and depletion of the Ogallala. One reason is that there appears to have been a tendency, in impact and technology assessment, sometimes to overlook lessons of history within a particular field. For example, there was relatively little evidence of our learning from earlier events as one major climatic impact study succeeded another during the 1970s (Glantz *et al.*, 1982). At present, several sizeable CO_2 assessment efforts are under way in the United States and internationally. There are strong similarities in structure, objectives, and methods, among these efforts and previous ones—to examine, for example, the consequences of climatic changes which may be brought about by supersonic stratospheric flight (Climate Impact Assessment Program, 1975), or the implications of climatic change for crop yields (National Defense University, 1980), or the consequences of drought in the Sahelian region of West Africa (Seifert & Kamrany, 1974). It is important to seek to ensure that the new undertakings benefit from past experience.

Just as there is sometimes insufficient attention paid to the lessons of the past within a particular field, there are often unused opportunities to learn from those with whom one may be working in parallel (Mar, 1974). Several environmental issues—for example CO_2, acid rain, ozone-layer depletion, soil erosion, and groundwater depletion—may have strong 'family' similarities. Yet, assessments of these issues are often conducted as if the particular kind of problem, both intellectually and socially, were being faced for the first time (Glantz & Orlovsky, 1983).

Yet another reason for using analogy may be suggested. Each major innovation or 'block-buster' assessment can be extremely expensive. By contrast, surveys of past and similar experiences are generally less expensive to carry out. They can enable us to avoid duplication of effort and to begin further studies from a higher level of sophistication and with greater awareness of possible pitfalls of analysis than would otherwise be likely. In a time when budgetary restrictions are strongly curtailing research agendas, thoughtful retrospective assessments and comparisons may prove to be a practical means of gaining insights into likely impacts of expected environmental changes.

A workshop report on possible effects of a CO_2-induced warming (US Department of Energy, 1980) recommended comparisons with previous historical periods of noticeable climatic change. It was suggested

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that appropriate case-studies might include those of warm periods in western and central Europe in the 14th century, and of the cool period in North America during the initial European colonization. However, as the report acknowledged, social, political, and technological, differences between periods almost certainly overwhelm similarities that may result from climatic factors, and thus raise doubts about uses of this sort of historical analogy. Comparison of possible effects of recent or contemporary environmental changes appears to be a more promising line of inquiry than comparison with those of previous historical periods.

The Issues and the Comparison

The Ogallala Aquifer

The Ogallala Aquifer is a geologic formation of water-bearing porous rocks which underlines parts of eight states in the higher, western portion of the American Great Plains. It stretches about 1,300 km from north to south and, at the maximum, about 650 km from east to west (Fig. 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 (Gutentag & Weeks, 1980). Lateral movement of water in the Aquifer is exceedingly slow.

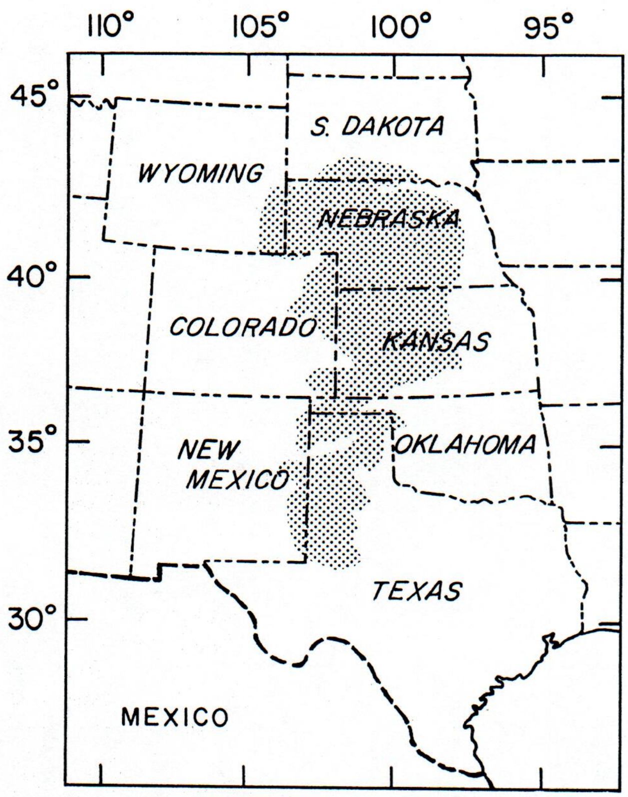

FIG. 1. *Sketch-map indicating approximate area (stippled) of the Ogallala Aquifer, underlying parts of 8 states in the western Great Plains area of the United States. The scale is indicated by the dimensions of the Aquifer, which is approximately 1,300 km long and 650 km wide in its widest (northern) part.*

The Aquifer has long been a major source of water for agricultural, municipal, and industrial, development in a large section of the Great Plains (Bittinger & Green, 1980). It is particularly valuable in the dry-climate parts of the area, where rainfall is highly variable, with runs of wet or dry years sometimes occurring. Utilization of the Aquifer began at the turn of the century in the southern part of the High Plains. The drought of the 1930s provided a major impetus to exploitation, as many dryland farmers resorted to ground-water to reduce their reliance on uncertain rainfall. When once they had been drilled, wells tended to remain in operation, even after the drought ended.

Since World War II, reliance on ground-water has increased steadily throughout the Great Plains, stimulated by drought in the 1950s, by new irrigation technology, by cheap energy for pumping, and by higher prices for food, feed-grains, and cotton. Tens of thousands of wells now dot the region above the Aquifer. Because irrigation farming (supplied by the help of these wells) can provide much greater economic returns per unit area than dryland farming, the agricultural economy has been transformed. Grain production increased to the extent that an extensive feedlot industry has developed in the Ogallala Aquifer region, supplying by the late 1970s about 40% of the national total production of grain-fed beef (Walsh, 1980).

The withdrawal of water has now greatly surpassed the Aquifer's rate of natural recharge (e.g. Wyatt *et al.*, 1976; Weeks, 1978). Some places overlying the Aquifer have already exhausted their underground supply as a source of irrigation; in others, rising costs of energy have either made it uneconomic to exploit ground-water or have prompted farmers to conserve it. On the High Plains of Texas, where the Aquifer is the main source of irrigation water, drawdown has been viewed as critical since the early 1950s (Firey, 1960). Other parts of the Great Plains, especially in Nebraska, have more favourable saturated thicknesses and recharge rates, and so are less vulnerable (Weeks & Gutentag, 1981). 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 (High Plains Study Council, 1982).

In 1976, the US Congress expressed its concern about the water-resource situation in the High Plains by authorizing a $6-millions, five-years study (Section 193 of Public Law 94-587). The legislation directs the Secretary of Commerce to study depletion of the natural resource and to develop plans to increase water-supplies in the Ogallala area. The year 2020 was selected as the date towards which to aim predictions. In addition to the Department of Commerce's High Plains Study, a separate $5.5 millions study was commissioned for the US Geological Survey to provide the hydrological information needed to evaluate the effects of continued ground-water 'development', and computer models to predict aquifer response to changes in ground-water 'development' (Weeks & Gutentag, 1981).

The final report of the High Plains Study (High Plains Associates, 1982; High Plains Study Council, 1982; US Army Corps of Engineers, 1982), released in February

1983, showed favourable conditions for agriculture until 2020 in most areas of the Aquifer. By 2020, however, most 'marginal' lands will have been put into use, and there will be little additional land after that time to bring into production to offset the loss of land removed from irrigation because of the depletion of the Aquifer elsewhere in the region. The High Plains Study explicitly assumed no climatic changes before 2020.

The CO_2 Issue

Let us now shift our attention from the Aquifer to the atmosphere, where the concentration of carbon dioxide, a naturally-occurring inert trace-gas, is an important factor in determining climate. Human activities—mainly the burning of fossil fuels and, to a lesser extent, deforestation and land-clearing for agriculture—have been increasing the concentration of carbon dioxide in the atmosphere (Clark, 1982). Continued growth in population and increased economic activity both imply increasing levels of CO_2—at least if a substantial share of the global energy-demand continues to be met by fossil fuels, and especially from the abundant supplies of coal. Energy projections typically point to a doubling of pre-industrial levels of atmospheric CO_2 within the next 50–100 years (IIASA, 1981; US Environmental Protection Agency, 1983; US National Academy of Sciences, 1983), if roughly half of the CO_2 emissions into the atmosphere from the burning of fossil fuels remain airborne.

While there is considerable uncertainty about what the detailed climatic consequences of increased CO_2 would be, numerical models of the atmosphere, and the climatic record of the last 100 years, suggest an increase in global annual average surface temperature of about 2 to 3°C with a doubling (Revelle & Shapero, 1978; Clark, 1982; US National Academy of Sciences, 1983). While such a shift may sound small, the Earth would then be as warm as it appears to have been during any period in the last 100,000 years (Flohn, 1981). Temperature increase would not be distributed uniformly among regions; warming is likely to be slight near the Equator and much more pronounced near the Poles (US National Academy of Sciences, 1982).

Changes in rainfall and soil moisture are also projected with such a build-up of atmospheric CO_2, but confidence in such findings is rather low (Hayashi, 1982). Current results are based on response of climatic models to large fixed increases in CO_2; the actual time-evolving regional climatic changes occurring from a scenario of CO_2 increase could well differ (Schneider & Thompson, 1981). Moreover, effects of human activities on global climate may not be convincingly distinguishable from the great natural variability of climate for another 10 or more years (Epstein, 1982). A large inventory of other so-called 'greenhouse' gases may further compound the CO_2 effect (Clark, 1982; US National Academy of Sciences, 1983).

If CO_2 continues to rise and the climate begins to diverge from its recent patterns, consequences in agriculture, water-supply systems, and many aspects of human life and of the environment, should manifest themselves with increasing frequency and intensity. Of course, the impacts of higher levels of atmospheric CO_2 and of changes in climate need not be negative. For example, increasing CO_2 could have a positive effect on food supplies through increasing photosynthetic rates and improved efficiency of water-use in plants (Rosenberg, 1982). The numerous possible beneficial and costly impacts and their distribution over regions, industries, and different population-groups, are beginning to be explored in a systematic way (e.g. US Department of Energy, 1980; Kates, in press).

While the consequences of increasing CO_2 and climatic change remain highly conjectural, numerous policy-groups in the United States have begun to take an interest in the question (US Senate, 1980; US Council on Environmental Quality, 1981). In the United States, the Department of Energy has the leading responsibility for conducting a multi-year Federal Government evaluation of the issue, and the National Academy of Sciences has recently published a major assessment (1983). The US Environmental Protection Agency has also released reports on the CO_2 issue (1983), while CO_2 and climatic change have occupied the attention of an increasing number of physical scientists (*see* Chilton *et al.*, 1981), as well as social scientists (e.g. Smith, 1982).

Comparison of the Issues

The CO_2 and Ogallala issues share several important characteristics. First, the two issues have in common a long time-scale: both are expected to become prominent over about the next 50 years, as the Ogallala becomes largely depleted and climate departs from the range within which it has remained for the past several thousand years. Both are expected to become increasingly serious as the next century unfolds. Unless transformed by political processes and the media, both issues are likely to become more serious and recognized in a gradual fashion.

Drawing of water and burning of fossil fuels are diffuse, continuous activities; the physical basis of the issues does not revolve around any small set of readily identifiable, discrete events. Moreover, the changes posed by both issues are cumulative and practically irreversible. In most parts of the Ogallala, rates of recharge are so slow that the Aquifer may be regarded as an exhaustible resource. The rate at which the oceans and the terrestrial biota can absorb additional CO_2 is strongly limited, so that when once the atmospheric CO_2 concentation rises substantially, it could well be centuries before natural processes reduce the concentration to much lower levels.

The changes are difficult to reverse from a socio-technical as well as a natural point of view, because of the inertia of water and energy systems. Furthermore, both issues stem from an implicit preference for short-term gains from use of large amounts of water or energy—gains which may bring long-term costs. In fact, cheap fuel can exacerbate both issues; if it is expensive to buy fossil fuels or to pump water, the problems may grow more slowly.

Both the CO_2 problem and the Ogallala depletion have features of a potential 'tragedy of the commons'—such as occurs when a shared resource which is freely available to all, is so heavily used that the resource is exhausted or degraded (Hardin, 1968). In the case of CO_2, all countries share the atmosphere and its capacity for disposal of waste; if many nations emit large amounts of CO_2, a climate may evolve which is much less favourable for human activities than the one we have today. The Ogallala, like CO_2, is an issue which becomes more serious if many actors behave in the same way. However, flow within the Aquifer is not so free or fast that the Ogallala is a common resource to the extent that a fishery, pasture-land, or the atmosphere, can be.

Both issues require widespread action to make most responses effective. It is worth noting that the histories of various local, regional, and subnational, commons (e.g. grazing-lands, river systems, or fisheries) offer excellent lessons in the variety and responsiveness of human institutions in the face of change in the supply of and demand for resources.

Consequences of resource exploitation are not necessarily distributed or shared in similar fashions for the two issues. Nations which burn the most coal may, or may not, suffer the most adverse consequences, while their actions could well impose large costs on others. However, several climatic studies do suggest that the USSR, China, and the United States—the countries with the largest coal reserves—will all experience some drying (e.g. Manabe *et al.*, 1981). The heavier users of the Aquifer are quite likely to suffer the more drastic consequences. The CO_2 issue offers greater possibilities for benefit than the Ogallala depletion, although judicious farmers and businessmen might gain from the adversity of others. The nature of economic markets means that even careful behaviour by an individual farmer or nation to gain insulation from the issue, will meet with only limited success.

While the degree of 'commonality' in the CO_2 issue is greater than in the Aquifer one, so is the degree of uncertainty. The question of how much CO_2 will be emitted and remain in the atmosphere is highly speculative: how much will the climate change; what will be the impacts on society and the environment; in what context of national and global events will the CO_2-induced climatic changes take place? In contrast, rates of draw-down of the Ogallala Aquifer, degree of depletion, depth from surface, saturated thickness, and recharge rates, are to a large degree measurable or calculable. The physical state may evolve in a nearly linear, predictable manner, while human-induced climatic change could be non-linear and surprising. Impacts of Aquifer depletion are also relatively direct and identifiable, while the impacts of climatic change on society may be arguable for a long time—even at the level of whether the proposed impacts are properly attributable to CO_2.

Efforts to evaluate the projected costs of impacts of climatic change and the Ogallala depletion have sometimes gone in a similar and challengeable direction. Among others, the Climate Impact Assessment Program (CIAP) study (1975) and parts of the High Plains Associates study (1982) employed economic models that were not originally intended 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. High Plains Associates (1982) employed an econometric model to project four decades into the future, though such models are designed primarily for short-term phenomena (up to a few years). Battelle research workers have recently proposed to use the same kinds of tools to assess the sensitivity of the US agricultural economy to changes in concentration of CO_2 (Callaway *et al.*, 1982).

While there are similarities and divergences between the two issues, there is also important possible convergence. Both have implications for availability of water for agriculture in the US Great Plains. One of the inferred effects of an increased level of atmospheric CO_2 is an increase in the frequency, duration, and severity, of droughts in the Great Plains. Numerical models of the climatic system, while qualified by much uncertainty, do indicate that with an increase of CO_2 in the atmosphere, the mid-latitude rain-belt will shift northwards, and areas in North America that are currently used for irrigated agriculture will grow drier (Manabe *et al.*, 1981; US National Academy of Sciences, 1982). More specifically, the mean value of soil moisture in summer becomes markedly reduced in a band north of 30–35°N, largely as a result of the earlier beginning of the period of relatively high evaporation-rates and the earlier occurrence of the spring-to-summer reduction in rainfall rate. Revelle & Waggoner (US National Academy of Sciences, 1983 Chapter 7) have shown that warmer air-temperatures and slight decrease in precipitation would probably severely reduce both the quantity and the quality of water resources in the western United States, and that similar effects can be expected in many water-short regions elsewhere in the world.

While both a CO_2-induced warming and depletion of the Aquifer might lead to reduced water-availability, there is a major difference in the ways in which the 'drying out' of the Great Plains would occur. The Ogallala issue is driven essentially by increasing or unabating water-demand, whereas a CO_2 drying-out of the Plains would be driven essentially by a decreasing water supply.

Prevention, Compensation, and Adaptation

To compare possible societal responses to depletion of the Ogallala and CO_2-induced climatic change, it is helpful to define categories of response and to give examples. Discussion of types of responses has been under way for several years in the geography and natural-hazards literature (e.g. Burton *et al.*, 1978). In a variation on the economists' analyses of policies for supply and demand, anthropologist Thompson (1980) has suggested a categorization of individual and group strategies in terms of relative emphasis on management of resources *versus* management of needs. While the response categories employed below come from the CO_2-impacts literature, exploration with such alternate frameworks is also enlightening and is omitted here only for the sake of brevity.

More than a dozen terms have been used to describe possible societal responses in the CO_2 literature. These include: prevention, controlling, finessing, averting, compensation, counter-measures, remedy, mitigation, adaptation, adjustment, alleviation, amelioration, and 'no response'. The meanings attributed to these terms obviously overlap, and they are sometimes used in contradictory or inconsistent ways by different authors or even by the same author. We will use the terms prevention, compensation, and adaptation, as defined by Meyer-Abich (1980) and illustrated by Robinson & Ausubel (1983).

The three terms are not mutually exclusive, but reflect the predominant character of broad stretches on a continuum which ranges from responding primarily to causes of environmental change to responding primarily to consequences or impacts of environmental change. *Prevention* refers to strategies that are intended to attack the problem at its origin—that is, strategies which reduce the creation of CO_2 or the consumption of water from the Ogallala. *Compensation* refers to strategies that allow the creation of CO_2 or extensive use of Ogallala water but then try to compensate for it by, for example, reafforestation which would reabsorb CO_2 or by importation of water to recharge the Ogallala Aquifer. *Adaptation* refers to strategies that allow the environmental changes to occur (a warmer earth and/or reduced regional water-supply) and involve becoming attuned to the new regime. Let us now consider these three in turn.

Prevention Strategies

Prevention with respect to the Ogallala issue translates into an attempt to preserve the Aquifer. Such preservation would require a limitation of withdrawals to a rate not exceeding natural recharge, and thus many possible tactics in this category relate to *water conservation.*

Water conservation could be accomplished over time and at some cost by extending use of farming practices that are conducive to the retention of soil-moisture (e.g. stubble mulching and minimum tillage); cultivating crops that consume little or no irrigation water (e.g. gopher-weed, kenaf, and Jerusalem artichoke) but require changes in consumer preference; shifting from high-water-use crops to lower-water-use crops (for example, from irrigated maize to irrigated wheat, or from sugar-beets to sunflower); shifting from irrigated to dryland crop-production; acceptance of lower-than-current yields for irrigated crops through reduction of water inputs; reduction of the number of cattle dependent on feed, and so on.

Institutional tactics would include tightening of regulations and steepening charges concerning water withdrawals. Lending institutions, such as the Federal Land Bank, could encourage prevention of depletion through loan practices that would discourage farmers from developing new irrigation facilities or expanding existing ones.

A prevention strategy might be implemented if, for example, it were believed that the value to society of the ground-water at some time in the future will be much greater than it is at present. Prevention would require policy-makers repeatedly to weigh short-term economic benefits for the current generation, against long-term benefits for future generations. Prevention seems an unlikely response—for that same reason and because there may be few farmers today who would willingly terminate their reliance on water from the Ogallala and revert to dryland farming and ranching; it would mean a return to subjugation to the vagaries of weather as well as a return to lower incomes.

Prevention would be an especially problematical option for the Texas High Plains area because of the extremely low recharge rate and relatively thin saturated thickness of the Aquifer in that region, and because of the region's high dependence on Ogallala water for agricultural activities. Many farmers in the High Plains of Texas have no alternative to irrigation, except bankruptcy. Their property was purchased at a price reflecting irrigated-land values, and annual loan payments preclude options that might diminish gross returns.

With respect to CO_2, prevention strategies relate primarily to evolving an energy system which uses less fossil fuel than at present. On one hand, a variety of energy sources which are cleaner with respect to CO_2 could be emphasized. Thus development of hydroelectric power could be subsidized; greater encouragement could be given than at present to solar technologies for heating, to generation of electricity, and to production of fluid fuels for transportation; biomass fuels, which balance creation and absorption of CO_2, could be substituted for certain fossil fuels. Alternatively, one could expand both conventional nuclear power and more advanced forms, such as those involving breeder technology. A final, supply-oriented strategy would be to encourage exploitation of natural gas, which emits less CO_2 per unit of energy than do other fossil fuels.

A variety of institutionally-oriented tactics could be directed towards prevention of CO_2 emissions as well. In theory, higher taxes might be instituted for CO_2-emitting fuels; carbon residuals permits could be required; ambient CO_2 or temperature standards 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 which come from burning of wood and oxidation of carbon in soils.

Several experts have argued that a preventive strategy, whether based on market mechanisms, governmental regulations, and laws, or on other forms of societal sanctions, is unlikely to succeed with respect to CO_2 (e.g. Meyer-Abich, 1980; Lave, 1981; US National Academy of Sciences, 1983 *see* especially Chapter 9). Shifts away from fossil fuel would require cooperation of many nations, especially the USSR, US, and China, who hardly have a good record of cooperation, though some groups or nations may be willing to gamble on the possibility of benefits.

The energy alternatives continue to appear at least as costly and risky as climatic change. Because of the long lead-time and capital needed for building new energy systems, significant decisions could be required before evidence about climatic change is convincing, and well before widespread degradation of climatic resources could occur. The long-time horizon and gradual nature of the issue do not match the political process, which tends to focus on problems where attention is quickly rewarded. At the same time, strong arguments can be made for the numerous benefits of shifting to non-fossil energy sources, while conservationist views of the atmosphere (or the Aquifer) as a sacrosanct domain may provide persistent impetus for adoption of prevention strategies.

Compensation Strategies

To turn to compensation: in the Ogallala case, such a response would be based on a commitment to maintain the existing level or rate of development of the economic activities which depend on the Aquifer's water-supply. One way to avoid disruption of supply would be to recharge the Aquifer artificially, perhaps by importing water into the region or by land management practices designed to increase the natural rate of recharge. 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 be to import water.

Large-scale water importation schemes have been proposed for various parts of the United States for several decades, and some large systems are in operation. Consideration of interstate transfers is a major component of the High Plains Study of the US Army Corps of Engineers (1982). Political opposition to interstate and interbasin water transfers is often strong. In the Corps' charge for the High Plains, both the Mississippi and the Columbia Rivers were placed off-limits as possible sources of water for the High Plains. Another technological or engineering 'fix' that is frequently suggested to compensate for diminished water-supply, namely weather modification (precipitation enhancement), also evokes strong political controversy, not to mention scepticism from the scientific community as to actual feasibility.

Several compensation-strategies have been proposed with respect to CO_2 (Albanese & Steinberg, 1980). The most frequently mentioned is massive reafforestation—decreasing atmospheric carbon dioxide by growing millions of trees which could absorb carbon and thus remove it from the free atmosphere. Strategies have also been proposed which are focused on other reservoirs and processes in the carbon cycle. It is theoretically possible to absorb carbon dioxide into soil–carbon banks, growing short-lived plants for conversion to humus, which would be stored in 'artificial peat-bogs'. Accelerated biological transfer to the deep oceans is also theoretically possible, if unlikely on a large scale; supplying phosphates and nitrates to surface waters could fertilize growth of marine organisms, which would incorporate carbon and eventually sink and settle on the ocean floor. Physical transfer to the deep ocean by geoengineering is conceivable as well—pipelines might, for example, gather CO_2 from power-plants and deliver it to points in the oceans whence currents would carry it down to deeper layers where it would remain for centuries.

Another compensation-strategy would involve using electricity generated from non-fossil sources to extract carbon from the atmosphere and convert it to a hydrocarbon for use in a steady-state cycle. As in the case of the Ogallala, there are proposals for 'climate management' in which other factors in the climatic system (clouds, albedo, etc.) would be manipulated to compensate for CO_2-induced climatic changes. Finally, large-scale water schemes, ranging from interbasin transfers to iceberg utilization, might be mentioned.

Doubts have been repeatedly expressed about the effectiveness and practicality of compensation strategies for CO_2. Lack of mechanisms for international cooperation and pressures for use of biomass for food, firewood, and fibre, limit opportunities. And when once the level of atmospheric CO_2 becomes very high, the strategies might not be feasible on a worth-while scale. Yet, the compensation strategies cannot be ruled out; the scale and diffusion of many of today's technologies were scarcely imagined a couple of generations ago.

Adaptation Strategies

If one chooses neither to prevent an issue from arising by suspending the cause, nor to compensate with countermeasures which suspend the undesirable effects, the remaining alternative is to allow cause-and-effect to hold sway and let society adapt to impacts as they arise. Of course, adaptation may involve anticipatory as well as *ex post facto* actions.

On a local and state basis, adaptation may begin with encouragement of diversification away from activities that are dependent on the Aquifer. At the farm level, adaptation can mean acceptance of lower well-yields, shifting to different crops, smaller irrigated acreage, reduced crop production, lower income, and ultimately relocation or a change to economic activities that are not necessarily related to agriculture. Several adaptive responses to the Ogallala depletion are already being pursued or are under consideration either by individual farmers and communities or by states and federal agencies.

If depletion is allowed to proceed without compensatory measures, not all places in the Great Plains will face the same pressures or choices for adaptation at the same time, even given similar rates of withdrawal of water. In Texas, depletion would have a major impact on the local communities, as well as on the state's economy. For Colorado, where there is less dependence on Ogallala water, the state's High Plains Study Team suggested that the economic effect of depleting the Aquifer locally would be of the same magnitude as closing a large military installation or factory (*Ogallala Aquifer*, 1981). Nebraska, with land that could still be put into production (the Sand Hills), a relatively high recharge rate, and deep saturated thickness, is in a more favourable position. These geographic variations in effects of mining the Aquifer, suggest a bias in favour of local adaptive responses (e.g. Walsh, 1980)—rather than a response built around a comprehensive interstate legal compact governing rates of use of Ogallala water. However, more equable distribution of costs might be a spur to collective action.

Adaptive measures suggested for CO_2-induced climatic change encompass many of the preventive, compensatory, and adaptive, responses to the Ogallala depletion. One group (US Department of Energy, 1980) speculated that an adaptive response to a warmer and drier regime in the Great Plains, such as might be induced by CO_2, would include: centralized planning of water-use; maintenance of present-day underground water-levels; water imports from non-Plains basins, even as far away as the Great

Lakes and the Canadian North; more Federal subsidization of Great Plains food production; planting of drier/hotter-tolerant varieties of wheat and sorghum; no-till practices; increased use of herbicides and pesticides; crop-growing geared to long-range weather forecasts, cycles, and cumulative soil-moisture indexes; increased wheat production in the Corn Belt and the East; and/or migration to an increasingly equable and usable Canadian North. To help towards mitigating desertification, relatively drought-resistant grasses could be planted, soil conservation practices could be improved, a soil-bank reserve programme could be instituted, while shelterbelts and windbreaks could be extended, and snow-supply management could be introduced.

While adaptive responses occur in relation to many aspects of climatic change, qualitatively the essential forms of adaptation are migration, re-education, and industrialization (Meyer-Abich, 1980). Change in agricultural policy and productivity, which are basic impacts of climatic change, means that the ratio of population to agricultural production in a given area is also changed, and such changes are followed by corresponding adjustments in the population—either through migration or by increasing agricultural or other economic activities, which almost certainly implies re-education and industrialization.

For a variety of reasons Meyer-Abich (1980) concludes that adaptation is the most likely societal response. Adaptation 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 for the time being; allows deferment of expenses most distantly into the future; and is the line of least resistance with respect to present patterns of interest and incentives.

It is not the purpose of this paper to choose from among prevention, compensation, and adaptation; rather do we hope to suggest that there may be families of problems and categories of responses. It is clear from the resource and environmental debates of the past decade that there are also abiding ideas for Nature—ideas which have little to do directly with such issues as a possible CO_2-induced climatic change or depletion of the Ogallala. Many authors, in several disciplines, have sought to explain why individuals and groups define issues, and make decisions, the way they do regarding environmental change (e.g. Kluckhohn & Strodtbeck, 1961; Saarinen, 1966; Douglas & Wildavsky, 1982). Consideration of cultural factors, kinds of rationality, and perception, is essential to furthering our understanding of the future course of the CO_2 and Ogallala issues; selection of response and tactics is not a clear-cut application of values but rather a complex function involving conceptual choices and underlying points of view.

Conclusions

Comparison and analogy appear to be instructive devices for examining the projected depletion of the Ogallala Aquifer and a potential CO_2-induced warming. In particular, we would like to emphasize the following points.

1. *Responses detailed for one issue may offer scenarios for responses to other issues:*—For example, several studies of possible responses to the Ogallala depletion are complete or are nearing completion, and these may be valuable guides for CO_2 assessments which are in earlier stages. In particular, portions of the High Plains Study could provide useful first approximations of how local, state, and regional, economies might respond to a CO_2-induced change in regional water-balance. More thorough review of the High Plains Study would determine which components of the Study might contribute to identification of potential regional CO_2 impacts. In addition, the identification of such potential impacts in one geographic region may prove to be of value in the identification of the potential impacts of a CO_2-induced global warming in other regions of the world.

2. *Categories of response can benefit from more consistent definition than is usual, and may be applicable to more than one issue:*—The area of response appears to be an unnecessarily confused field in which some underlying patterns might be discerned. While there is richer detail in assessments of the Ogallala issue, there has been more consideration of conceptual frameworks for the CO_2 issue. Categories taken from the CO_2 literature—prevention, compensation, and adaptation—offer a useful perspective on responses to the Ogallala Aquifer depletion. It may be timely to take these two issues, and other long-term, gradual, and cumulative, environmental changes, and examine frameworks in which responses can be identified and evaluated. Thus far, such issues as acid rain, air pollution, and soil erosion, have been expressed only as casual analogies with the CO_2 issue.

3. *The CO_2 and Ogallala issues should be considered jointly:*—To date, these two issues have been assessed separately in the scientific as well as policy-making communities, and as parallel but unrelated environmental changes that could affect agricultural production in the American Great Plains. The separation is partly a result of the division of jurisdiction in the United States between the Department of Energy, leading in CO_2 assessment, 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 consider them together because *their effects on society may converge*, if present trends in exploitation of the Aquifer continue and if speculation about the CO_2 issue and its impacts on the region prove to be correct. Impacts that have been suggested for these environmental changes separately, could either combine to make a difficult situation even much more desperate, or could be countervailing. *Policies judged to be expensive for one issue might seem more affordable as responses to a combination of both (and perhaps other) issues.*

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Summary

Much attention within the scientific community has focused on the effects of a possible increase in atmospheric carbon dioxide. The impact of the increase in the CO_2 content of the atmosphere is usually discussed in terms of global averages. Little information has been presented on what the regional effects of a CO_2-induced global warming might be. Recent attempts at identifying local effects of such a warming suggest that, as the atmospheric CO_2 content continues to rise, there will be an increase in the frequency, duration, and severity, of droughts in the United States Great Plains.

Agricultural activities in the Great Plains today are highly dependent on water drawn from the underlying Ogallala Aquifer. Yet, there is great concern that the water is being drawn out at rates that far exceed its natural rates of recharge. While the Aquifer's thickness and rates of drawdown differ at different parts of the Great Plains, some regions are already in precarious positions because of the depletion of their portion of the Aquifer.

In this paper we compare and contrast these two long-term, slowly developing but cumulative, environmental problems, one of them actual (the depletion of the Aquifer) and the other potential (the CO_2-induced warming of the Earth's atmosphere), but each of them having major implications for the future availability of water resources in the Great Plains. Recent scientific assessments of the status of the Aquifer and its agricultural uses have become available as a result of a $6-millions programme financed by the US Congress. These assessments may provide an insight into how individuals and society might cope if the expected impacts in the Great Plains of a CO_2-induced global warming become a reality. Linking such issues by comparison and analogy could enable us to learn, on the basis of how society responds to one issue, how it might respond to others.

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