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ANTHROPOGENIC CLIMATE CHANGE AND A NEW PARADIGM OF NATURAL RESOURCE PLANNING*

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Heightened public concern, pending federal legislation, and calls for an international treaty to reduce emissions of greenhouse gases have placed pressure on resource planners to mitigate the causes and impacts of anthropogenic climate change despite uncertainty over its timing and magnitude. Traditional resource planning, however, is predicated on the assumption that future environmental conditions will emulate the past, and is based on local and national, rather than global, objectives. The threat of global warming calls for a new paradigm of resource planning, including expanded sensitivity analysis, incremental response as the threat evolves, an expanded range of adjustments, and planning in a global context. **Key Words: natural resource planning, climate change, global warming, greenhouse effect.**

During a recent presentation to water resource engineers on the potential impacts of anthropogenic climate change, I was pointedly reminded that the country's water projects were designed to accommodate a wide range of hydroclimatological extremes, and thus could absorb significant climate change. Later, during congressional hearings on the issue, a senator from a timber-products state pressed the panel in which I participated to support his theory that the midlatitude forests were not a significant source of atmospheric carbon dioxide, implying that US forestry practices need not be modified in the face of global warming.

These two anecdotes illustrate modes of thinking about natural resources management that are becoming outmoded in the face of increasingly credible projections of global climate change. If water project planners have struck a reasonable balance between reliability and social and technical design constraints, then they should give careful consideration to any external factor that threatens to change that balance. Are they willing to accept decreasing reliability as projects "absorb" climate change? The senator's attempt to isolate US forestry from its global ramifications is inappropriate when Brazil and other tropical countries are being pressed to limit forest cutting.

These instances suggest the kind of premature limits being placed on the range of options for responding to global warming. The threat of anthropogenic climate change calls for a new paradigm of natural resources management that includes greater experimentation with alternative futures and recognizes global linkages between regional activities. In this paper, I examine the global warming issue, and describe the initial components of this paradigm.

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The Threat of Global Warming

Anthropogenic climate changes are likely to be detectable amid the noise of natural climate variability during the next decade or so, and some analysts believe that record warm temperatures in the 1980s indicate global warming is already evident (Hansen et al. 1988; Hansen and Lebedeff 1988). Global average temperatures are likely to increase 3–5°C by the middle of the next century (World Meteorological Organization 1985; Carbon Dioxide Assessment Committee 1983). No credible challenges to these projections have emerged, although significant scientific uncertainty surrounds such issues as the possible dampening effect of increased cloudiness in a warmer world.

Our ability to assess the impacts of climate change has improved in concert with growing expectations of warming. Geographers in particular are developing methods for projecting the social implications of climate change (Kates et al. 1985), applying theory from human ecology (Butzer 1980), natural hazards (Warrick and Riebsame 1981), political economy (Watts 1983), and decision-making (Morrisette 1988). Geographers have studied historical climate-society relationships (Parry 1981; Bowden et al. 1981), explored the international implications of climate impacts (Kates 1980), and assessed climate change impacts on agriculture (Parry et al. 1988), food supply (Liverman 1987), and water resources (Cohen 1986).

A decade after the first World Climate Conference (World Meteorological Organization 1979) a variety of methods can now be used reliably to estimate impacts of climate change. A frequent finding of impact studies is that even relatively small climate changes can have disruptive effects on natural resources (Parry et al. 1988; Riebsame 1988c). Not all impacts are negative, but the negative effects can be surprisingly large. For example, minor warming may dramatically decrease freshwater runoff (Revelle and Waggoner 1983), or small shifts in the seasonal distribution of precipitation or temperature may sharply reduce crop yields (Warrick et al. 1986).

The Policy Response

Global climate warming is now a high-priority national and international policy issue. Impact projections have led to calls for concrete policy actions (White 1988; World Meteorological Organization 1989), aimed chiefly at altering energy, agriculture, and forestry practices in order to limit global warming by reducing greenhouse gas emissions. Natural resource planners are being pressed to anticipate and mitigate future impacts: over two dozen bills to reduce and prepare for global warming were under preparation in the US Congress by early 1989 (e.g., Senate Bill 2667, the National Energy Policy Act), and credible social institutions worldwide are calling for anticipatory action. The United Nations Environment Program (UNEP), which brokered the recent ozone protection treaty, is committed to forging an international climate treaty by the early 1990s (United Nations Environment Program 1987).

Much less attention is being paid to the way systems for managing climate-sensitive resources can cope with rapid climate change. Yet global warming in the range of 1–2°C is likely to occur in the next few decades even with immediate greenhouse gas limitations, due to accumulated gases and thermal inertia in the climate system (Jones et al. 1987). If global warming projections are correct, then both preventive and adaptive steps will be needed.

A Resource Planning Conundrum

The threat of global warming undermines the conventional natural resource planning assumption that, while social factors (e.g., population) may change dramatically, basic environmental elements like climate are essentially stable. Climate change would affect the efficacy of resource management plans in meeting future social needs and desires. Because global warming is anthropogenic, it also raises the question of how those plans contribute to the problem.

Policy-makers are responding to arguments for quick action to stem greenhouse gas emissions and to prepare for climate change, even without further improvements in scientific understanding of the problem. This response is evident in federal legislation now under consideration and in calls for a global treaty to protect the climate. The public, elected officials, and researchers increasingly appreciate the potential impacts of global warming and the relationship between policy delays and worsened future impacts (US Environmental Protection Agency 1989; Jäger 1988). Most resource managers, however, have adopted a wait-and-see posture on global warming, and are attracting criticism for failing to address the issue aggressively (US Senate Agriculture Committee 1989; *New York Times* 1989).

A wait-and-see approach is justified chiefly by three arguments: climate change predictions are too uncertain, especially at the regional level, for specific action (Katz 1988); current systems can absorb significant climate change without failing (Hanchey et al. 1988); and technological change can override the negative effects of climate change (Wittwer 1980). All of these arguments have merit. Global warming predictions do lack the regional details necessary to alter development plans to accommodate climate change: It is premature to build new reservoirs or to plant different tree species because of the greenhouse threat. Yet current planning approaches overlook even the logic of conducting initial assessments of the threat in climate-sensitive resource sectors. Moreover, current resource planning policies dissuade managers from accounting for potential impacts on global commons such as the atmosphere and climate (Schelling 1983).

The conundrum, then, is how to respond to the pressure for action in the face of large uncertainty. Resource planners must develop a strategy that reflects: (1) the sensitivity of resource systems to climate change; (2) the uncertainty surrounding climate changes and how it can be incorporated into their response repertoire; and (3) the role that resource activities play in worsening the greenhouse problem. The remainder of this paper expands on these points, and describes components of a new paradigm for natural resource planning that fits the policy environment being shaped by the global warming threat (cf. Riebsame 1988a).

Climate Sensitivities in Resources Management

Environmental planners should take the opportunity, while interest is high and before climate change is expressed in disruptive impacts, to assess the sensitivity and adaptability of resource systems and management practices. While projections of climate change are too uncertain for specific response implementation, the threat calls for a wide-ranging evaluation of resource system capacity to absorb climate change, and the creation of adjustment contingency plans.

Management of most renewable resources, and of some stock resources like fossil fuels, is sensitive to climate fluctuation (Kates et al. 1985). Factors affecting sensitivity and adaptability include: (1) the degree to which elements such as temperature and precipitation affect resource yield or the maintenance of desired management criteria; (2) the planning horizons of resource system changes; (3) the method and frequency with which operational criteria are evaluated and updated; and (4) whether potential impacts may be incidentally accommodated or exacerbated as planners seek other goals (e.g., increased energy- or water-use efficiency). Climate sensitivities are especially evident in water resources, agriculture, forestry, energy, floodplains and coastal zones, and certain aspects of architecture and urban and regional planning. Water resources management illustrates this sensitivity.

The Case of Water Resources Management and Climate Change

Climate change will affect flood control and surface water supply management. Flooding is consistently the most costly natural hazard in the United States, accounting for the majority of all presidentially-declared disasters over the last decade (Riebsame et al. 1986). In standard project planning, expected flood frequencies and magnitudes are determined from empirical relationships between intensity and duration of precipitation and runoff (Hoyt and Langbein 1955). From these expected conditions, planners choose a project flood for design purposes, typically an event likely to occur less than once in 100 or 200 years (the return period). A maximum probable flood, often with a return period of 1000 or more years, may also be calculated in designing facilities, like spillways, whose failure would be catastrophic.

The surface water supply problem in the face of climate change centers on the reliability of the runoff collected, stored, and delivered to users. Water supply managers design projects and plan dry period operations to produce a minimum safe yield based on the lowest annual runoff or river discharge expected in a century or more (Russell et al. 1970; Georgeson 1986; Riebsame 1988b).

Water Project Sensitivity. Potential global warming raises the obvious question of how well water projects based on historical conditions will cope with future climate change. Most water projects are designed for both flood and supply management, and involve planning horizons of several decades, within the timeframe of potentially large global warming effects (Schwartz 1977; Cohen 1986; Schilling et al. 1987). Project management criteria are predicated on hydrological conditions established from data for the past 30 to 100 years, with liberal safety margins to accommodate errors and unusual conditions. Indeed, Hanchey et al. (1988) argued that project planners had:

> over the course of fifty years of application and refinement [developed] a large body of empirical and theoretical procedures and decision rules that have yielded what are generally considered to be fairly robust and resilient project designs . . . . This empirical approach, emphasizing as it does extremes of climate variability over the past 100 years, encompasses a significant proportion of the anticipated [climate] changes, at least for large scale water management. (399)

This risk-averse design approach considers relationships between critical climate variables (e.g., runoff) and water project operating limits (Fig. 1a). Designers plan for extreme events within technical and economic limits, and add additional safety margins according to rules of thumb and the overriding principle that the project simply must not fail (Georgeson 1986; Dziegielewski 1986). The net social costs and benefits of this strategy are unknown (Schilling et al. 1987), though it has indeed produced mostly reliable water projects.

The simple fact remains, however, that climate change is, by definition, a change in the statistical properties of climatic elements. Depending on the safety margins designed into a project, climate change will alter the frequency of conditions that approach or surpass failure thresholds (Fig. 1b). If planners have achieved socially-acceptable project reliability, then any climate change larger than the uncertainty inherent in hydroclimatological analysis violates explicit and implicit planning criteria.

Without project sensitivity analyses linked to climate change projections, however, we cannot know how significant this violation may be. Assessments of the vulnerability of water projects to climate change are rare, and beyond a reassuring sense that they have been designed in a risk-averse manner, the capacity of most existing projects to accommodate climate change is unknown. The assumption of climate stability remains a potentially dangerous blind spot in water project design in light of the threat of global warming (Lettenmaier and Burgess 1978; Changnon 1984; Katz 1988).

Potential Adjustments. Water projects can be adjusted to climate change by al-

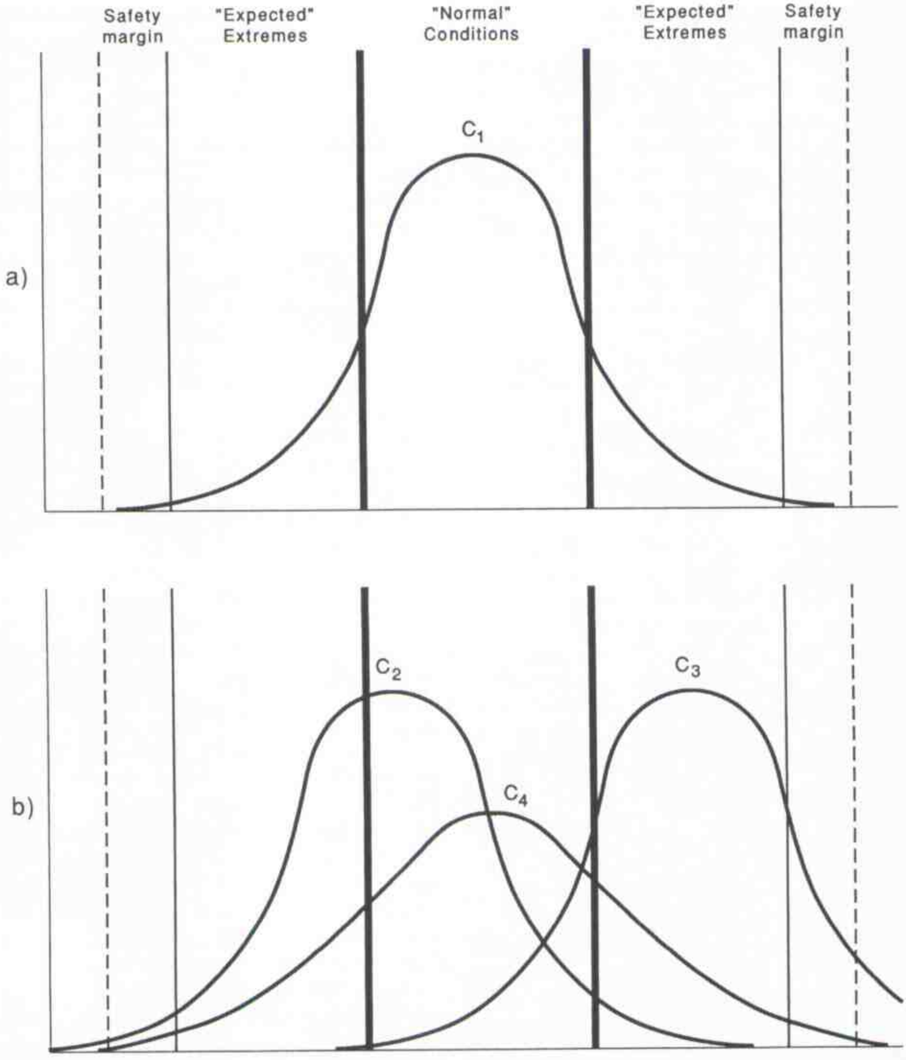

Figure 1. (a) Schematic relationships between water project operating limits and a hydroclimatological variable such as runoff under current climate (c_1); (b) hypothetical new climates under greenhouse forcing (c_{2-4}) with altered frequencies of events approaching or surpassing operating limits.

tering project goals (e.g., accepting lower reliability), operations, or physical facilities. Goal and operational changes are common in a project's lifetime, but tend to be made only when droughts or floods cause near or actual system failure (Glantz 1982; Rhodes et al. 1984; Phillips and Jordan 1986; Riebsame 1988b). Physical facility changes occasioned by new information on environmental threats are much less common, though a few recent studies of geological risks to dams have led to physical modifications (West 1988).

Changes in water project planning and

operation unrelated to climate may either heighten or lower adaptability to a changing climate. The trend toward increased water-use efficiency could mitigate the impacts of climate becoming drier. Alternatively, reduced federal contributions to water project construction and operation will probably result in smaller projects more closely attuned to local fiscal and environmental sensibilities (National Council on Public Works Improvement 1987, 126–42). These projects will have smaller excess capacity than has been traditionally maintained to absorb climate shocks, and will thus be more sensitive to climate change.

Problems in Adjusting Resource Systems

Resource system adjustment to global warming will be subject to the same broad constraints of technical feasibility, economics, and social acceptability that affect all planning. But certain characteristics of natural resource planning, including the assumption that the broad environment is stable, are especially likely to delay or complicate adjustment to climate change. Besides water resource planning, this bias for stability permeates range science, agronomy, architecture, and other fields where average climatic parameters are used in yield models or as design criteria (Morrisette 1988; Holling 1986).

Yet, this assumption is inconsistent with expectations about the social forces acting on resource systems: population, demand, consumer tastes, and other socioeconomic variables are expected to change in the future and much effort is invested to predict these changes and their impacts. The US Forest Service, for example, projects forest product demand by analyzing changes in foreign and domestic consumption, competition, and substitutes over time using complex econometric models (US Forest Service 1988). With modification, such models could be used to evaluate climate change sensitivities, but that use has been ignored even in the Forest Service's long-term planning process (US Senate Agriculture Committee 1989).

Additional constraints on adjustment might derive from resource managers' perceptions of climate change *per se*. Responses to events seen as isolated extremes rather than as indicators of cumulative trends are likely to be piecemeal and temporary (Fischoff 1981; Heathcote 1985; Whyte 1985). Trends unrelated to climate change can also exacerbate or lessen future impacts, but it may be difficult to distinguish the difference much in advance. For example, crop subsidy reductions called for in the 1985 Food Security Act may make farms more or less adaptable to climate change. Subsidies might allow farms to survive in increasingly hostile climates, thus delaying and worsening inevitable failures. Alternatively, they could provide the resources needed for crop changes or other adaptations. New research should address ways to lessen such uncertainties.

A New Paradigm of Resource Planning

The threat of global warming calls for a new paradigm of resource planning, one which elaborates rather than replaces traditional planning approaches based on empirical analysis, economic efficiency, and environmental protection. The new paradigm should incorporate at least four elements: (1) resource sensitivity analysis that explicitly recognizes the potential for fundamental environmental change; (2) stepwise adjustment tied to the increasing certainty of greenhouse effects; (3) an enlarged range of alternative adjustments; and (4) planning in a global context and recognizing links between the causes and impacts of anthropogenic climate change. Each component is now briefly described.

Resource System Sensitivity Analysis

Despite increased research on climate impacts, the broad sensitivity to climate change of most natural resource systems has not been analyzed. Rather than focusing on a specific future climate and its effects, planners should assess how a range of climate conditions would affect resource systems as currently configured and as they might be adjusted over time. This approach can indicate how soon significant impacts might occur, and provides ranges of potential effects less affected by inevitable changes in the details of climate projections than assessments based on a particular projection (Katz 1988; Lamb 1987).

Climate scenarios for use in sensitivity studies can be created in several ways (Lamb 1987). The most common approach is to extract climate statistics from global models simulating heightened (usually doubled) greenhouse gas levels. Transient response simulations, based on increments of the greenhouse effect, complement this approach by providing projections of the secular evolution of climate change impacts. Historical, paleoclimatological, and arbitrary scenarios can also be used in sensitivity assessments, and tests can be applied to assure that projections are consistent with current understanding of climate change (Wigley et al. 1986). To make assessments more realistic, the traditional focus on average climate conditions should be expanded to include changes in variability and the frequency of extremes (Mearns et al. 1984; Mearns 1988).

Climate scenarios can be linked to resource models which use empirical or theoretical relationships to extrapolate impacts on variables such as runoff, crop yields, and ecosystem characteristics (Gleick 1987; Rosenzweig 1985; Shugart et al. 1986). Biophysical changes can then be used as inputs to economic or resource management simulations such as farm or water system models (Parry et al. 1988).

The credibility of impact studies can be improved by focusing on the most robust elements of climate change projections. For example, different climate models yield relatively consistent temperature patterns, but predict widely dissimilar precipitation changes (Schlesinger and Mitchell 1985). Thus, the most credible studies will be in resource activities that are sensitive chiefly to temperature trends, particularly warming.

A Stepwise Adjustment Process

Heightened public concern over global warming suggests that greater demand for mitigating action will be a salient feature of the policy-making environment in the near term, especially in the wake of events such as the 1988 drought. The next several years will also be marked by improved projections of future climate, and, perhaps, the conclusive detection of anthropogenic climate change as a distinct signal amid natural climatic fluctuation. To cope with this changing context to their activities, resource planners should differentiate between planning steps to be taken immediately and those that should await further refinements in climate projections or more solid evidence for global warming.

Resource managers cannot be expected to adopt costly or disruptive adjustments aimed at reducing the impacts of uncertain climate change; nor are they likely to support drastic changes to limit greenhouse gas emissions. Yet they also cannot ignore the issue. The obvious response strategy is for planners to focus initially on adjustments, such as increased energy- and water-use efficiencies, that can be justified for other environmental or economic reasons (Schneider 1989).

The threat of rapid climate change, however, is now sufficiently credible that planning should also encompass the greater adjustments that will be necessary due to climate change *per se*. This foresight is especially important for resource systems which might fail under modest climate change. For example, slight warming and drying of the Great Plains could disrupt dryland wheat production (Rosenzweig 1985), requiring massive land use changes. An initial step might assess how current farm policies affect adaptation to a changing climate, targeting those that limit flexibility. Contingency plans for changes in cropping patterns, resource protection, and rural development should then be fashioned and elaborated as the climate change threat is clarified.

Similarly, even relatively small changes in climate could cause serious water shortages in the Colorado Basin, where supply and demand are closely balanced (Revelle and Waggoner 1983). Adjusting the system to climate-induced changes in runoff will be difficult because the physical and institutional structures for managing Colorado River water are especially rigid (Brown 1988). Colorado Basin water planners should differentiate between adjustments that can be effected under current system arrangements (e.g., modifying reservoir operations and changing local water supply plans within the basin), and those that would require more lengthy implementation (e.g., renegotiating the interstate water allocation agreement or enlarging reservoir capacity). The social disruption, cost and irreversibility of adjustments must also be considered, and weighed against the risk of impacts. Renegotiation of the Colorado River Compact to accommodate lower flows would produce winners and losers among the basin states even without climate change, and may be premature given current uncertainties.

In analyzing trade-offs and matching adjustments to the evolving threat of global warming, planners can adopt several different formal or informal decision aids, such as cost-benefit analysis, risk analysis, and public input (Murphy and Katz 1985). Whatever decision guide is chosen, one clear lesson from natural hazards and resources management research is that decision-makers must strive to avoid the trap of considering only a few responses due to tradition or institutional constraints (O'Riordan 1986). Approaches that enlarge the range of alternative adjustment considered by resource managers need to be devised and improved.

Enlarging the Response Repertoire

To avoid being pressured into action prematurely, or paralyzed by uncertainty, managers need to consider a wider repertoire of planning approaches than has been relied upon traditionally. Responses should include adjustments that are easily and cheaply implemented and reversed as needed (e.g., more frequent evaluation of reservoir operating rules in water systems), and those that expand, rather than limit, future options (e.g., floodplain land use that places less fixed investment at risk, and efforts to conserve crop genetic diversity).

The "tie-in" strategy proposed by several climate and policy analysts (cf. Schneider 1989), in which immediate steps to reduce greenhouse gas emissions are justified because they also solve current environmental problems such as acid precipitation, needs to be elaborated. This approach can be strengthened by an additional tie-in to decisions that also make resource management systems less sensitive to current climate fluctuations and more adaptable to future climate change. These strategies coalesce in three realms where: (1) social needs and desires are met and current environmental problems are solved; (2) greenhouse gas emissions are limited; and (3) sensitivity to current and potential future climate fluctuations is reduced (Fig. 2).

Resource Management in a Global Context

The global nature of the greenhouse problem requires new linkages between local, national and international decision-making. Because so many resource activities, from power generation to rice cultivation, produce greenhouse gases, policy discussions on global warming inevitably embrace links between national resource planning and the global threat. Resource managers at all levels must be prepared both to address climate change impacts on their plans as well as the role their activities play in the global greenhouse effect.

Exactly how this heightened concern will translate into altered resource management policy remains uncertain, but the general shape of these imminent changes can already be discerned. The issues associated with resources planning in a global context are complex and beyond

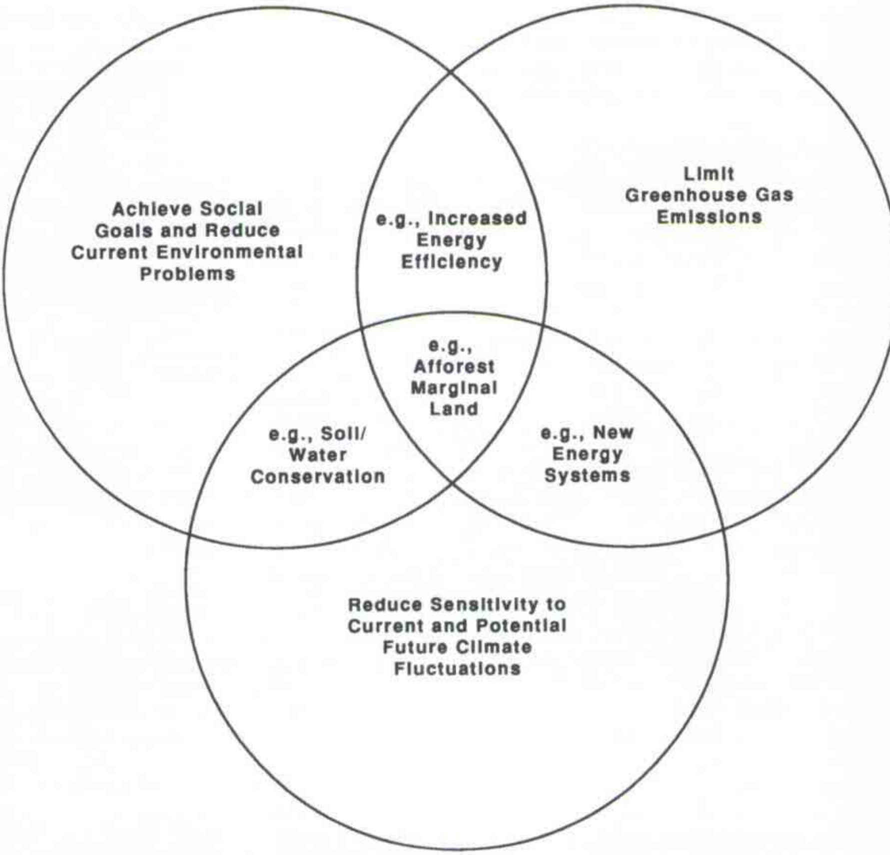

Figure 2. Sets and intersections of options for adjusting natural resources management that achieve a mixture of goals, including limiting and preparing for anthropogenic climate change.

the scope of this paper, but two principles appear to be emerging from the international dialogue on global warming (cf. World Meteorological Organization 1989). First, the problem has been caused chiefly by the industrialized nations, and they must bear the main burden of its solution. Second, solutions must accommodate Third World needs for economic development. Developing countries cannot be asked to limit greenhouse gas emissions by reducing their energy use, forest cutting, or rice cultivation without equal or better substitutes for the resources those activities yield.

If these principles hold, then resource planners, even at the local level, will come under pressure to change their activities to meet multilateral objectives. The nature of such planning principles and global linkages will be determined at the highest policy levels, presumably through the international treaty already called for by several political and scientific leaders (World Meteorological Organization 1989: 292–99). In anticipation, resource planners at all levels should begin to establish the roster of mechanisms that could effect complementarities between management activities (e.g., Fig. 2), and start to evaluate ways to link local resource decisions to the emerging global environmental policy framework. For example, local, state and federal forest managers in the United States might begin to account for and alter the carbon balance of their activities in accordance with international agreements (Sedjo 1989), or the US Department of Energy might increase research on noncarbon energy systems and on ways to implement them in developing countries without derailing economic growth. In this way, the threat of anthropogenic climate change adds novel dimensions to traditional planning approaches like economic efficiency and multiple use.

Conclusion

Calls for international cooperation to reduce the threat of global warming signal a changing social context for natural resources planning at all scales. Initial components of a new paradigm for natural resources management have been described here; these ideas must be quickly elaborated so that plausible responses can be offered to demands for action. The most immediate need is for better strategies to deal with the conundrum of growing pressure to respond to global warming while large uncertainties surround its manifestation and impacts. Geographers and other researchers should also be exploring approaches to linking local and national resource activities to the global scale.

The threat of global warming has not yet changed how managers make choices about resource development and allocation. However, unless new information emerges soon to negate the growing consensus that anthropogenic climate change is imminent, a wait-and-see approach will increasingly appear to be a reckless rather than cautious policy.

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