STRATEGIES FOR ADAPTING TO THE GREENHOUSE EFFECT

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Summary

Increasing concentrations of CO_2 and other gases seem likely to warm the earth in the next century. We examine opportunities to prepare for the consequences, focussing on options that are rational even if one is skeptical about global warming. Some responses can be postponed. But many low-cost opportunities will slip away if we fail to act; and reaching a consensus on what is fair is easier when the consequences seem remote. We conclude that some changes in land use and water allocation should be implemented today, even if effective dates are several decades in the future.

Introduction

In the last three decades, a scientific consensus has emerged that humanity is gradually setting in motion a global warming by a mechanism commonly known as the "greenhouse effect." If current trends continue, our planet is likely to warm 3-5o C in the next century – as much as it has warmed since the last ice age. Such a warming would raise sea level a meter or more, and threaten water supplies, forests, and agriculture in many parts of the world. In response, the U.N. General Assembly has created an Intergovernmental Panel on Climate Change to develop a plan for decreasing worldwide emissions. However, climatologists have generally concluded that it is too late to prevent a one or two degree warming.

Should planners begin to prepare for the consequences of the greenhouse effect? The need to respond today depends on (1) the likelihood of global warming; (2) the magnitude of the impacts; and (3) the potential for anticipatory measures to reduce adverse impacts if sea level rises or climate changes as expected, without imposing substantial costs if the changes do not unfold. Although the literature on the first two factors is extensive, the latter issue has rarely been mentioned. As a result, some people assume that it would be unwise to prepare for global warming until its eventuality and consequences are firmly established.

In this article, we show that for many of the possible consequences of global warming, one can develop anticipatory responses that would substantially reduce adverse impacts of global warming with relatively little risk of the response proving to be ill-advised should the expected effects of global warming fail to unfold. After briefly summarizing the literature on the causes and effects of global warming, we suggest a number of criteria for evaluating response strategies, and present several example responses in detail. Although most of the examples involve the United States, similar opportunities are available in other countries. We hope that this article helps motivate planners throughout the world to begin preparing for the uncertain consequences of a global warming.

The Greenhouse Effect: Causes, Effects, and Responses

The Swedish chemist Svante Arrhenius (1896) coined the term "greenhouse effect" at the turn of the century: The water vapor and carbon dioxide found naturally in the earth's atmosphere allows sunlight to penetrate but retains outgoing infrared radiation, in a manner somewhat analogous to the glass panels of a greenhouse. Arrhenius estimated that if the combustion of fossil fuels were to result in a doubling of atmospheric CO_2 levels, global temperatures could rise 5^{o} C.

Until 1957, scientists generally expected the oceans to absorb the CO_2 released by human activities. Since that time, however, we have learned that only half the CO_2 dissolves into the oceans, and that atmospheric levels of CO_2 are increasing (Keeling et al. 1982). For the last decade there has been a consensus among climatologists that a doubling of CO_2 – expected by the middle of the next century – would raise global temperatures 1.5-4. 5^{o} C (Charney et al. 1979), although recent assessments suggest that the warming could be greater (Lashoff 1989). Moreover, a number of other gases released by human activities also have a greenhouse effect, including methane, chlorofluorocarbons, nitrous oxide, and carbon tetrachloride (Ramanathan et al. 1985).

Most of the consequences of global warming would result from one of three physical changes: sea level rise, higher local temperatures, and changes in rainfall pattern (Figure 1). Sea level is generally expected to rise 50-200 cm in the next century (Dean et al. 1987); such a rise would inundate 7,000 square miles of dry land in the United States (an area the size of Massachusetts) and a similar amount of coastal wetlands, erode recreational beaches 100-200 meters, exacerbate coastal flooding, and increase the salinity of aquifers and estuaries (Titus 1989).

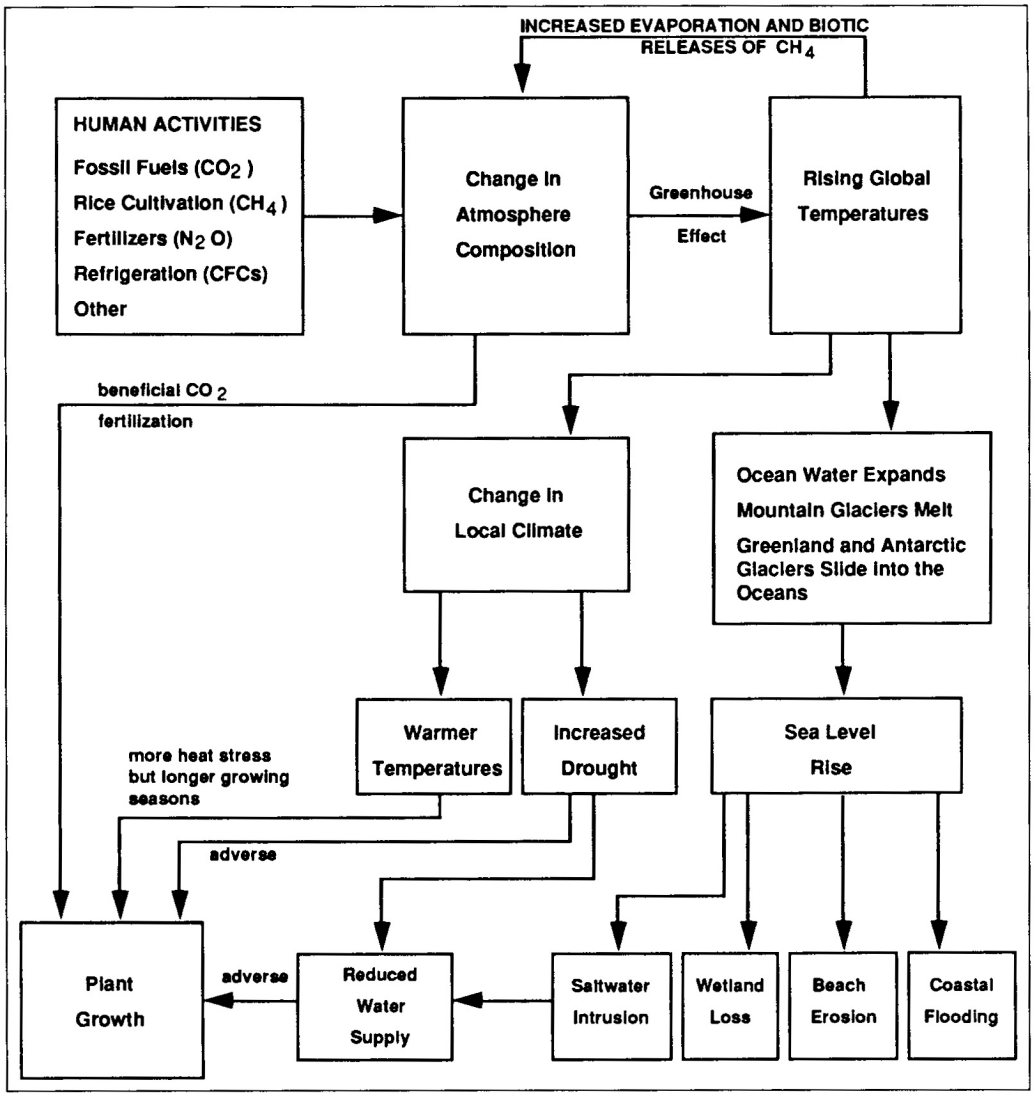

FIGURE 1: The causes and effects of global warming, before society responds.

For most practical purposes, the rise in sea level would be uniform – both geographically and seasonally – because sea level is a global process (although the impacts would vary greatly). By contrast, climatologists generally expect important seasonal and geographical variation in precipitation and temperature changes; the warming, for example, is likely to be greatest in winter and at higher latitudes. Unfortunately, no one can predict how the climate of particular regions will change. Although there is a general expectation of wetter winters and dryer summers in mid-latitude continental areas (Manabe and Wetherald 1986), the possibility of wetter summers can not be ruled out for any particular location.

A number of impacts now seem likely, largely because the relatively certain increases in temperatures would overshadow the unknown changes in rainfall. Higher temperatures would increase evaporation; hence the Great Lake levels are likely to drop even if rainfall increases moderately (Marchand et al. 1988). Snow packs will melt several weeks earlier, implying that less water will flow into California's Central Valley (Lettenmaier et al. 1989). Regardless of soil moisture, many crops fail when temperatures exceed 100oF, which could become commonplace in the southeast (Peart et al. 1989); temperatures are also likely to exceed the tolerance of the dominant forest tree species in the southeast (Urban and Shuggart 1989).

Table 1 presents some possible responses for several of the effects of global warming. As the table indicates, the response will often involve a fundamental choice between maintaining economic activities in their current locations and preserving the environment. Coastal ecosystems can not migrate inland and terrestrial ecosystems can not migrate north if blocked by development; rivers can not remain unspoiled if their water is diverted for agricultural and urban uses. As with most issues faced by planners, the political process will have to make these tradeoffs; but conflicts can be minimized if strategies are implemented in advance of the problem.

Table 1.
Responses to Global Warming

Effect	Economy shifts to accommodate the environment	Environment changes to accommodate economy
Beach erodes from sea level rise.	Allow shores to retreat; prohibit private construction of seawalls; set new houses farther back from the shore.	Dredge sand from offshore and place it on the beach.
Lowlands are inundated.	Remove structures as shoreline retreats.	Construct bulkheads to protect houses from inundation and lose wetlands.
River flooding due to increased storm severity.	Elevate houses on pilings or prohibit construction in new floodplains.	Construct dams to moderate river surges; construct levees to contain river flow.
Decreased rainfall threatens water supplies.	Conserve water; relocate water-intensive activities to where water is more plentiful.	Construct dams to provide seasonal storage of water; construct pipelines and aqueducts.
Hotter and dryer summers disrupt agriculture.	Abandon marginal farms and open new farms in wetter and cooler areas.	Expand water-supply infrastructure to support increased irrigation.
Climate change and sea level rise make nature preserves less hospital for wildlife.	Extend park boundaries inland in the case of sea level rise, create new parks in a more favorable climate.	Artificially feed animals; provide warming huts (i.e., convert parks to zoos).
Hotter temperatures become a nuisance.	Encourage migration to colder areas.	Increase use of air conditioning, which will result in increased power consumption.

Setting Priorities

One of the most fundamental issues facing decision makers is whether to implement responses today or defer preparation until the impacts are better understood and more close at hand. The fact that global warming might eventually necessitate a particular action does not necessarily imply that the action should be taken today. On the other hand, the likelihood of global warming is sufficiently well-established and the time it takes to develop a response sufficiently long that deferring all preparation could lead us to overlook inexpensively opportunities to prepare.

In evaluating potential responses to global warming, policy will have to consider a variety of criteria:

- Economic Efficiency: Will the initiative yield benefits substantially greater than if the resources were applied elsewhere?
- Flexibility: Is the strategy reasonable for the entire range of possible changes in temperatures, precipitation, and sea level?
- Urgency: Would the strategy be successful if implementation were delayed ten or twenty years?
- Low Cost: Does the strategy require minimal resources?
- Equity: Does the strategy unfairly benefit some at the expense of other regions, generations, or economic classes?
- Institutional feasibility: Is the strategy acceptable to the public? Can it be implemented with existing institutions under existing laws?
- Unique or Critical Resources: Would the strategy decrease the risk of losing unique environmental or cultural resources?
- Health and Safety: Would the proposed strategy increase or decrease the risk of disease or injury?
- Consistency: Does the policy support other national state, community, or private goals?
- Private v. Public Sector: Does the strategy minimize governmental interference with decisions best made by the private sector?

Although planners routinely consider these issues in addressing current problems, the nature of global warming may alter their role in the planning process. (1) While urgency usually means that a problem is imminent, in the context of the greenhouse effect the question is whether the opportunity to solve the problem is likely to vanish if no action is taken soon. (2) Equity may be easier to achieve: solutions that take effect several decades hence, for example, are less likely to be unfair since people have ample time to adjust. Finally, (3) because current institutions were not designed with global warming in mind, they may be unable to address the issue; on the other hand, the magnitude of the problem may be great enough to compel legislators to change laws that planners usually must accept as fixed.

Perhaps the greatest difference, however, concerns the difficulty of weighing present versus future benefits. all the criteria to economic efficiency, except for institutional feasibility and equity, and circumvent the latter problem by proposing that winners compensate those who lose from a policy (this part of the theory is often overlooked by practitioners). For example, "discounting" future benefits is often used to determine the "present" value of costs and benefits in the distant future, but the procedure only addresses economic efficiency; i.e. whether solving a problem now is superior to investing the same level of resources in a trust fund that can be used to clean up the problem later. Unfortunately, most governments can not simply establish a trust fund. Some people assume that the analysis also indicates whether an action today is superior to no action; but such an assumption implies indifference regarding how many unsolved problems we pass on to future generations, since it equates no action with establishing a trust fund.

Moreover, financial theory shows that the appropriate discount rate equals the return on risk free investments (e.g. Treasury Bonds) plus a risk premium reflecting the correlation between the return on the investment and the overall success of the investor's portfolio. In the 1980s, the U.S. Office of Management and Budget required federal agencies to use a 10-percent discount rate, effectively assuming that benefits from federal policies are highly correlated with the stock market and society's overall well-being. However, strategies to prepare for the greenhouse effect would help the most if the consequences are severe; hence these policies can be viewed as insurance, which implies that the appropriate discount rate is less than the (real) return on Treasury bonds and may even be less than zero, which produces nonsensical results if an analysis is extended into the indefinite future.

Given the limitations of cost-benefit analysis, we suggest that planners first concentrate on the "easy" solutions, that is, those that are low cost; reasonable for the entire range of likely changes in climate; institutionally feasible; urgent; and equitable. In mature fields of endeavor, the easy solutions have already been implemented; but preparing for global warming is a new field.

Example Strategies

Responses to climate change can be broadly divided into four categories.

- No action today where least-cost solutions could be implemented as the problem emerges with existing technology and institutions;
- Anticipatory action, where it would be wise to take concrete measures today;
- Planning, where we do not need to physically change what we are doing immediately, but where we need to change the "rules of the game" now, so that people can respond to new information in a way that furthers social goals;
- Research and education in cases where it would take decades to develop solutions and train people to carry them out, or where the need to take action has not yet been assessed.

We now examine examples of each type of response, identifying easy solutions where possible.

No Action Today

The urgency of responding to climate change depends not only on the severity of a potential impact, but also the extent to which taking action today would diminish the ultimate cost of adaptation or allow us to avoid problems that will be unavoidable if we wait before taking action. If the solution to a problem is well-defined and can be implemented quickly, there is little reason to take action.

Miller and Brock (1989) examine decision rules that governing releases of water from reservoirs, which are generally based on historic climate variability. For example, if the flood season is March to May and droughts are from July to September, reservoir managers will typically lower the water levels by the end of February to ensure adequate flood control capacity, and allow the levels to rise in June so that there is adequate water in case of a drought. If global warming advanced the flood season by one month, managers would eventually shift the schedule of water releases; but there is no need to do so today.

Similarly, the rise in sea level would eventually require the Republic of Maldives to raise its inhabited islands, probably by mining certain coral areas for material (Figure 2); seaside resorts will have to pump sand onto eroding beaches (Figure 3); and levees will be necessary to protect cities, but these activities can await the actual rise (Dean et al. 1987). Changes in rainfall and temperatures will eventually lead farmers to shift crops (Adams et al. 1989), but shifting today would be counter-productive.

Figure 2: Tulhadoo, Baa Atoll, Republic of Maldives. Many coastal barrier and atoll islands throughout the world will have to be raised as sea level rises.

Figure 3: High rises south of Rio de Janeiro will eventually require artificial beach nourishment.

Anticipatory Action

Nevertheless, studies have identified a number of instances in which physical responses are appropriate even today, either by (1) incorporating global warming into long-term projects that are already underway; (2) taking actions today that without global warming might not be necessary until later, if at all.

Incorporating Global Warming into Long-Term Projects

The rationale for doing so is that the outcome of projects initiated today will be altered by the effects of global warming. Modifying plans to consider global warming would frequently be an "easy" solution: The cost of factoring climate change will often be a small percentage of the total project cost; it is "urgent" because once the project is under construction it will be too late to incorporate climate change. Because a consideration of the greenhouse effect would often ensure that projects are adequate to address current climate variability.

Consider, for example, the replacement of a century- old street drain in Charleston, South Carolina (Titus et al. 1987). If designed for the current 5-year storm, such a system might be insufficient if sea level rises one foot or the severity of the design storm increases 10 percent, necessitating a completely new system long before the end of the project's useful life. On the other hand, installing slightly larger pipes sufficient to accommodate climate change might cost only an additional 5 percent. In such a case, designing for increases in precipitation might prove to be worthwhile if these changes occur; even if they do not occur, there would be some benefits because the system would provide protection during the more severe 10-year storm. Wilcoxen (1986) made a similar argument regarding the location of San Francisco's West Side Sewage Transport. Similar situations will occur throughout the world.

Because some commercial tree species live as long as 70 years before being harvested, forest products companies may want to reconsider location and types of species. For example, some types of Douglas fir need at least a few weeks of cold winter temperatures to produce seeds. Currently, companies concentrate planting efforts at the bottoms of mountains, from which logs can be most readily transported; considering future warming may lead them to plant further up the mountain or in colder regions. In some cases, an "easy" solution may be to shift from long-lived species that are vulnerable to climate change to those that are less vulnerable or have shorter growing cycles. If two species were equally profitable today but one would fare much better if climate changes, shifting to the latter species involves little risk and might substantially help long-term profits. Shifting to a species with a 20-year lifetime would enable harvests to take place before climate changes enough to adversely affect growth, and would make it easier to respond to climate change as it occurs.

Undertaking Projects Today

In a few cases, where authorities are already contemplating public works for which the economic justification is marginal, the prospect of sea level rise or climate change might convince decision makers to proceed. For example, a surge in the Thames River in the 1950s that almost flooded London led the Greater London Council to develop plans for a massive movable barrier across the river. Many questioned whether it was worth building. But the fact that flood levels had risen steadily one foot every 50 years for the past five centuries convinced their technical advisory panel that the barrier would eventually be necessary; once that eventuality was recognized, there was a consensus that the project should go forward (Gilbert and Horner 1984).

Constructing a project because of the greenhouse effect will rarely if ever be an "easy" solution: It requires more certainty than incorporating climate change into a project that would be undertaken anyway, because (1) undertaking a new project requires the legislature or board of directors to initiate major appropriations, rather than approve supplemental increases and (2) the project can be delayed until there is more certainty. Even if future impacts are certain, action is

unnecessary unless the time it will take for the impacts to occur is no greater than the time it will take to design, approve, and build the project. Thus, only the near-term impacts and those solutions would take several decades to implement require remedial action today.

In the United States, Louisiana is already losing 100 square kilometers of land per year due to subsidence and human alteration of natural deltaic processes. If current trends continue, most of the wetlands will be lost by 2100 (Louisiana Wetland Protection Panel 1988.) But if sea level rise accelerates, this could occur as soon as 2050. The immediacy of the problem is greater than these years suggest, because the loss of wetlands is steady. Assuming the additional loss of wetlands to be proportional to sea level rise, half the wetlands could be lost by 2030, with some population centers threatened before then.

Whether or not sea level rise accelerates, the majority of wetlands can only survive in the long run if society restores the natural process by which the Mississippi River once deposited almost all of its sediment in the wetlands. Because billions of dollars have been invested in the last 50 years in flood-control and navigation-maintenance projects that could be rendered ineffective, restoring natural sedimentation would cost billions of dollars and could take twenty years or longer. Because of the wide variety of interests that would be affected and the large number of options from which to choose, it could easily take another ten to twenty years from the time the project was authorized until construction began.

Thus, if sea level rise accelerates according current projections, and a project is initiated today, about half of the delta will remain when the project is complete, while if is authorized in the year 2000, 60-70 percent might be lost before it comes on line. By contrast, if sea level does not accelerate, the two implementation dates might imply 25 and 35 percent losses of coastal wetlands. Because a delay would not substantially reduce the costs of such a project, and because there would be considerable benefits from an earlier implementation date even if sea level rise does not accelerate, it would be more economically efficient to authorize it today than ten hears hence.

Elsewhere, the Nile Delta is eroding rapidly as a result of the Aswan Dam (Broadus et al. 1986), and the capital of Nigeria is being moved from Lagos in part because a major dam on the Niger River is causing shores to erode 50 meters per year. Because sustaining deltas in the face of rising sea level will require increased sediment, planners at the World Bank and other international development agencies may want to reconsider the implications of new dams along some rivers.

Purchasing Land could keep options open for water resources management and protecting ecosystems. In regions where climate becomes drier, additional reservoirs may eventually be necessary. However, because accurate forecasts of regional climate change are not yet possible, water managers in most areas cannot yet be certain that they will need more dams. Even in areas where earlier snow melt or sea level rise is expected to necessitate increased storage – such as California (Williams et al. 1988) and Philadelphia/New York (Hull and Titus 1986), respectively – the dams will not have to be built for decades. Nevertheless, it may be wise to purchase the necessary land today; otherwise, the most suitable sites may be developed, making future construction more expensive and perhaps infeasible. A number of potential reservoir sites have been protected by creation of parks and recreation areas, such as Tocks Island National Park on the Delaware River.

Governments often purchase land to prevent development from encroaching on important ecosystems. Particularly in cases where ecosystem shifts are predictable, such as the landward migration of coastal wetlands, it may be worthwhile to purchase today the land to which threatened ecosystems would be expected to migrate. Even where the shifts are not predictable, expanding the size of refuges could limit their vulnerability (Peters and Darling 1985).

Land purchases for allowing ecosystems to migrate have two important limitations. First, they could probably only be used for protecting a few strategic ecosystems. As a general solution, the cost would be prohibitive: Protecting coastal wetlands would require buying most of the

nation's coastal lowlands; and many types of terrestrial species would have to shift by hundreds of miles. Second, land purchases do not handle uncertainty well. If temperatures, rainfall, or sea level change more than anticipated, eventually the land purchased will prove to have been insufficient.

Planning: Changing the Rules of the Game

"Doubt is an unpleasant situation," Voltaire once wrote, "but certainty is absurd." While some professions deal strictly with facts, planners must look into the future, which is inherently uncertain. Thus, defining "rules of the game" – how we respond to particular events should they occur – is often more important to planners than taking concrete action. If an agricultural region might be developed in 20 to 50 years, for example, the need is not to build highways and sewers today but to determine where they would eventually be located so that activities in the intervening years are consistent with the long-term situation.

Although concrete action in response to global warming is necessary today for only a few types of problems, defining the rules of the game may provide "easy" solutions for a much wider class of problems. Doing so increases flexibility: if climate changes, we are better prepared; if it does not, preparation has cost us nothing. Political feasibility may be enhanced because it is easier to reach a consensus when no one is immediately threaten – ed. Moreover, such planning reduces risk to investors: although they still face uncertainty regarding climate change and sea level rise, planning can prevent that uncertainty from being compounded by uncertainty regarding how the government will respond. Land use and water allocation provide two examples.

Land Use

Society may want to guide development away from areas where it might conflict with future environmental quality or public safety. A primary rationale for most local land-use planning is that by themselves, real-estate markets do not always produce economically-efficient or socially-desirable outcomes, because people do not bear all the costs or reap all the benefits from their actions. As long as zoning and other land-use restriction are implemented long before anyone would want to undertake the prohibited actions, they do not unreasonably burden anyone—major reason these restrictions have withstood legal and political challenges.

Planning offers institutional capabilities for addressing environmental impacts of climate change when the direction of the impact is known. Consider, for example, the goal of ensuring that development does not block migration of ecosystems or preclude construction of a dam. Without planning, the land could be vacated only by requiring abandonment with relatively little advance notice, which would often require compensation and would always hurt someone. Planning measures can either (1) limit development through zoning (or purchase of land, discussed above), or (2) set up the social constraint that ecosystems will be allowed to migrate, while allowing the market to decide whether or not development should proceed given the constraint. (See Howard et al. 1985. for options to retreat from the ocean coast.)

The most common tools for controlling land use are master plans and the zoning that results from them. A major limitation is that zoning tends to be flexible in only one direction – allowing more development; if a town elects a pro-development council that relaxes zoning, it will be difficult to reimpose the restrictions later. Moreover, as with purchases, one has to make an assumption regarding how far an ecosystem needs to migrate; if temperatures, rainfall, or sea level change more than anticipated, the ecosystem will not be protected in the long run.

Another mechanisms for controlling land use is "presumed mobility," which allow people to develop property, subject to the constraint that the development will not be allowed to block migration of ecosystems (Titus 1990). The primary rationale is that preventing development is not economically efficient because in some cases it might be worthwhile to develop a property even

if it would subsequently have to be abandoned; rolling easements minimizes governmental interference with private decisions, allowing markets to decides whether a property is worth developing given available information. Another important advantage is that neither uncertainties nor the long-term nature of global warming undermines the feasibility of instituting it – in fact, they probably increase the feasibility: unless or until the sea rises enough to inundate a property, the policy imposes no costs. Thus, people who doubt the sea will rise or are unconcerned about the distant future have few grounds to object.

The State of Maine (1987) has recently issued regulations stating that structures along the ocean and wetland shores would have to be removed to allow wetlands to migrate inland in response to sea level rise. Numerous states prohibit seawalls along the ocean. Because these rules do not interfere with the use of property for the next several decades, they have a minimal impact on property values, and thus do not deprive people of their property. The major limitation of this approach is that it may be too flexible: if sea level rise begins to require a large-scale abandonment, a state or local government may find it difficult to resist pressure to repeal the rule.

An alternative that avoids the risk of backsliding is to modify conventions of property ownership. One example would be long-term leases (or fee simple determinable) interests in land, which expire at a remote date or when a "condition" occurs (e.g. high tide rises above a property's elevation), with property reverting to the government or a private conservancy. Although the leaseholders (or owners of the fee simple) would want free renewals to their leases (or invalidation of the reversionary interest), conservancy groups would have little problem saying "no," and local governments – not to mention the courts – find it easier to enforce contracts (or and interests in land) than regulations.

Conditional and long-term leases could be created either as a part of a process for permitting coastal development or through eminent domain purchases (Titus 1986.) Although they would involve some institutional changes, the changes would not be unprecedented. National Park Service acquisitions often involve conversion of property ownership to leases the expire upon the former owner's death, and the principal of conditional ownership is generally taught to beginning real estate agents (Galaty et al. 1985). Property on coastal barrier islands on Babylon, New York and Pensacola Beach, Florida is under long-term lease.

Water Allocation

In the southwestern United States, the water supply infrastructure is guided by policies embedded in contracts and laws that prescribe who gets how much water. Many of these rules are not economically efficient; water is wasted because of rules that do not allow people with too much water to sell it to people with too little. In many cases the equity of the formulas is sensitive to climate; during wet periods, everyone may have plenty, while in dry periods some get enough while others get none. Many ways by which the impact of climate change might be reduced are already being advocated in order to address current climate variability: legalizing water markets; curtailing federal subsidies which lead to waste by keeping prices artificially low; and modifying allocation formulas. (Gibbons 1986; Bureau of Reclamation 1987).

Nevertheless, the changes required by global warming may be different in one crucial aspect: the effective date in any rule changes. Because the most severe changes in rainfall from the greenhouse effect are still decades in the future, the problem can be addressed even if the effective date is not until 2020. This situation may enhance the political feasibility of instituting a response today, since no one need be immediately threatened. By contrast, if planning is deferred another twenty years, the impacts of climate change may become too imminent for potential losers to agree to the necessary changes.

Increasing our Understanding: Assessments, Research, and Education

The fact that a particular problem will not require solutions for a few decades does not necessarily mean that society should not begin preparing. In some cases, the necessary solutions are decades away; in most cases, no one has systematically examined the costs and results of various options. We now examine three vehicles for expanding our knowledge.

Strategic Assessments

Strategic assessments seek to determine whether, when, and how one should respond to global warming, based on what we know today. In some cases they formally assess the costs and benefits of alternative responses; in others a qualitative analysis is sufficient.

Any organization that makes decisions whose outcomes stretch over periods of thirty years or longer should examine the implications of climate change. In many cases, these studies can use existing analytical tools, and hence they are relatively inexpensive. From the standpoint of economic efficiency, these assessments are good investments. If they reveal that action today is worthwhile, the savings from such action can be orders of magnitude greater than the cost of the study. Even if they show that no action is necessary, many organizations will find it useful to know that their projects are not vulnerable, and the studies will contribute to society's understanding of the magnitude of the impacts of global warming.

These assessments can be implemented either as supplements to evaluations of specific projects, or as special studies focusing on particular problems or programs. The most cost-effective strategic assessments are those conducted as a routine part of the evaluation of ongoing projects. Because they are oriented toward a specific near-term decision, they are not likely to be ignored. Their cost is often minimal because they supplement existing studies and hence have little overhead. The Corps of Engineers has announced that it intends to estimate the impacts of global warming in future feasibility studies and environmental impact statements for coastal projects; and the Council of Environmental Quality is considering the possibility of requiring other federal agencies to consider climate change in environmental impact statements. Table 2 lists other examples.

Agencies with many potentially vulnerable activities may need program-wide assessments. In some cases, the combined economic impact of climate change can be summarized by a single variable, such as federal insurance claims. On the other hand, some programs face a variety of impacts, each of which must be examined separately.

Finally, legislative committees, National Academies of Sciences, nonprofit institutions, and international organizations may have to conduct problem-oriented assessments for problems that are explicitly the responsibility of no one while implicitly the responsibility of several different groups. The combined impacts of farm closures and forest dieback raises land-use questions that would be outside the scope of any single organization. Water resource problems requiring the participation of several groups would include potential impacts of increased agricultural water demand on aquifers and the levels of the Great Lakes and the flow of rivers that pass through more than one country.

Figure 4 illustrates the relationship between the different types of assessments for a hypothetical evolution of society's response to wetland loss from sea level rise. In the example, federal and state programs are unable to address the problem, although isolated local governments, in response to particular projects, are able to issue permits that solve the problem. Because no institution has the responsibility to protect wetlands as sea level rises, a Congressional committee assesses the entire problem, which leads to legislation. In response to the new Act, federal and state program assessments develop guidelines. Given the new

regulations, developers reassess the viability of planned projects, while conservancies decide whether to offer to buy the property.

TABLE 2.
Example Strategic Assessments

Decision Maker	Question
Decision-oriented assessments	
Home buyer	Is one willing to accept long-term risk of erosion and flooding?
Forest company	Are appropriate species being planted? If so, when would it be necessary to shift?
Farmer	Would a new well be even more useful if climate changed?
Utility company	Is size of proposed power plant optimal given projected climate change?
City engineer	Should new drainage facilities be designed with extra margin for sea level rise and possible increased rainfall?
Water resource agencies	Is dam designed properly? Would its benefits be Different if climate changes?
Federal agency developing EIS	Would the environmental impacts of the project be different if sea level rises or climate changes faster than currently assumed?
Local Hazard Planner	Is it safe to build in an area that is barely outside the floodplain?
Program-oriented assessments	
Research Director	For which impacts can we develop a solution? What would be the costs of the research and the potential benefits of anticipated solutions?
Utility Company	Does system capacity need to be expanded? If not, when would it be necessary?
Flood Insurance	By how much would claims on the program increase? Does expanding program to include erosion increase or decrease impact of climate change?
Agricultural Planners	Do current farm programs help or hinder adjustments climate change might require?
Public Health Agencies	Would climate change increase the incidence of malaria and other tropical diseases in the United States?
Air Pollution Agencies	Does climate change imply that current regulatory approach should be supplemented with incentive systems, new chemicals, or relocation policies?
Problem-oriented assessments	
Natural Resource Agencies	Do we need a program to aid the survival of forests and other terrestrial ecosystems?
Wetland Protection Agencies	How do we ensure that wetlands can migrate as sea level rises?
Canada and the United States	What is the best way to manage fluctuations in levels of Mississippi River and Great Lakes?
State Coastal Zone Agencies/City Planners on barrier island communities	Would the state provide necessary funds to hold back the sea on barrier islands? If the State won't provide funds, would the town bear the cost of holding back the sea or adapt to a retreat? Are current erosion and flood programs consistent with long-term response?
Water Resources Agencies	What should be done to address increased salinity in Sacramento Delta?
Air Pollution Agencies	Will climate change alter the results of current air-pollution strategies?
Public Utility Commissions	Should Power Companies Be Building Extra Capacity for Increasing Demand?

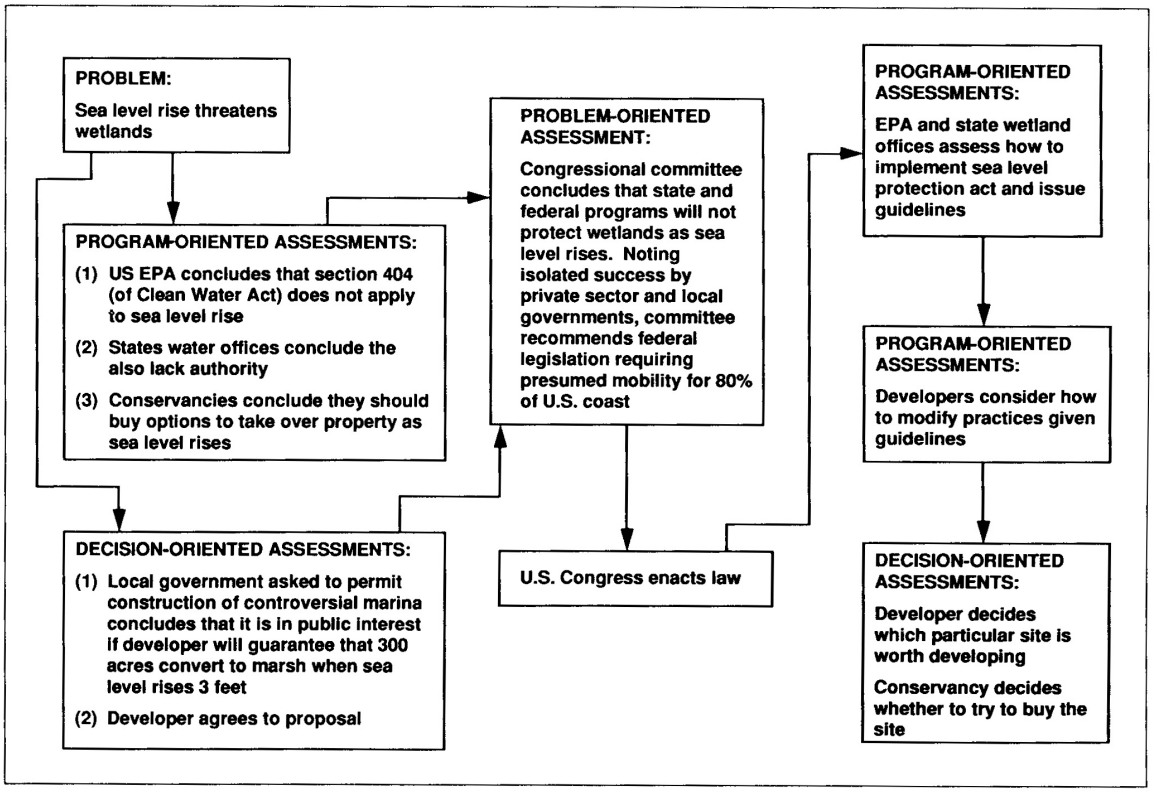

FIGURE 4: The relationship among strategic assessments for a sample problem.

Research and Development

These expenditures could often be economically justified in cases where immediate physical responses could not be. Most of the impacts of climate change could at least theoretically be mitigated, but in many cases, effective solutions have not yet been developed. Like strategic assessments, the value of the research is potentially the savings it makes possible.

Research is also a vehicles by which one generation improves life for succeeding generations. Even if the economic efficiency of taking action to mitigate impacts can not be demonstrated, it seems only fair for this generation to provide solutions to accompany the problems we pass to the next generation.

Table 3 lists a number of research questions whose solution would assist adaptation. However, for the most part, strategic assessments have not been undertaken to determine the cost and probability of developing solutions or the magnitude of potential savings that might result, so it is difficult to be certain that the research would benefit society. The most notable exception is improvement in estimates of future climate change and sea level rise. Although many responses warranted in spite of current uncertainties, better projections would improve planning for every impact of global warming.

Education

Efforts to prepare for climate change can only be as enlightened as the people who must carry them out. Education must be critical component of any effort to address the greenhouse effect because (1) there will be an increased need for personnel in some professions, (2) people in other professions will need to routinely consider the implications of global warming, and (3) an informed citizenry will be necessary for the public to support the public expenditures and institutional changes that may be required.

Table 3.
Example Research Problems and Applications

Research Problem	Applications
Synergistic impacts of CO_2, climate change, and air pollution on plants	Shifts in Mix of Trees and crops, drought-tolerant crops.
Shifts in habitats of birds, fish, and land animals	Restoration Ecology: rebuilding ecosystems that are lost
Ability of Wetlands coral reefs to keep up with sea level	Mechanisms to accelerate vertical growth
Erosion of beaches due to sea level rise and changing wave climate	More efficient placement of sand when beaches are restored
Ability of alternative plant strains to tolerate harsh climate	Develop heat- and drought-resistant crops
Magnitude of changes in sea level and regional climate	All responses to global warming
Shifts in pests due to climate change	Development of integrated pest management programs
Shifts in microorganisms that currently impair water quality in tropical areas	Long-term water supply planning

For many professions, the likelihood of a major expansion due to global warming will depend on how society ultimately responds to global warming. Will our response be in agriculture be primarily to develop new crops to grow on existing farmland (plant scientists) or to facilitate the migration of farmers to newly productive areas (planners)? Will our response to coastal wetland loss be to remove development from lowlands so that they can migrate naturally (planners), or to maintain existing land uses and support existing wetlands artificially (hydrologists and ecologists)?

The demand for coastal engineers will almost certainly increase as cities erect levees and resorts pump sand onto their beaches. An unfortunate paradox is that at the very moment when the public is becoming increasingly concerned about sea level rise, and the need to develop new environmentally-sensitive responses, the field's founding fathers are retiring and are not always being replaced.

Professionals in various disciplines must be educated about global warming so that decison makers can consider its implications. This process has proceeded farthest in the case of sea level rise, where federal and state agencies have sponsored several large conferences on the subject each year since 1983. This process is now beginning to unfold in the fields of utility planning and water-resource management, and may soon emerge in other fields.

Except during universally recognized crises, such as war and disease, governments do not usually take the lead in creating public awareness. In the short run, that function is generally carried out by the news media; in the long run, it is performed by school systems. Nevertheless, governments can support these institutions by sponsoring public meetings and translating the results of technical studies into brochures and reports that are accessible to reporters, teachers, and the general public. Artists can also play an important role (Figure 5).

Planning for the Long Run

History offers few examples in which society undertook actions for the sole purpose of heading off a problem that was not expected for decades or centuries. Yet the Thames River

Barrier, the U.S. Constitution, and international efforts to control world population illustrate that people can plan for the very long run when a present-day crisis puts an issue on the table. Once the public decides that it wants a problem solved, it is almost always willing to pay the extra cost of ensuring that the solutions do more than merely delay the day of reckoning.

The worldwide reaction to recent warm years suggests that there may soon be a public consensus to solve the problems associated with the greenhouse effect. But unless planners begin preparing rational responses, politicians will not know what to do when they are ready to act. In some cases they may be willing to commission studies and wait. But they are just as likely to act (or not act) based on whatever options are available at the time. Even if better options are discovered later, there is no guarantee that there will be a public outcry to revisit the issue.

Photo by Avon Rubber

Figure 5: The arts often promote public awareness. This composite photo showing what would have happened to London if a 1953 storm tide had been slightly higher was used to help convince the public of the need for the Thames River barrier.

The example responses we have outlined suggests that for most problems, one can envision a number of easy solutions that would at least begin to address the problem without arousing a constituency in opposition or subsequently appearing to be ill-advised. The examples also suggest that in many cases, the more costly options necessary to solve the whole problem would still prove to be good investments even if the climate does not change as expected.

Because of the severity of the potential impacts, it is completely appropriate for policy makers and the public to focus primarily on measures to limit the extent to which humanity raises the earth's temperature in the years ahead, an issue outside the domain of most planners. Nevertheless, past and current emissions suggest that it is too late to completely prevent a change in climate, so we will have to learn to live with the consequences. Although planners are sometimes frustrated by the futility of focussing politicians' attention on events beyond the next election, global warming may be an opportunity to help them show the voters that they are thinking about the type of world we pass on to future generations. But whether the politicians lead or follow, they public will have to decide the type of world we plan to achieve: if something has to give, should our priority be to maintain current patterns of land and resource use, to avoid tax increases, or to protect the environment?

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