CHAPTER 3

THE SOCIOECONOMIC CONTEXT FOR CLIMATE IMPACT ASSESSMENT

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CLIMATE IMPACTS AND THEIR ASSESSMENT

It is obvious,from history and everyday observation, that weather and climate can have impacts on people. Human impacts can arise from weather and climate events at many scales:from individual extreme events such as hurricanes or ice storms;from anomalous seasons such as an unusually cold winter or dry summer;or from multi-year departures from normal climate conditions,such as the drought of the 1930s.

Although particular climate impacts may be clear, their mechanisms of causation can be complex and the degree of influence climate has on human affairs in aggregate remains controversial. The view that climate determines major historical events and the character of societies and economies,which has been periodically expressed since antiquity and enjoyed perhaps excessive respect in the early 20th century (e.g.,Huntington,1915),has fallen into perhaps excessive disrepute,although it has never been fully refuted. More persuasive arguments for significant climatic influence on particular historical events or characteristics of societies continue to be advanced (e.g.,Myrdal,1972;Bryson et al.,1974; Lambert,1975;Schneider, 1984;Diamond,1997; Sachs,1999),but it remains the case that the aggregate degree and mechanisms of climatic influence on human affairs are not fully understood (Riebsame,1985).

Given an assumed state of America's society and economy, the *impacts* of a specified weather or climate event are the changes it induces in matters of human concern. Defining climate impacts as changes implies an alternative,the baseline climate against which changes are measured. For studying the impacts of climate change,the baseline is normally assumed to be continuation of the climate of the past few decades. Describing impacts also requires specifying the perturbed climate,whose effects relative to the baseline are to be measured. Methods for specifying such hypothesized changes in climate,through model projections and historical analogs,are discussed in Chapter 1.

A specified climate change may have multiple impacts. For example,an unusually warm winter can have diverse impacts on home heating bills, driving safety, recreational opportunities,ski area profitability, and the over-wintering of household or crop pests. Impacts may be beneficial or harmful, with most climate scenarios bringing mixed effects: benefits to some people,places,and sectors,and harm to others. A system is more or less *sensitive* to climate depending on whether a specified change in climate brings large or small impacts.

The simplest framework for assessing climate impacts involves specifying the climate change and climate baseline,and attempting to infer impacts directly. The state of the society or economy that bears the climate change is not considered (Kates, 1985). Although this framework has been widely criticized as too simplistic,it is adequate for studies of some important impacts,which can be described without detailed or explicit consideration of socioeconomic conditions. In particular, assessments that only describe climate's first-order effects on environmental characteristics,or biological or physical resources whose importance to society is clearly evident,can be conducted without explicit consideration of socioeconomic context. Assessments of this type might, for example,attempt to calculate the effects of specified climate change on the range of sugar maple trees in New England,the productivity of loblolly pine forests in Georgia,the expected wheat yield in Kansas,the mean annual runoff in the Colorado basin,the average July heat index in Chicago,or the expected frequency and intensity of storms in North Carolina. Most assessments of climate impacts conducted to date have followed this framework. With a few exceptions,this Assessment has from necessity followed the same practice.

Conducting assessments using this approach is difficult. It requires projecting future behavior of the climate system,and of managed and unmanaged ecological systems. These projections are challenging because the systems are highly complex,interactive,and uncertain,and because we do not understand all the factors that control their operation.

But this approach, challenging as it is and useful as it can be,is not sufficient for a full assessment of climate impacts that seeks to identify, describe,and value their effects on people,economies,and societies. Climate variability and change occur in a social and economic context that contributes to determining impacts. In some cases,socioeconomic conditions may mediate or alter even first-order biophysical impacts such as the examples listed above, so socioeconomic information will be necessary to describe and assess even these impacts. The effect of a specified climate change on wheat yields or pine productivity will depend on how the farm or forest is managed,as well as on how the climate changes. The heat index in Chicago is strongly influenced by the urban heat island effect, which depends on the size, density, and surface characteristics (e.g., building, roofing, and paving materials) of the city. Runoff in the Colorado basin under a specified climate can be altered by large-scale land-use change in the basin, as well as by water engineering projects. A specified runoff event may cause a flood or may not, depending on the infrastructure present. Winnipeg survived the Red River flood that destroyed Grand Forks, because a large emergency flood channel had been constructed around Winnipeg decades earlier.

More fundamentally, the impacts of climate change that matter to people are not limited to direct biophysical impacts, but can also include many indirect effects on such factors as health, income, and employment; the price, availability, and quality of goods and services; property values and losses; recreational opportunities; the character of the landscape; and the political, social, and economic character of their community – as well as the direct effects of weather and climate on people's experience. Such impacts are not exclusively caused by weather or climate, but are mediated by many characteristics of the economy and society. They can only be meaningfully defined relative to specified individual and collective perceptions, interests, and values, which in turn may themselves be subject to change. For example, what is the value of fall foliage in New England, and what would be the impacts if it changed? The settlement patterns and demographic structure of the population, the prosperity and structure of the economy, the technologies available and in use, the patterns of land and natural resource use, and the institutions and policies in place will all contribute to how – and how much – climate will matter to people, and what they can and might wish to do about it. Climate conditions and societal conditions jointly cause climate impacts (Kates, 1985).

Because of this joint causation, making a coherent assessment of climate impacts requires careful, systematic assumptions about future socioeconomic conditions as well as future climatic conditions. However challenging it is to model and project future climate, projecting future socioeconomic conditions is even more so. As is the case for climate and ecosystems, the nation's economy, society, patterns of resource use, technology, and land use, are shaped by highly complex, interactive, and uncertain processes. But while most aspects of climate projection are based on well understood physical processes, our understanding of the basic structure and causal factors operating in socioeconomic systems and their evolution is vastly more limited. Reasonable judgments can be drawn about what kinds of futures are more or less likely, but causal laws of society and history – if they should exist at all – are not known.

The central place of socioeconomic conditions in determining impacts requires that they be considered, and for many analyses, be explicitly projected. But the profound limits to our knowledge of the factors that determine socioeconomic change require that explicit acknowledgment of uncertainty be central to such projections. This requirement cannot be met by assuming any single socioeconomic future. Rather, multiple scenarios representing a plausible range of alternative socioeconomic futures are needed, ideally with explicit quantification of judgments about uncertainty. The sensitivity of results to alternative assumptions should also be examined. In particular, the charge to not assume just one socioeconomic future applies to the widespread practice of studying the impacts of future climate changes as if they were imposed on today's society. Although it has long been recognized that this practice introduces serious biases to impact assessment, and several major studies have demonstrated the alternative of explicit, coherent socioeconomic projections (e.g., Rosenberg, 1993), the practice remains widespread. This practice, often advocated in order to avoid criticism for engaging in speculation, is equivalent to assuming that the future society that will bear the impacts of climate change will resemble the present in all relevant ways – an assumption that may be acceptable for near-term assessments, but grows increasingly unacceptable as the time horizon lengthens. To see how wrong this assumption is likely to be, one need only compare America's society and economy of today to that of 100, 50, or even 25 years ago.

CLIMATE IMPACTS IN SOCIOECONOMIC CONTEXT

Lessons from History

Looking backward a century underscores the extent to which impacts of climate depend on socioeconomic conditions. It also shows the severity of the challenge posed by attempting to project socioeconomic conditions up to a century in the future. At the turn of the 20th century, most of the US workforce was employed on farms; aircraft, electronics, and antibiotics had not been invented; aluminum was a semi-precious metal; the automobile existed only as a primitive novelty;and the predominant form of transportation – and the predominant urban environmental problem – was the horse. Over the intervening century, the population of the United States nearly quadrupled,from 76.2 million to 275 million (US Bureau of the Census,1998),while US real GDP increased more than thirty-fold,from just under $300 Billion to about $9.5 Trillion (1996 dollars,Bureau of Economic Analysis,2000) – corresponding to a nearly ten-fold increase in real per capita income.

These increases in material welfare,and the process of industrial transformation that drove them,have had profound effects on the nation's relationship and sensitivity to climate. As first the industrial sector and later the services sector grew to dominate the American economy, fewer Americans'livelihoods have been directly tied to climate. Moreover, wealthier nations – like wealthier individuals – are in general better able to cope with the negative impacts of climate variability and change,and better able to take advantage of the opportunities they present. Wealthy societies can spare resources to support adaptation,can better afford to make required changes in technology and infrastructure, and can more easily endure climate-related losses. Within societies, climatic harms and opportunities will not be equally distributed among individuals and communities:some will face greater burdens than others. Moreover, high rates of economic and population growth can themselves impose stresses on natural systems,through rising pollution (including greenhouse gases),congestion,and demands for land and resources,potentially increasing these systems'vulnerability to climatic stresses.

Much of our recent prosperity has been fueled by new technology. Although technological change can also carry significant social and environmental costs, in aggregate it has greatly contributed to Americans' increased material well-being over the 20th century. For example,in the past decade,computers and new communication technologies have transformed many activities,bringing increases in productivity as well as new products and services.

Technology affects society's relationship to climate in many ways. Technological change will strongly influence the success of future efforts to control greenhouse gas emissions. Many technological changes,large and small,have reduced Americans' vulnerability to weather and climate in a host of ways. A striking example has been weather and climate forecasting,which with increasing understanding of large-scale patterns of variability is now developing substantial predictive skill on weekly and even seasonal intervals. Other examples include better roads and automobiles,navigation and instrument systems for aircraft and shipping,broadcasting and other forms of wireless communication,air conditioning and improved heating technology, new construction materials and techniques that have allowed construction of huge indoor spaces,and technologies that have made many forms of outdoor sport and recreation (e.g.,skiing and climbing) safer and more accessible.

Technology can also increase society's vulnerability to climate,particularly to extreme climate or weather events. This can happen because modern societies are organized around the available technologies,and become dependent on them. Contemporary American society relies in critical ways on electric power, transportation,and communications systems,all of which can be disrupted by extreme events if systems have not been adequately designed to deal with them. Large-scale loss of power lines in an ice storm can have catastrophic effects on a modern industrial society, even though all societies,including early industrial ones,functioned without widespread electrical service only a century ago.

US population has not simply grown in the past century, it has also shifted markedly in its demographic structure and its distribution around the country. These trends have also shaped patterns of sensitivity to climate. For example,the US population is growing older. The fraction of Americans aged 65 or over has increased from 1 in 25 in 1900 to 1 in 8 in 2000. Older people are physiologically more vulnerable to heat stress. Without adaptive measures, a more aged society will be more vulnerable to increases in heat-related illness and death under a warmer climate. A warmer climate may also bring a reduction in cold-related mortality, a trend that will also interact with the aging of the population, although the effect of temperature changes on mortality appears to be weaker for cold conditions than for hot. Recent migration to the South and Southwest demonstrates that many older Americans prefer warmer climates,although the nearly universal spread of one technology – air conditioning – has played an essential role in allowing the rapid growth of these regions. At the same time, rapid population and economic growth in arid parts of the Southwest has sharply increased vulnerability to water shortages.

America is also becoming more urban. Over the 20th century the fraction of Americans living in cities increased from 40% to more than 75% (US Bureau of the Census,1999). Urbanization affects climate vulnerabilities and capacity for adaptation in multiple and complex ways. City dwellers depend less on climate-sensitive activities for their livelihoods,and have more resources and social support systems close at hand. But the dense concentration of people and property in coastal or riverside metropolitan areas,dependent on extensive fixed infrastructure such as water, sewer, and energy utilities, and roads,tunnels,and bridges (which are aging and overburdened in many US cities),can increase vulnerability to extreme events such as floods,storm surges,and heat waves. Combined with other urban stresses such as congestion,pollution,and the urban heat island effect, climate change could significantly harm urban quality of life and health.

Americans are also moving to the coasts. Some 53% of the total US population now live in the 17% of land area that comprises the coastal zone,and the largest continuing population increases for several decades are projected to be in coastal areas. This trend is exacerbating wetland loss and coastal-zone pollution. In addition,locating more people and more valuable property in low-lying coastal areas increases vulnerability to storms,storm surges, coastal erosion,and sea-level rise – as severe recent losses in Florida,Georgia,and the Carolinas,as well as a century of damage trends,all confirm (Changnon et al.,2000).

Observing past patterns of climate impacts reveals how America's vulnerability to climate and its capacity for adaptation have depended on many highly detailed and specific characteristics of its economy and society. For particular communities or activities,the most important factors shaping climate vulnerability might be as diverse as local zoning ordinances,housing styles,or building codes;popular forms of recreation;the age and degree of specialization of capital in particular industries; world market conditions;and the distribution of income. For example,the vulnerability of American agriculture to past climate extremes has been shaped by a host of socioeconomic factors,including the size and structure of farm families, agricultural practices and available technologies,markets for alternative crops, available capacity for storage and transport, groundwater accessibility, local and nationwide markets for capital and labor, bank lending practices and the nationwide organization of banking and capital markets,global trade rules,and public policies.

Over the 21st century, population and demographic structure,settlement patterns,economic output and structure,technology, policy, and other social and economic factors will continue to affect the ease with which American society can adapt to,or take advantage of, climate variability and change. Continuing income growth and continuing development of new technologies remain likely, in aggregate,to reduce our vulnerability to climate. But as in the 20th century, specific climate impacts and vulnerabilities in the 21st century are likely to remain dependent on many detailed and specific characteristics of America's society, with the particular factors that turn out to be most important not evident in advance. Moreover, the changes in these factors over the 21st century are likely to be at least as great, and at least as unpredictable in their details,as the changes that took place over the 20th century.

ADAPTATION AND VULNERABILITY

People need not merely suffer the climate conditions they face,but can change their practices,institutions,or technology to take maximum advantage of the opportunities the climate presents and to limit the harms they suffer from it. Through such *adaptations*, people and societies (like ecosystems) adjust to the average climate conditions,and the variability of conditions they have experienced in the recent past. Present climates are not tuned to maximize human welfare,of course,so some potential changes might be purely benign (e.g.,if there was a reduction in maximum hurricane wind speeds). But when habits,livelihoods,capital stock, and management practices are finely tuned to current climate conditions,the direct effect of many types of change in these conditions,particularly if the change occurs rapidly, is more likely to be harmful and disruptive than beneficial.

But just as societies adapt to the present climate, they can also adapt to changes in it. Adaptation can be intentional or not,and can be undertaken either in anticipation of projected changes or in reaction to observed changes. Society's capacity to adapt to future climate change is a crucial uncertainty in determining what the actual consequences of climate change will be. Societies and economies are *vulnerable* to climate change if they face substantial unfavorable impacts,and have limited ability to adapt. Like impacts themselves,the set of options and resources available to adapt to change,and the ability of particular individuals,communities,and societies to adopt them,depend on complex sets of linked social and economic conditions. Such factors as wealth,economic structure,settlement patterns, and technology play strong roles in determining vulnerability to specified climate conditions (Downing et al.,2000).

Human societies and economies have demonstrated great adaptability to wide-ranging environmental and climatic conditions found throughout the world,and to historical variability. Wealthy industrial societies like the US function quite similarly in such divergent climates as those of Fairbanks,Alaska and Orlando,Florida. While individual adaptability also contributes,it is principally social and economic adaptations in infrastructure,capital,technology, and institutions that make life in Orlando and Fairbanks so similar that individual Americans can move between them (in either direction) with at most moderate discomfort.

But adaptability has limits, for societies as for individuals,and individuals' ability to move through large climate differences tells us little about these limits. Moving between Fairbanks and Orlando may only be uncomfortable,but rapidly imposing the climate of either place on the other would be very disruptive. The countless ways that particular local societies have adapted to current conditions and their history of variability can be changed,but not without cost,not all with equal ease,and not overnight. The speed of climate change,and its relationship to the speed at which skills,habits, resource-management practices,policies,and capital stock can change,is consequently a crucial contributor to vulnerability. Moreover, however wisely we may try to adjust long-lived decisions to anticipate coming climate changes, we will inevitability remain limited by our imperfect projections of the coming changes. Effective adaptation may depend as much on our ability to devise responses that are robust to various possible changes,and adjustable as we learn more,as on the quality of our projections at any particular moment. While societies have shown substantial adaptability to climate variability, the challenge of adapting to a climate that is not stable,but evolving at an uncertain rate,has never been tested in an industrialized society.

While adaptation measures can help Americans reduce harmful climate impacts and take advantage of associated opportunities,one cannot simply assume that adaptation will make the aggregate impacts of climate change negligible or beneficial. Nor can one assume that all available adaptation measures will necessarily be taken. Even for such well-known hazards as fire, flood,and storms,people often fail to adopt inexpensive and easy risk-reduction measures in their choices of building sites,standards,and materials – sometimes with grave consequences. In this first National Assessment,potential climate adaptation options were identified,but their feasibility, costs,effectiveness,and the likely extent of their actual implementation were not assessed. Careful assessment of these will be needed.

SOCIOECONOMIC SCENARIOS IN IMPACT ASSESSMENT

Coping with Complexity

One way to assemble the socioeconomic assumptions needed for impact assessment is to construct scenarios. Scenarios are coherent,internally consistent,and plausible descriptions of possible future states of the world,used to inform investigations of future trends,potential decisions,or consequences (IPCC,1994). Scenarios can be simple or complex, quantitative or qualitative,stochastic or deterministic,and can provide variable levels of detail according to their purpose. In most usage,scenarios are exogenous to the analysis:they describe aspects of the world that must be specified for the analysis to proceed,but which are simply assumed,not calculated within the analysis.

In assessments of climate change,the craft of developing and applying scenarios is most advanced for the scenarios of future greenhouse-gas emissions used to drive climate models. Scenarios for the largest sources of emissions can be developed by projecting a few aggregate characteristics of the nation or region being considered,such as population,economic growth,and changes in the energy intensity and carbon intensity of economic output (Nakicenovic and Stewart,2000). While projections of these variables may have wide uncertainty ranges,they can be based on widely available consistent historical data and their complexity is not overwhelming. Moreover, because emission trends depend jointly on trends in population,economic growth,and technological change,it is possible to generate a wide range of emissions futures while considering only a narrow, largely benign range of population and economic futures, by making widely divergent assumptions of technical change.

Developing scenarios for assessment of impacts is a fundamentally different and more complex problem, on which less experience is available. No simple aggregate technical coefficients are known,analogous to energy intensity or carbon intensity in emissions scenarios,which would largely define impacts. Indeed,impacts and vulnerability are likely to depend on highly specific,detailed,often local characteristics of particular communities or activities, for which reliable consistent data are unlikely to be available – if we even knew what the relevant characteristics were. Also in contrast to emission scenarios,scenarios for impact assessment must consider the possibility of sustained low economic growth as well as high,since income and wealth are likely to be important determinants of vulnerability and adaptive capacity.

A working group of the NAST was charged with developing scenarios for the socioeconomic assumptions necessary for the Assessment. Because of the complexity and diversity of the socioeconomic characteristics that might be important determinants of impacts and vulnerability, and because of the highly decentralized nature of the National Assessment process,this working group judged it infeasible to attempt to develop fully detailed socioeconomic scenarios centrally. To do so would amount to trying to predict a century of American history. Moreover, such an attempt would be inappropriate because the determinants of impacts are likely to vary among regions,and identifying the most important ones is likely to require detailed regional expertise. Rather, the working group attempted to balance the Assessment's competing needs – to reflect regional concerns and expertise while maintaining enough consistency to allow national-level synthesis – by recommending a two-tracked approach to scenario development,partly centralized and partly decentralized.

The centralized track comprised a few key socioeconomic variables likely to influence many domains of impact,such as population,economic output,and employment. For these,where nationwide consistency was most important,the working group developed three internally consistent socioeconomic scenarios,which were used in all region and sector studies in the Assessment. The three scenarios spanned a wide range of high- and low-growth futures. Projections of population,income,and employment were provided in substantial detail through 2050 – by county and by thirteen economic sectors – and at the national level through 2100. These scenarios are described in Appendix 1 of this chapter.

The decentralized track was to be used when particular analyses required specifying future values of more specific or local socioeconomic characteristics. In such cases,the relevant assessment teams were asked to develop and document the required assumptions themselves. A common template was provided to guide teams in developing scenarios, which involved identifying two or three key characteristics they judged to have the most direct effects on the impact of interest,constructing uncertainty ranges for these characteristics,and varying them jointly through their ranges. In addition,two background papers were provided that reviewed alternative methods and attempts at projecting future trends in technology and institutions (Patt et al., 1998;Wilbanks,1998). The template for the decentralized track is described in Appendix 2 of this chapter.

Teams were also requested to attempt an alternative, exploratory approach to projecting impacts in 2100,which would avoid the need for 100-year socioeconomic projections. This exploratory approach involved reversing the relationship between assumed socioeconomic futures and climate impacts. The standard approach used throughout the Assessment involved assessing the impact of a specific climate scenario under a specific future socioeconomic scenario. Instead,this alternative, exploratory approach involved specifying *only* a future climate scenario,and trying to identify plausible socioeconomic conditions that would make for large variation in the impacts of this specified climate. For the region or sector in question,what potential future socioeconomic conditions might make this climate change seriously harmful? What conditions might make it insignificant? What conditions might make it greatly beneficial? The purpose of this alternative approach was to engage teams in a more open-ended process of thinking through potential socioeconomic futures,to scout for potential vulnerabilities and opportunities that might escape notice in a more conventionally structured inquiry.

In this first Assessment,the region and sector teams made very limited use of the socioeconomic scenarios and template provided. In some cases,such as the Human Health sector, teams judged the state of knowledge in their domain insufficient to support any prospective,scenario-based analysis. In several other cases,analyses projected only first-order biophysical impacts such as changes in forest productivity or streamflow, for which no socioeconomic assumptions were needed. The few analyses that attempted to project impacts further down the causal chain to effects on humans only required, or could only effectively use, the scenarios of economic and population growth specified by the centralized track. No analysis in this Assessment used the full template for socioeconomic scenario development discussed in Appendix 2. The limited use of socioeconomic scenarios in this first Assessment has limited the extent to which impacts can be described or assessed in terms of human relevance – e.g., in terms of monetary loss or gain, valuation of non-market changes, or the incidence of such extreme events as bankruptcy, property loss or abandonment, or regional economic booms or busts. Further developing, testing, and applying such methods for constructing scenarios sufficiently rich and detailed to do impact assessment, but that still sufficiently limit complexity and maintain enough consistency to permit aggregation, will be a key methodological and research challenge for subsequent assessment of climate impacts.

The approach taken in this Assessment to projecting socioeconomic futures has obvious limitations. On the one hand, it represents a vast simplification of the linked climatic, ecological, economic, and social processes that will actually determine climate impacts and adaptive capacity. On the other hand, it is so complex and difficult to implement, that no analysis undertaken as part of this first Assessment was able to follow the template fully. Still, this general approach of combining central guidance on over-arching assumptions with structured use of decentralized expertise for other assumptions has allowed us to make a start. It has allowed this Assessment to take a first look at climate impacts, more detailed and consistent than has hitherto been conducted, which can be refined and extended as substantive knowledge and assessment methods are progressively improved.

MULTIPLE STRESSES

Human society has imposed various stresses on the environment, at diverse spatial scales, for centuries. Over the 21st century, climate change will occur in parallel with, and be jointly determined with, many other environmental stresses and many other forms of change. The same social, economic, and ecological systems that will bear the stress of climate change will also often be bearing other simultaneous stresses. These will include environmental stresses such as air pollution, acid deposition, coastal and estuarine pollution, loss of habitat and natural ecosystems, and unsustainable exploitation of marine resources. They will also include broader socioeconomic stresses such as rapid shifts in technology and world market conditions, potential increases in migration and in economic inequality, and overloading of infrastructure in rapidly growing metropolitan and coastal regions. Other technological, economic, institutional, or social trends may help to increase systems' adaptability and mitigate the effects of climate change and other stresses. As climate varies and changes, so will these other factors. The aggregate impacts on ecological, economic, and social systems will reflect the joint application of multiple environmental and other stresses, as well as potential interactions between them.

For most US ecosystems, other stresses currently greatly exceed those arising from climate. Pacific Salmon populations are predominantly stressed by fishing, dams, and watershed alteration. Maple trees in New England are predominantly stressed by pests and air pollution. Endangered species are predominantly stressed by loss of habitat. Over the coming decades, some non-climatic stresses are likely to decline while others increase. For example, increasingly strict emission controls are likely to reduce acidifying pollution, while larger and wealthier populations are likely to increase the stresses that development, land-use conversion, pollution, and recreation impose on forests, mountain regions, wetlands, and coastlines. Although non-climatic stresses exceed climatic ones for most systems at present, one cannot assume that this will remain so – particularly for natural ecosystems, which in general are much more dependent on climate than socioeconomic systems. People may move with little discomfort between Alaska and Florida, but species adapted to the climate of one of these States could not survive in the other: a Martin or an Arctic Tern could not live in the wild in Florida, nor a Great White Heron or a Manatee in Alaska. Moreover, climate variability is already a discernible stress for some systems. A changing climate, interacting with other environmental and socioeconomic trends, is likely to become an increasingly important stress for many more systems. A system already bearing multiple stresses at high levels is likely to be less able, other factors being equal, to adapt to climate change. This observation is likely to apply not just to natural ecosystems, but also to managed ecosystems and communities, such as marginal agricultural lands or resource-dependent communities suffering job loss and out-migration.

Although it is likely that interactions among multiple stresses will be key dimensions of socioeconomic and ecological vulnerability, our current knowledge of how stresses interact is very limited. This first National Assessment has only been able to undertake the most preliminary investigation of interactions and multiple stresses. Several specific examples of multiple-stress effects have been identified as high priority needs for research and analysis, in order to improve our ability to analyze and respond to multiple stresses in future assessments.

THRESHOLDS, BREAKPOINTS, AND SURPRISES

The response of many systems to external changes is continuous:if you touch the accelerator, the car speeds up a little;if you touch the brake,it slows down a little. Many of the analyses of climate impacts discussed in this Assessment assume such continuous responses,so the projected impacts are often extensions of processes and trends that are already underway today.

Sometimes,however, systems can respond in highly discontinuous or nonlinear ways:if you tighten the propeller of the rubber-band airplane by one more turn,it can break into a dozen pieces. While many natural and social systems are likely to respond gradually to climate change, responses can also be sudden if a small additional stress pushes the system over a threshold or breakpoint.

Such discontinuities or surprises can be seen clearly after they happen,and attempting to explain them often generates important advances in our understanding,but they are extremely difficult to predict. It is imperative to remember that complex climatic, ecological,and socioeconomic systems might surprise us – by sudden or discontinuous response,or by evolving in some other way quite different from what we expect. We have been surprised by environmental and socioeconomic changes many times. Environmental examples include the failure of rain to “follow the plow”in the 19th Century American West,the appearance (and cessation) of the 1930s drought,and the 1980s appearance of the Antarctic ozone hole. Several possible surprises and discontinuities have been suggested for the Earth’s atmosphere,oceans,and ecosystems.

Equivalently high-consequence surprises could also arise in socioeconomic systems,causing emissions, impacts,or vulnerability to be markedly different than we expect. Potential candidates for such surprises might include rapid development and deployment of technologies for non-fossil energy or carbon sequestration – which could greatly reduce future carbon dioxide emissions – or for coal-based synthetic fuels,which would greatly increase emissions. Other candidates include exhaustion of major reinsurance pools from high weather-related casualty losses,leading to financial destabilization;or climate-related emergence of new epidemic diseases. Still more potential for surprise arises from the intrinsic unpredictability of human responses to the challenges posed by climate change.

Even if the probability of any particular surprise occurring is low – which is widely assumed,but may or may not be true – potential surprises are so numerous and diverse that the likelihood of at least one occurring is much greater. We do not know how far the climate system,or the systems it affects, can be perturbed before they respond in quite unexpected ways. As with multiple stresses,in this first Assessment we have only been able to identify this possibility and conduct some preliminary speculation. Potential large-consequence surprises present some of the more worrisome concerns raised by climate change,and pose some of the greatest challenges for policy and research.

By their very nature,surprises are unpredictable. But two broad approaches can help us prepare to live with a changing and uncertain climate, even considering the possibility of surprise. First,some of our assessment effort can be devoted to identifying and characterizing potential large-impact events, even if we presently judge their probability to be very small. Second,society can maintain a diverse and advancing portfolio of scientific and technical knowledge,and conditions that encourage the creation and use of new knowledge and technology. Continually advancing knowledge and technology, and the social,economic,and policy conditions that support them,provide a powerful foundation for adapting to whatever climate changes might come.

INTEGRATED ASSESSMENT

Thinking About the Future

Multiple climatic and socioeconomic characteristics jointly determine climate impacts. Further complexity arises from the fact that the multiple socioeconomic factors likely to determine impacts and adaptive capacity all influence each other, and are in turn influenced by patterns of environmental change. Patterns of population growth,technological change,economic growth,and structural change all affect each other, and collectively determine the character and degree of environmental stresses society imposes,including the emissions that contribute to climate change. Public policies will also contribute to this complex mix,both those directed toward climate change and others. Tax policy can influence investments in research. Immigration policy can influence the rates of both population and economic growth,and the cultural,educational,and economic mix of the population. Reliable prediction of such complex and uncertain processes is not possible.

Since the early 1990s, research groups have sought to represent linked processes of global environmental change and associated ecological,economic,and social processes in "Integrated Assessment"models of global climate change. These models are intended to allow consistent examination of the human contributions to climate change and ways to mitigate them,with the human consequences of climate change and ways to adapt to them. They consequently allow coherent assessment of possible responses including both emissions reduction and adaptation to resultant change,and the tradeoffs between them. They also thereby allow consistent comparison of uncertainties in all domains of the climate issue – future emissions and means to reduce them,the responses of the climate system at global and regional scales,and the resultant impacts and means to adapt to them (Weyant et al.,1996; Parson and Fisher-Vanden,1997;Rotmans and Dowlatabadi,1998).

Over the past ten years this work has yielded significant insights into the economic determinants of emission trends,potential feedbacks between climate change and managed and unmanaged terrestrial ecosystems,and the relative contributions of atmospheric,ecological,and socioeconomic uncertainty to uncertainties in future climate impacts and advantageous responses. While the promise of important further insights from such work remains substantial,the characterization of impacts and adaptation remains the weakest element of integrated assessment at present.

APPENDIX 1:

Three Scenarios of Future Socioeconomic Conditions

The three socioeconomic scenarios developed by the NAST working group all assumed that broad 20th century trends of population and economic growth are likely to persist,to varying degrees,in the 21st century. Barring major wars or other catastrophes, US population growth is likely to continue,though at a declining rate,moving toward a stable or nearly stable population in the second half of the 21st century. The population is also likely to continue to grow older for several decades or more,depending principally on the balance between immigration and increased life expectancy, and is projected to continue present trends of moving to metropolitan areas and the coast. Income and employment growth are projected to move with the people to the cities and coasts,and to continue the long-standing shift among sectors away from agriculture, resources,and primary industry and toward technology, trade,and services.

The Assessment focused on two target dates,2030 and 2100. While both are far in the future,2030 lies within the range of some projection models and strategic-planning tools,while 2100 lies beyond the useful range of nearly all such tools. Consequently, the Assessment provided socioeconomic projections with substantial spatial and sector detail for 2030, but only aggregate national projections of a few key variables for 2100.

For 2030,the Assessment provided detailed high, medium,and low scenarios of population and economic growth. These three scenarios were based on alternative assumed trends in fertility, mortality, and migration,labor-force participation by age group, and labor productivity, and were implemented using a commercial regional economic growth model. (Terleckyj,1999a,1999b). This model provided annual projections of population, by sex and by five-year age cohort, for each state,county, and metropolitan area in the United States. The NAST working group specified the assumed trends in fertility, mortality, and migration that determined nationwide population trends,while the model's demographic module calculated the resultant age structure of the population and its economic module distributed people around the nation.

In specifying these aggregate demographic trends, the working group used the Census Bureau's assumptions for future trends in US age-specific fertility and mortality (US Bureau of the Census,2000), but applied a wider range of assumptions for future immigration. The low scenario followed the Census Bureau's low immigration assumption,which reduces net immigration from roughly 750,000 per year in the mid-1990s (0.3% of population) to 300,000 per year in 2000,and holds it numerically constant thereafter. The middle and high scenarios each projected that recent trends of increasing immigration will continue,using growth trends derived from two different recent periods. The middle scenario took the average trend in the ratio of annual net immigration to current population that has prevailed over the past thirty years (1967-1997), and projected this trend forward until 2025. Projected in this way, net immigration reaches 0.46% of the population in 2025,and is held constant at this fraction of population thereafter. The high scenario differed from the middle only in that it calculated the trend in the ratio of immigration to population over the most recent ten years (1987-1997), a period of particularly rapid immigration growth. Projecting this steeper trend forward,net immigration reaches 0.86% of population in 2025,and is held at that fraction of population thereafter. In all three scenarios,the aging of the post-war baby boom generation brings sharp increases in the fraction of older Americans. The fraction of Americans aged 65 or over begins to surge after 2010 from its present value of 12.5%, reaching 20% by 2030. Still greater increases are projected in the fraction of Americans in the oldest age groups. The fraction of Americans aged 85 and over is projected to triple to 4.5% by 2050,while those 100 and over are projected to increase seven-fold,to 0.2%.[1]

The three scenarios also provided projections of employment and income for thirteen major economic sectors (including three government sectors), with the same level of spatial detail – by state,metropolitan area,and county. As in the case of population,the NAST-specified assumptions determined nationwide economic trends – in this case,trends in nationwide labor productivity and age-specific labor-force participation rates – while the distribution of employment and income among locations and economic sectors was calculated internally by the model.

Rates of labor-force participation were varied only for older workers. For workers under 55,participation rates were held at present levels. For workers aged 55 through 64,all three scenarios project increases in participation that extend recent trends, reaching a higher, constant level in 2025. Only the high scenario differs,in projecting an increase in participation for workers 65 and over, which also levels off in 2025. For productivity, the middle scenario assumes a continued constant increase of 1.2% annually in real economic output per worker, equal to the average annual increase over the 20th century. The high and low scenarios double and halve this rate of productivity growth respectively, to 2.4% and 0.6% per year.

Considering three alternative trends for population and productivity growth and two for labor-force participation yields eighteen possible combinations. If practicality dictates using only a few scenarios,only a small subset of these possible combinations can be considered. The recent IPCC scenario exercise faced a similar but much more complex problem of selecting scenarios from a large set of combinatorial possibilities,because their scenarios included diverse growth trends for multiple world regions. To reduce this complexity, they constructed narrative storylines that provided broad political and social context for particular worldwide patterns of population and economic growth (Nakicenovic and Stewart,2000).

In constructing the three scenarios for this Assessment,high population growth and high economic growth were combined in the high scenario, while low population and economic growth are combined in the low scenario. This combination of high population with high economic growth would not be appropriate in constructing scenarios for the world as a whole,because historical evidence and demographic theory both suggest that higher rates of economic growth are associated with lower rates of population growth. This situation is reversed, however, for projections of American growth in the 21st century, because most of the variation in population growth arises from variation in the assumed level of immigration. In contrast with natural population increase,immigration tends to follow economic opportunity, so the pairing of high population growth with high economic growth is more plausible than the reverse.

For 2100,the more distant target date of the Assessment,a much less detailed set of socioeconomic projections was specified. Over this time horizon, the likelihood of fundamental changes in economic structure,technology, and culture are likely to render the incremental methodology of the near-term regional economic model invalid. Indeed,any attempt to specify century-scale socioeconomic trends with the spatial and sector detail the NPA model provides for the near term is likely to be ludicrous. No detailed assumptions for the regional and sector distribution of population,employment,or income were specified for the second half of the 21st century.

Rather, a simple aggregate set of nationwide projections of population,employment,and GDP for the US were developed. As in the case of the more detailed projections through 2030,three scenarios were

[1] These figures are for the middle scenario. In the Census Bureau's highest scenario – which is not identical to the Assessment high scenario because the Census assumes less immigration and consequently an older population – centenarians reach 0.75% of the total population by 2050.

developed that combined high,medium,and low population and economic growth. Each of these scenarios was constructed to track the growth of national population and output in the corresponding more detailed scenario for the near term,then to converge in growth rates of both population and productivity over the second half of the 21st century. The scenarios were constructed using a simple reduced-form integrated-assessment model (Scott et al,1999),and were broadly consistent with three of the "marker" scenarios developed for the IPCC Third Assessment Report (Nakicenovic and Stewart,2000).[2]

The assumptions specified for these long-run scenarios are as follows. Population growth rates in the three scenarios converge beginning in 2050,until they become equal in 2075 and follow a common path thereafter, declining from 0.35% per year in 2080 to 0.15% in 2100. Aggregate rates of labor-force participation also converge after 2050,but not to full equality, reaching 75%,77.5%,and 80% in the three scenarios by 2100. Finally, annual growth rates of economic output per worker begin converging and declining after 2050, reaching 1.12% per year in 2075 and remaining at that level through 2100.

The consequences of these assumptions for US population and GDP are shown in Tables 1 and 2,and Figures 1 and 2, for both target years 2030 and 2100.

[2] The correspondence with IPCC scenarios is not exact,in part because of differences in time-steps and the definition of regions (the US is not a complete region in the IPCC scenarios).

US population is projected to reach 356 million by 2030 in the middle scenario (corresponding to an average growth rate of 0.86% per year between 1995 and 2030),with a range of 305 to 398 million in the low and high scenarios (0.39% to 1.21% annual growth). By 2100,the US population has reached 494 million in the middle scenario (average annual growth of 0.47% from 2030 to 2100),with a range from 353 to 640 million (0.21% to 0.68% average annual growth). United States GDP grows from its present $7.2 trillion to $14.4 trillion by 2030 (range $10.3 to $24.1 trillion),and to $39.2 trillion by 2100 (range $19.2 to $114.7 trillion).In terms of GDP per person,these scenarios give a range from $33,800 to $60,600 in 2030 ($40,500 in the middle scenario),and from $54,400 to $179,200 in 2100 ($79,400 in the middle scenario).[3]

APPENDIX 2:

Template for developing socio-economic scenarios

If a team required more detailed or specific socioeconomic assumptions to conduct an analysis than were provided in the centrally defined scenarios, they were asked to develop and document them using a common template,as follows.

[3] All monetary figures are expressed in 1992 dollars.

Table 1: Scenarios of US Population (Millions)

	1997	Growth rate, 1995-2030	2030	Growth rate, 2030-2100	2100
Present Population	268				
Low Scenario		0.39%	305	0.21%	353
Middle Scenario		0.86%	356	0.47%	494
High Scenario		1.21%	398	0.68%	640

Table 2: Scenarios of US GDP (Trillions of 1992 Dollars)

	1997	Growth rate, 1995-2030	2030	Growth rate, 2030-2100	2100
Present GDP	$7.2				
Low Scenario		1.1%	$10.3	0.9%	$19.2
Middle Scenario		2.1%	$14.4	1.4%	$39.2
High Scenario		3.7%	$24.1	2.25%	$114.7

First,each team was to select *a few key issues* they judged would be most important for their region or sector, or would best illustrate important patterns of impact. These are the “key issues”discussed in each of the regional and sector chapters. Second, for each key issue the team was asked to identify *one or two key socioeconomic factors*, such as specific aspects of development patterns,land use,technologies,or market conditions,that they judged likely to have the *most direct influence* on climate impacts, capacity for adaptation and vulnerability for that issue. In choosing their key issues and key socioeconomic factors,each team was requested to use whatever combination of preliminary analysis, expert judgment,and stakeholder consultation they judged most appropriate. They were then to examine the impacts of specified climate-change scenarios on their key issues,under a range of values for their chosen socioeconomic factors. If they identified more than one key socioeconomic factor, they were asked to construct a few alternative socioeconomic scenarios by varying the factors jointly between high and low values. Other than the few key factors they chose to vary, any other required socioeconomic assumptions were to be fixed at baseline or best-guess values.

The ranges chosen for key socioeconomic factors were intended to reflect all sources of socioeconomic uncertainty *except* climate change itself and US policy responses to climate change. Since the purpose of the Assessment was to examine the effects of climate explicitly, these did not need to be embedded in variation of socioeconomic input assumptions. In contrast,the ranges were to include climate-related uncertainty outside the US,if the team judged such uncertainty to matter for US impacts. This situation might arise, for example,in estimating demand for US grain exports or immigration to the US,either of which could be influenced by climate-related impacts abroad.

The template also provided some guidance in deciding how wide a range of values to assume for the key socioeconomic factors. In general terms,teams were asked to make the range wide enough to generate instructive variation in impacts,but to remain within their judgment of plausibility. Specifically, the range chosen for any factor should correspond to roughly a 10% chance that the true value would lie above the upper end of the range,and a 10% chance that it would lie below the lower end. The NAST working group followed this same guideline,constructing ranges to capture the true value with 80% confidence,in developing the three scenarios of aggregate US population and economic growth discussed above. In constructing these ranges,participants were cautioned to draw them wide,seeking to mitigate people’s widely known tendency to be too confident in estimating unknown quantities (Kahneman et al.,1982;Morgan and Henrion,1990).

Scenarios of 21st Century Growth in America

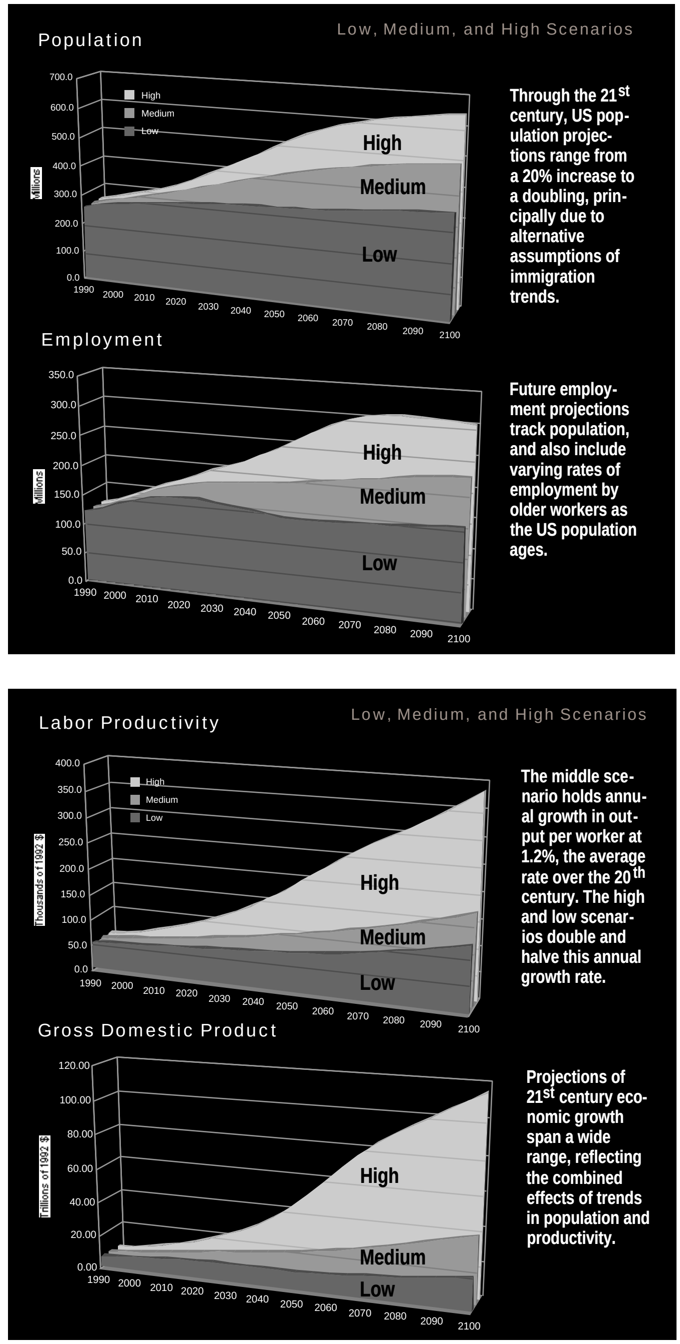

Figure 1. The Assessment considered high, medium, and low scenarios of future US population and economic growth. Future trends in population, economic growth, and technological change will all shape our contribution to climate change, our vulnerability to it, and our ability to adapt.

The combination of climate scenarios and socioeconomic scenarios provides the raw materials for assessing climate impacts. Imposing a specified climate scenario – whether derived from historical experience or from a model projection – on a specified socioeconomic scenario,and examining its effects relative to the baseline climate,provides a first-order illustration of potential climatic impacts. How this difference varies among alternative climate scenarios illustrates how impacts depend on uncertainty in climate. How the difference varies among alternative socioeconomic scenarios illustrates how socioeconomic factors shape vulnerability to impacts. How it varies with specific hypothesized responses (such as changes in management, policy, institutions,or infrastructure),illustrates key decisions that may shape vulnerability and adaptive capacity.

For example,in the Pacific Northwest,the projected climate scenario had warmer wetter winters and drier summers. As one of their key issues,the Northwest team identified the impacts of this change on seasonal streamflow and freshwater supplies. In two separate analyses,they examined impacts of climate variability and change on the risk of winter flooding,and on the reliability of summer water and hydroelectric supplies. For the flooding analysis,they were able to define flooding purely by hydrological characteristics,without regard to socioeconomic conditions. However, more detailed assessment that considered not just occurrence of floods but the damages they cause would clearly have to consider settlement patterns,construction standards,emergency response measures,and other socioeconomic conditions as well. For the shortage analysis,they examined impacts of summer shortages on multiple uses under two alternative sets of operating policies to manage flows and allocate supply (Mote et al.,1999).

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