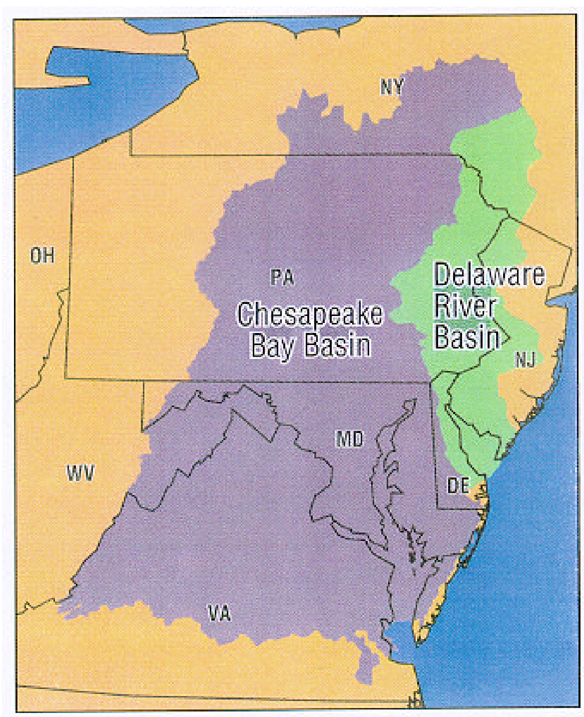
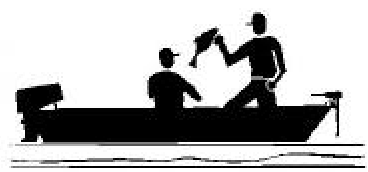
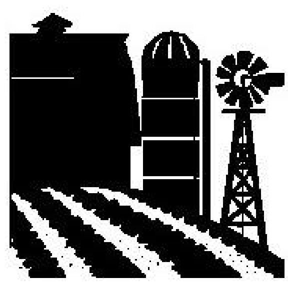
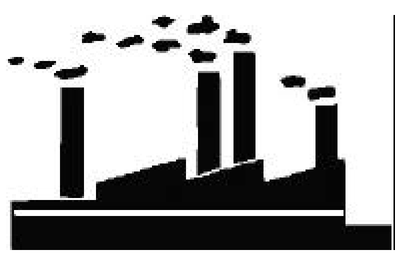
CLIMATE CHANGE IMPACTS IN THE MID-ATLANTIC REGION – A WORKSHOP REPORT









CLIMATE CHANGE IMPACTS IN THE MID-ATLANTIC REGION – A WORKSHOP REPORT

The Pennsylvania State University
Nittany Lion Inn

September 9-11, 1997

Compiled by Ann Fisher, Eric Barron, Brent Yarnal,
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Edited by Ann Fisher and Ron Smart

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CLIMATE CHANGE IMPACTS IN THE MID-ATLANTIC REGION – A WORKSHOP REPORT

EXECUTIVE SUMMARY

PURPOSE

Recognizing that global climate change will be felt differently by people depending on where they live, Vice President Gore and the Office of Science and Technology Policy (OSTP) encouraged the U.S. Global Change Research Program (USGCRP) to initiate a series of workshops in 1997. The purpose of these regional workshops was to examine climate change issues within regions and to obtain information for analysis of climate change impacts at the national scale.

A spectrum of interested parties from academia, industry, government, and environmental organizations convened to address impacts of climate change in the Mid-Atlantic region, focusing on the watersheds of the Chesapeake and Delaware Bays. Small groups worked to: (a) identify potential climate impacts in the context of other stresses on the region, (b) ascertain what is known now and what needs to be known in order to make informed decisions in response to opportunities and challenges posed by climate variability and change, and (c) suggest early actions for addressing the potential impacts of climate variability and climate change. These working groups relied on three background papers, presentations during plenary sessions, and their own expertise.

Pennsylvania State University (Penn State) was asked by the U.S. Environmental Protection Agency (EPA) USGCRP to host the Mid-Atlantic Workshop, held September 9-11, 1997.

The Region's Unique Characteristics

The Mid-Atlantic Region has several characteristics that make its people, economy, and ecosystems sensitive to climate change. These include:

- Extensive shorelines
- Significant agricultural, forest, and fishery sectors
- A large population
- Historical settlement patterns along waterways
- An economy based on abundant water
- Unique natural resources, such as the Chesapeake Bay

The region also has features that may help to make is resilient to climate change. These include:

- A highly developed, diversified, dynamic economy.
- Significant potential to adapt through technological and institutional change

MAJOR FINDINGS

- **The Mid-Atlantic Region is reasonably robust with respect to climate variability.** This conclusion is based on factors such as the region's abundant water resources, varied ecosystems, diversified economy, and history of managing weather-related disasters. Working groups representing different sectors (economic growth, industry and commerce; ecosystems; water resources; natural hazards; human health; agriculture, forestry and fisheries) potentially vulnerable to climate impacts ranked climate low in importance relative to factors such as poverty, global market pressures, and water and air quality. They viewed these other factors as presenting more immediate, tangible impacts.

- **Climate change could have adverse impacts on the region's people, economy, and ecosystems**. When working groups accepted model-based future climates as indicative of the future, climate impacts took on greater importance. Some impacts were judged to be as important as other major issues that influence the region's economic and societal well-being.

- **Potential impacts could vary widely by sector depending on the sensitivity of the sector and the potential for adaptation**. The working groups that discussed health, ecosystems, and recreation expected profound effects in these sectors. Significant sea level rise would have a marked and extensive impact in the Mid-Atlantic area. In contrast, the working group for agriculture did not consider this highly adaptable component of the regional economy to be seriously threatened under the climate change scenarios. Global markets are likely to be a greater driver for agriculture than climate. Similarly, the region's economic growth was not viewed as seriously threatened under the climate change scenarios adopted for the workshop. This conclusion largely reflects the group's expectation that the regional economy's size, diversity, and adaptability make it resilient with respect to the impacts of climate change. On the other hand, impacts could be substantial and important on a local scale. This working group expressed uncertainty about how factors governing economic growth, such as water availability and transportation infrastructure, might be affected by climate change.

- **The importance of climate change in influencing the severity or frequency of natural disasters is unclear**. In general, working groups could identify the types of vulnerabilities, but were unable to assess their magnitudes given the uncertainties inherent in future climate predictions.

RECOMMENDATIONS

The uncertainties highlighted in the background papers and presentations and in the working group and summary discussions led to three types of recommendations: research needs, education and communication needs, and near-term strategies for adaptation to climate variability and change.

Research Needs:

The scientific information available for assessing regional impacts of climate change and variability is extremely limited. Assessments based on this limited information could grossly miscalculate either the threat or opportunities to the region. Essential information for improving the assessment of how the Mid-Atlantic region would be affected by climate change include:

- how climate change will affect the regional climate (i.e., frequency and intensity of severe weather, the nature and timing of precipitation events, frequency and severity of droughts);
- the rate and magnitude of climate change at the scale of public and private decision makers in climate sensitive sectors (e.g., agriculture, forestry, water supply);
- how climate change will affect the region's natural resources and ecosystems;
- how climate change will affect the productivity of agriculture, forests, fisheries and other sectors;
- differences in risk between private and public sector activities;
- differences in risk for different population segments;
- the role of information in initiating responses to minimize risks or maximize opportunities;
- how institutional and technological change can diminish risks and enhance opportunities;
- the current state of Mid-Atlantic ecosystems, and the associated monitoring and modeling of ecosystem changes; and
- expected regional demographic changes.

Education and communication:

Essential needs include:

- enhancing environmental education within medical training, and
- ensuring that the nature of climate predictions and their uncertainties are well-articulated and widely available to the full spectrum of interested parties.

Near-term strategies:

Actions can be taken now to address problems that are already recognized or that represent a "win-win" approach to climate impacts. These include:

- enforcing restrictions on construction and eliminating subsidies for rebuilding in flood-prone areas,
- expanding the use of urban heat warning systems,
- developing flexible water management across regional or local districts, and
- improving land-use and drought planning.

While many strategies can be conceived that would reduce existing and expected stresses, some would have high economic or societal costs. For example, enhancing the infrastructure for water management through increased storage capacity is logical given the Mid-Atlantic region's propensity to drought. But the region needs to consider the environmental implications of dams and reservoirs along with their construction and operating costs. Thus additional analysis can examine the cost effectiveness of proposed strategies to address current stresses likely to increase because of expected economic and population growth. Such actions offer benefits of reducing the region's vulnerability to climate as a bonus.

PREFACE

Recognizing that global climate change will be felt differently by people depending on where they live, Vice President Gore and the Office of Science and Technology Policy (OSTP) encouraged the U.S. Global Change Research Program (USGCRP) to initiate a series of workshops in 1997. The purpose of these regional workshops was to examine climate change issues within regions and to obtain information for analysis of climate change impacts at the national scale. The objectives were to:

- increase understanding of high priority regional environmental issues for which climate change is likely to be important;
- increase understanding of the region's vulnerability to climate variability and climate change;
- identify how individuals, governments and industry in the region currently cope with environmental stresses, including climate stresses (e.g., droughts and floods);
- identify future coping mechanisms and options for adjustment and adaptation;
- identify existing information and research needed to reduce vulnerability and improve adjustment and adaptation options;
- define a preliminary, prioritized research agenda for the region;
- define follow-on activities in the region;
- initiate regional analyses to support national assessments of climate change impacts.

Pennsylvania State University (Penn State) was asked by the U.S. Environmental Protection Agency (EPA) USGCRP to host the Mid-Atlantic Workshop, held September 9-11, 1997. Aided by consultation with a 17-member Steering Committee (listed in Appendix), the organizing committee set up an agenda (see Appendix). The 92 invited participants represented federal, state and local government, industry, academia, and public interest groups.

By the end of the workshop, participants reported becoming more informed about climate change and its potential for regional impacts. They were enthusiastic about education and information dissemination, especially for reducing uncertainties about climate variability– at scales fine enough to help water managers and farmers with their planning. They expressed strong concerns about potential impacts from sea-level rise on ecosystems and recreation and about human health impacts.

The workshop was sponsored by the U.S. Environmental Protection Agency (EPA) and by the following Penn State units: Earth System Science Center (ESSC) and Center for Integrated Regional Assessment within the College of Earth and Mineral Sciences, Department of Agricultural Economics & Rural Sociology and the College of Agricultural Sciences, Environmental Resources Research Institute, and Office of Research.

Many individuals contributed to the success of this workshop. EPA's Joel Scheraga, Mike Slimak, Susan Bassow and Anne Grambsch provided vital assistance when the decision was made to add the Mid-Atlantic region to the first round of regional workshops, and Scheraga contributed an excellent public address when, at the last minute, Vice President Gore could not come. Wanda Haxton navigated EPA's paperwork channels on a short time schedule. Our Steering Committee provided valuable feedback on drafts of the background papers and suggestions about whom to invite and how to make the agenda most effective.

Special thanks to Richard Horan for his contribution to the third background paper and to developing pre- and post-workshop questionnaires, to Jeff Carmichael for coordinating the cadre of graduate students who summarized the plenary and working group sessions, and to Patti Anderson for constructive suggestions on the draft report. The administrative assistance provided by Deb Detwiler, Linda Spangler and Lori Lynch, was superb and contributed to the success of the workshop. Phil Kolb set up the web page report (www.essc.psu.edu/ccimar), which has been maintained and updated by Mary Easterling.

The workshop's most important component was the hard work put in by the participants. Rapporteur Baruch Fischhoff noted that participants became readier to engage in the network being built, so that the Mid-Atlantic region can make smarter decisions related to impacts from climate change. Many of those participants now serve on the Advisory Committee for the First Mid-Atlantic Regional Assessment of Impacts from Climate Change (MARA); others are collaborating with MARA's large Penn State team. We look forward to continued interaction with stakeholders as we proceed. While at OSTP, Jerry Melillo stressed that the regional workshops could be a first step toward more systematic thinking by the region's citizens about planning for a sustainable future. As co-chair of the National Assessment Synthesis Team, he continues to see the regional assessments as providing a framework for smart decisions about the future. We agree.

Ann Fisher, Eric Barron, Brent Yarnal, C. Gregory Knight, James Shortle
(Organizing Committee)
February 1999

CHAPTER 1: SETTING THE STAGE

THE MID-ATLANTIC REGION'S GEOGRAPHY AND PEOPLE, BY COLIN POLSKY

A. INTRODUCTION

An assessment of likely regional impacts from climate change begins with the baseline setting, including the region's climate and the natural and human environments. For the Mid-Atlantic Region (hereafter MAR; cover and Figure 1), historical climate is outlined in Yarnal (this document). The natural and human environments and their changes over the past three decades are described below. This brief, general profile of the region provides context for the analyses that follow.

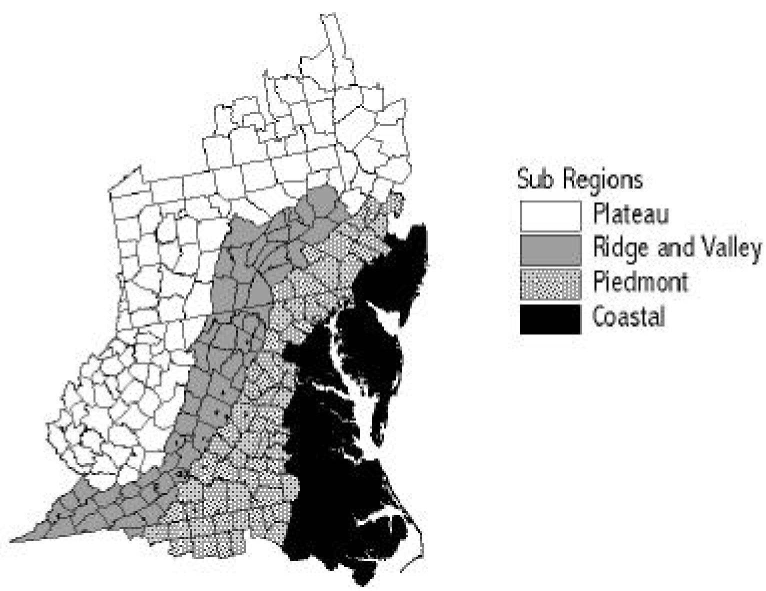

Figure 1. The Mid-Atlantic Region and its sub-regions.

The MAR as defined for this assessment of climate change impacts includes all of the Chesapeake Bay and Delaware River drainage basins. These basins include all or parts of 232 counties in New York, Pennsylvania, New Jersey, Delaware, Maryland, Virginia, West Virginia, and the District of Columbia, and cover approximately 277,000 km^2 (112,000 square miles). For the purposes of this analysis, the MAR is divided into four physiographic regions, or areas of similar landforms (Tarbuck and Lutgens, 1996; Miller, 1995). Table 1 relates the size of these regions relative to the greater MAR. In all, the

MAR covers about 3 percent of the land area in the 48 contiguous United States (U.S. Bureau of Census, 1997).

Table 1. The Mid-Atlantic Region at a Glance

	Counties	*Surface Area*
Coastal Plain	72	52,376 km^2
Piedmont	54	57,360 km^2
Ridge & Valley	54	59,227 km^2
Appalachian Plateau	52	107,919 km^2
Mid-Atlantic Region	232	276,882 km^2

Source: NPA, 1998.

B. THE NATURAL ENVIRONMENT

The Physiographic Regions

The relatively flat coastal plain is composed mostly of sedimentary rock and extends inland from the oceans and estuaries. This zone traverses all of Delaware and parts of New Jersey, Maryland and Virginia. The piedmont plateau is the foothills region covering the eastern, lower portion of the Appalachian Mountain range, which is composed mostly of metamorphic and igneous rock and found in north-central New Jersey, southeastern Pennsylvania and in the central portions of Virginia and Maryland.

The MAR ridge and valley zone has folded terrain with a series of parallel, eroded mountains. This strip of land extends from the northwest corner of New Jersey to the southwest, passing through Pennsylvania, Maryland and Virginia. A notable part of this zone is the so-called blue ridge region, the extended, thin ridges of the Appalachian Mountains– including the highest points of that range– located primarily in Virginia and Maryland, with smaller representations in Pennsylvania and New Jersey. The Appalachian plateau describes a swath of land from the New York portion of the MAR through northern and western Pennsylvania, the western edge of Maryland and most of West Virginia. This region is composed mostly of relatively flat sedimentary rock, dissected in many places by meandering waterways (Tarbuck and Lutgens, 1996; Miller, 1995).

Land Use and Land Cover

The MAR has two principal types of land cover, forest and agricultural lands (U.S. EPA, 1997). (Certain MAR counties in New York and New Jersey are not included in these land cover calculations.) These two categories account for almost all of the land cover in the MAR, with forest cover being the leading category. The highest concentrations of forest area are in and around West Virginia and north-central Pennsylvania; agriculture is the predominant land use in the lowlands to the east of the Appalachians. About 5 percent of the MAR is classified as federal land (U.S. Bureau of the Census, 1997).

All MAR watersheds have at least half of their total stream length in forest cover, reflecting a reasonable safeguard against agricultural runoff and other pollution to water sources (U.S. EPA, 1997). However, all MAR watersheds also have some agriculture operations and many have roads located near the streams, indicating a potential for considerable, if diffuse, risk for water pollution (U.S. EPA, 1997). For instance, two-thirds of the nutrient and sediment loading in the Chesapeake Bay comes from upstream and non-point sources. This pollution is long-lived: the Chesapeake Bay flushing rate, at about 350 days, is one of the slowest rates for a water body in the United States (NOAA, 1998).

C. THE HUMAN ENVIRONMENT

The People

Tables 2 and 3 show recent trends and geographic distributions of the MAR population and economy. Approximately 34.5 million people live in the MAR (1996 estimate; Table 2), representing about 13 percent of the entire U.S. population (NPA, 1998; U.S. Bureau of the Census, 1998b). More than three-fourths of the total MAR population, income and jobs are concentrated in the coastal plain and piedmont, where the large urban agglomerations are found. This density translates into a markedly higher per capita income for these two sub-regions compared to the Ridge & Valley and Appalachian Plateau sub-regions. This concentration also reflects the importance of the Atlantic Ocean, Chesapeake Bay, and the Delaware and Susquehanna Rivers for regional food, employment, energy and recreation. While large cities do not cover much of the MAR surface area, collectively they constitute one of the more important population concentrations in the country. Of the MAR urban areas, Philadelphia, Pittsburgh, Baltimore, Washington, D.C., Richmond and Norfolk are among the largest cities in the U.S., accounting for more than half of the total MAR population (U.S. Bureau of the Census, 1998a).

Table 2. Geographic Distribution of Key Socio-Economic Variables for the Mid-Atlantic Region: 1996 (Percent and Value)

	Coastal Plain	Piedmont	Ridge & Valley	Appalachian Plateau	*MAR Totals*
Population (million people)	49% 17.0	28% 9.6	11% 3.7	12% 4.2	*100% 34.5*
Income (billion 1992$)	52% $428	30% $251	9% $72	10% $79	*100% $829*
Income per Capita (1992$)	$22,047	$21,678	$18,014	$17,427	*$19,987*
Total Employment (million jobs)	52% 10.6	27% 5.4	11% 2.2	10% 2.1	*100% 20.3*
Total Farm Employment (thousand jobs)	19% 34.3	31% 56.8	26% 46.4	24% 44.1	*100% 181.6*

Source: NPA, 1998.

Table 3. Changes in Key Socio-Economic Variables for the Mid-Atlantic Region: 1967-1996

	Total Change	Average Annual Change
Population	28%	0.9%
Income	139%	3.1%
Income per Capita	91%	2.3%
Total Employment	71%	1.9%
Total Farm Employment	-36%	-1.5%

Source: NPA, 1998.

The MAR population increased by approximately 28 percent during the past three decades, slightly less than 1 percent per year on average (Table 3). This trend resembles that for the nation as a whole, which grew by 33 percent at an annual rate of 1 percent (U.S. Bureau of the Census, 1998b). Total regional personal income grew by about 140 percent over this period, and per capita income almost doubled. Income in the service sector recorded significant growth over the period (over 300 percent), such that services, government and manufacturing presently account for nearly one-half of all regional income (NPA, 1998). Total employment has increased by about 70 percent since 1967, fueled largely by non-farm industries such as services, which more than doubled over the period. On the other hand, farm-related employment fell by more than one-third. When combined with the growth in services and other sectors, this reduction in farm employment points to a diminished economic role for agriculture in the region, similar to the larger national trend.

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CLIMATE VARIABILITY IN THE MID-ATLANTIC REGION, BY BRENT YARNAL

A. INTRODUCTION

One way to estimate how a region will react to future global climate change is to study how the region has been affected by past climate variations. Before determining (1) what we already know about past climate variations in the Mid-Atlantic Region and (2) what we need to learn, it is important to clarify some basic definitions and facts about climate, climate change, and climate variability.

Although climate is often thought of as average weather, it is much more than that. Weather is the hour-to-hour and day-to-day state of the atmosphere. In contrast, climate encompasses the longer-term condition of the atmosphere. Climate reflects the frequency and intensity of weather experienced at a time and place, including storms, cold outbreaks, and heat waves.

The climate system varies and changes because of the atmosphere's interaction with the total Earth system of water, rock, soil, and life. This variation and change includes the commonplace daily and seasonal cycles and short-term extreme events such as floods and droughts, as well as long-term episodes such as wet and dry decades, cool or warm centuries, and glacial-interglacial cycles.

There is much confusion over the terms *climate variation* and *climate change*. However, for the United Nations Convention on Climate Change, scientists, decision-makers, and other stakeholders have resolved that climate variation refers to natural variation in climate, while climate change pertains to those variations in climate attributable to human activity. These human activities– such as industrial operations or land transformations– influence the planetary energy balance by emitting or leading to the creation of the radiatively active gases carbon dioxide, methane, nitrous oxide, and the halon family, or by injecting microscopic particles into the atmosphere. Radiatively active gases enhance the natural greenhouse effect and are believed to be warming the planet, while microscopic particles screen out incoming sunlight and cool the surface.

Climate change arises from human activity, but climate variation is the result of natural forces operating at different time scales. The two most fundamental variations in climate are day and night and the seasons, which result from relationships between the sun and Earth on time scales of days and years, respectively. The third most important identified variation in the climate system is El Niño-Southern Oscillation (ENSO) events, which perturb the global oceanic and atmospheric circulations and can produce droughts and floods in certain regions. For example, during warm phases of ENSO (known as El

Niño), the southern United States tends to be very wet and may suffer floods; during ENSO cold phases (known as La Niña), this region is prone to drought. These extremes of ENSO usually occur every three to five years and last for about a year and a half. Scientists are developing the ability to predict these events and their regional patterns of flood and drought many months in advance. Many other causes of variability on seasonal to interannual time scales, such as volcanic eruptions, are difficult to predict.

Climate also varies on time scales ranging from decades to millions of years. Decade-long variations result from interactions among the different components of the Earth system (atmosphere, ocean, land, biosphere, and ice). Because each of these components is characterized by different response times, their interactions produce climate variations on many different time scales. Decade-long variations can also result from variations in solar output tied to sunspot cycles. On century time scales, planetary warming and cooling may be caused by long-term oscillations in solar output. In the last two to three million years and on time scales of ten thousand years or more, variations in Earth's orbit around the Sun may have been responsible for more than 20 glacial-interglacial cycles. Even longer-term changes in the configuration of the continents and associated mountain-building episodes result in climate variations over ten million years or more, such as the ice age conditions of the last 35 million years or the generally warm Earth inhabited by the dinosaurs.

Climate varies over space as well as time. In any given year or decade, the climate in one region may be anomalously warm, cool, wet, or dry, while temperature and precipitation in an adjacent region may be close to average. Climate patterns in some regions may be particularly sensitive to phenomena such as ENSO.

A regional understanding of climate variation is important because biophysical and human impacts are felt regionally, rather than globally. In the United States, storms, floods, heat waves, droughts, and cold outbreaks are regional phenomena, although their impacts may be serious enough to spread throughout the nation and the world. For example, the 1988 drought so devastated the Midwest that it had a measurable influence on the national and world economies.

Understanding regional climate variation and its impacts is crucial to understanding climate change. There is uncertainty about how climate change will influence specific regions, but many scientists think that it will be felt primarily through regional climate variations. Some regions may suffer more frequent and intense droughts, for instance, while others may have fewer and weaker droughts. Either way, because regional variations in climate are normal, it may be difficult for individuals, including scientists, to distinguish anthropogenic climate change from natural climate variation. Current scientific efforts are aimed at determining what climate change plus natural variability would look like at a regional scale.

As a first step in understanding how climate variation affects the Mid-Atlantic Region's climate today and may influence it in the future, this section first addresses seasonal and decadal climate variations observed in the region during the past century. Then it looks at the region's longer-term climate variations of the last 1000 years. It concludes by summarizing what we know about climate variation in the Mid-Atlantic Region and what we need to learn.

B. RECENT CLIMATE VARIATION IN THE MID-ATLANTIC REGION

There is a wealth of observed climate data– that is, data recorded by weather instruments– for the Mid-Atlantic Region. However, the relatively short period of these data provides insight only on recent climate variations of years and decades; assessment of longer time scales of climate variation require data sets of greater length. To deduce longer time-scale variations or to determine how climate varied before the invention of weather-recording instruments, it is necessary to reconstruct climates by recovering and interpreting natural phenomena and human artifacts containing climate information. Section C below discusses the reconstruction of pre-instrumental climate in the Mid-Atlantic Region.

The National Climatic Data Center (NCDC) has monthly data for Mid-Atlantic Region temperature, precipitation, and Palmer Drought Severity Index (PDSI). The PDSI is important to agriculture because it tracks soil-moisture conditions. These three variables extend back to 1895 and are presented here for the Mid-Atlantic Region (see Figure 2), defined by the watershed boundaries of the Chesapeake and Delaware Bays.

The figure shows that the temperature, precipitation, and PDSI of the Mid-Atlantic Region have varied substantially on annual and decadal time scales over the last century. These surface climate variations can be linked to variations in the region's atmospheric circulation.

Precipitation

The Mid-Atlantic Region appears to have experienced three distinct precipitation regimes during the last century; each was separated by a period with sharply reduced precipitation. The first regime extended from the beginning of the record until about 1930. With few exceptions, precipitation totals were below the long-term average. This period ended in the early 1930s when the driest period in the last century contributed to a sharp, but short-lived precipitation deficit. The second regime started when precipitation rose to slightly above average totals. This regime ended with the 1960s, when nearly every year was well below average. In 1970, the third regime began when precipitation totals took a dramatic jump, with all but a few years in the last 27 being above normal. Many of these years were very wet; the wettest year in the record is 1996.

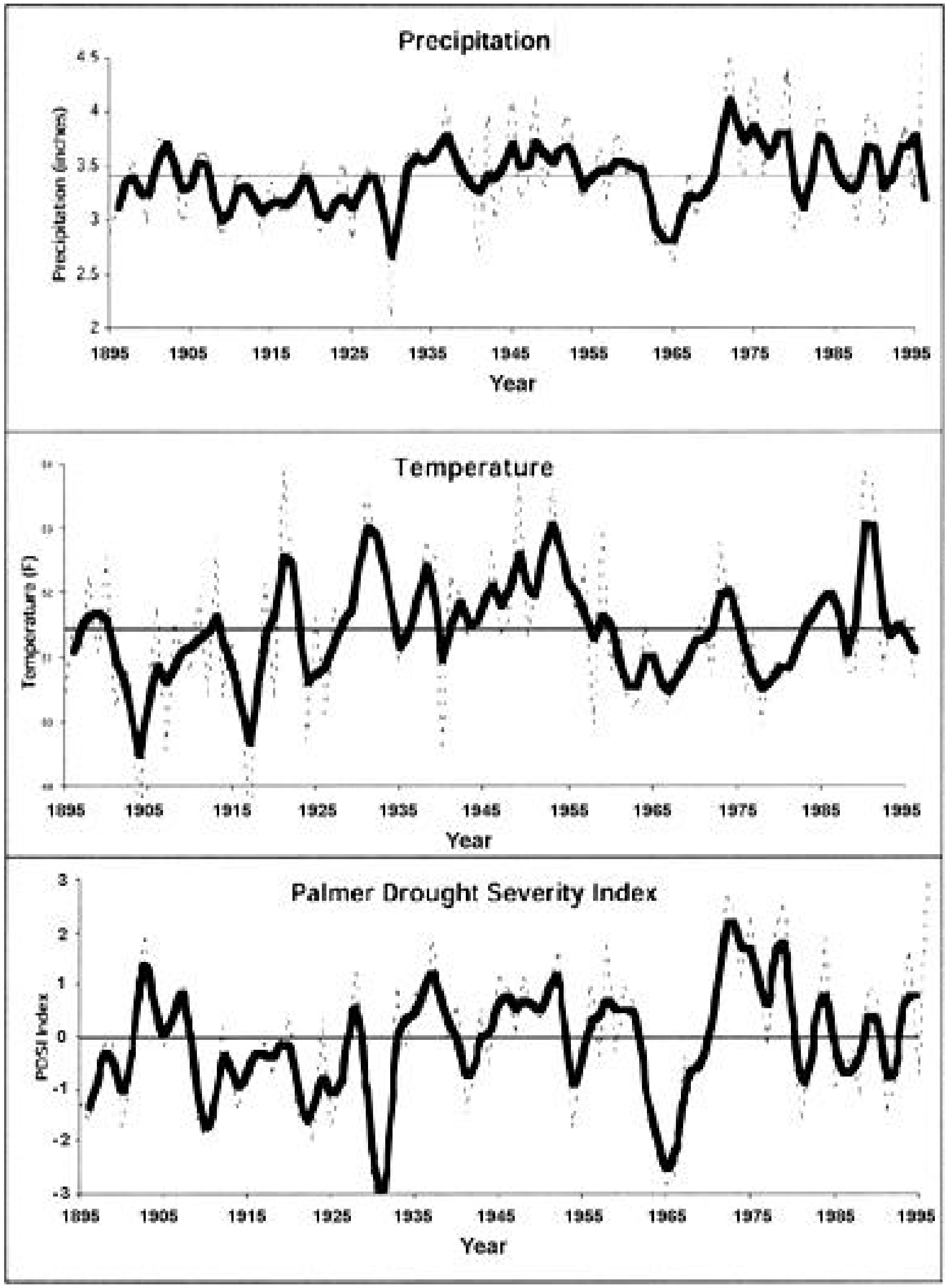

Figure 2. Departures from long-term (1895-1996) average monthly precipitation (inches), annual temperature (° Fahrenheit), and annual Palmer Drought Severity Index for the Mid-Atlantic Region. The dashed line denotes average annual values, while the bold, solid line is a five-year running average.

Temperature

From the beginning of the record until the late 1920s, Mid-Atlantic Region temperatures were well below the long-term average (although a few years during this period had noticeably above-normal temperatures). Then, except for a couple of conspicuous cold years, temperatures from the late 1920s until about 1960 were well above average. Note that from the beginning of the record to the mid-1950s, there was a marked warming trend. This trend ended when temperatures started to drop in the mid-1950s, falling well below average by the 1960s and staying there (except for a few years in the mid 1970s) until approximately 1980. Since then, temperatures have oscillated above and below normal, with a couple of remarkably hot years in 1988 and 1989.

Palmer Drought Severity Index

Except for several moist years in the 20th century's first decade, this index was well below the long-term average (i.e., conditions were dry) until the mid-1930s. The last few years of this period – the infamous Dust Bowl years in the Great Plains– were exceptionally dry. The succeeding period from the mid-1930s until the early 1960s tended to be moist. The 1960s were very dry, while the 1970s were extraordinarily wet. The period from the 1980s through the first half of the 1990s was the only time in the 102-year record that precipitation oscillated around the normal mark. The Mid-Atlantic Region droughts of 1980, 1986, 1988, and 1991 are evident. Also remarkable is the sharp spike at the end of the record caused by the exceptionally wet year 1996.

Relationship to atmospheric circulation variations

There are clear relationships among the Mid-Atlantic Region's precipitation, temperature, and PDSI variations of the last century. In general, from the beginning of the record to about 1930, the climate was cool and dry. The early 1930s saw a couple of exceedingly hot, dry years associated with the midwestern Dust Bowl. This short, sharp drought was replaced by nearly three decades of relatively warm, moist climate. This period was replaced by a cool and very dry climate in the 1960s. In contrast, the 1970s were exceedingly wet, but varied between warm and cold. Since the late 1970s-early 1980s, temperature and precipitation have varied above and below normal.

These variations in regional climate since World War II can be explained by changes in the atmospheric circulation. (Earlier periods lack the jet stream-level data needed to make the following generalizations.) A zonal regime dominated the atmospheric flow over North America through the late 1940s and early 1950s. (Note: a *zonal* flow regime means that the jet stream over the United States tends to flow from west to east, with few of the north-south excursions that produce ridges of warm air and troughs of cool air. In contrast, during periods of *meridional* flow, the jet stream has a much greater north-south amplitude, often producing a big ridge of warm sub-tropical air over the western United States and a deep trough of polar air over the eastern half of the nation.) Such a regime produced normal to slightly above-normal temperatures and variable precipitation over the Mid-Atlantic Region. Then in the mid- to late 1950s, the circulation experienced a change from zonal to meridional flow; a stable meridional-flow regime was fully entrenched by the 1960s. During this decade, the Mid-Atlantic Region tended to be influenced by an anomalous, deep trough of continental polar air, a storm track southeast of its long-term mean position, and precipitation often falling off the Atlantic coast. This regime promoted a relatively cool, dry climate. The early 1970s saw the continuation of this meridional regime, but the trough migrated westward, putting the average position of the storm track over the Mid-Atlantic Region. This change caused a significant increase in precipitation. Finally, the mid- to late- 1970s brought a large change in the atmospheric circulation. The period following this change– which has extended to the present– has been associated with significant increases in the interannual variability of the atmospheric circulation, with unusually large variations in the shape and positioning of the month-to-month and year-to-year jet stream flow over North America. Such major variations in circulation have produced a highly variable surface climate.

Recent Mid-Atlantic Region climate extremes

Current trends suggest a change towards a less extreme Mid-Atlantic Region climate. The last frost of spring is tending to come progressively earlier, while there are fewer very cold winter days. These changes imply that the region's winters are warming. At the same time, the number of very hot summer days appears to be decreasing (although there is some question about the reliability of these data). Although many experts think that human-induced climate change will bring more extreme climate to most regions, it is possible that the above trends could be the realization of climate change in the Mid-Atlantic Region.

Comparison to nation and globe

How do the Mid-Atlantic Region variations discussed above compare to rest of the United States and the world? Comparable, but different, interannual and decadal variations in temperature and precipitation have been detected in all regions of the United States. Scientists have found that average air temperature in the United States warmed by about 0.7°F over the last century. However, that increase was not linear, and not all areas of the country warmed. The nation was relatively cool until the 1930s, at which time temperatures rose sharply. Temperatures fell during the 1950s to 1970s, with sharpest declines during the 1960s. Temperatures rose again in the 1970s and have remained high since then. These patterns roughly coincide with the temperature trends for the Mid-

Atlantic Region, although the area has warmed more during the century than the national average. Variations in global surface temperature observations also roughly correspond to those of the Mid-Atlantic Region, with the region warming more than the global average of approximately 0.5-1°F.

Precipitation variations for the United States also show surprising resemblance to the Mid-Atlantic Region variations. Notably, since about 1970, precipitation has tended to remain above the 20th century mean and has averaged about 5% more than in the earlier part of the record. Some of the largest precipitation increases over the century occurred over the Mid-Atlantic Region, especially the northern parts of the Chesapeake and Delaware Bay drainage areas. Globally, precipitation over land has gone up 1% during the 20th century. However, global precipitation has been relatively low since about 1980, which does not correspond with Mid-Atlantic Region and United States observations.

The 1960s drought in the Mid-Atlantic Region shows up in the national PDSI record, but is overshadowed by the great midwestern droughts of the 1930s and 1950s. Perhaps more important, similar to the Mid-Atlantic Region record, the United States has tended to be unusually wet since approximately 1970. PDSI is not calculated globally, so it is difficult to make comparisons with the Mid-Atlantic Region record for this variable.

Finally, has the global atmospheric circulation matched the variations noted over North America and the Mid-Atlantic Region? The behavior of the equatorial Pacific ENSO phenomenon has been unusual since the mid-1970s, especially since 1989. During that time, El Niño events have been more frequent and persistent than La Niña. These findings can partly explain the behavior of the atmospheric circulation over North America and the Mid-Atlantic Region since the mid-1970s, but cannot account for variations in the circulation and regional climate before then. Research suggests that these earlier variations were related to changes in the extratropical North Pacific and North Atlantic, not the equatorial Pacific.

C. THE CLIMATE OF THE LAST 1000 YEARS

Long records of climate variations are needed so that scientists can compare the natural variation of the period before the Industrial Revolution with the mixed natural and anthropogenic climate signal observed since then. Unfortunately, comprehensive climate observations are restricted to the last century and a half, and to even shorter periods in many regions. Consequently, pre-instrument (paleoclimate) climate variations must be deduced from proxy data for climate-sensitive phenomena, such as tree rings, corals, glacier ice cores, and alpine glacier advance and retreat. Chronologies for quantitative data can also be culled from historical records, such as journals and tax and mercantile records. The data from the last 1000 years are especially important because they are relatively abundant and fresh and because the variations they portray are most relevant to the current climate.

Although tree ring data are the most plentiful of the natural proxy data, they are still too sparse to provide a complete global picture over time. Ice core, coral, and glacier advance-retreat data are even less common. Thus, the majority of the data for the last millennium may reflect regional, rather than global climate signals.

Despite these data problems, glacier ice cores and a variety of other paleoclimate reconstructions show that *globally* the 20th century has been warmer than any century since 1400 AD, and is probably the warmest century in the last 1000 years. Furthermore, some evidence suggests that this century is perhaps as warm as any comparable period in the last 10,000 years– that is, since the retreat of the continental glaciers from North America and Eurasia. On century time scales, it has also been estimated that the variability of global mean temperature over the last millennium has been less than ±0.9°F. The temperature increase that coincided with the end of the Industrial Revolution may soon exceed this range. It is important to note that century-scale climate data suggest that natural variation can be abrupt and large.

Knowledge of Mid-Atlantic Region climate since the mid-17th century is based primarily on reconstructions using tree rings and historical data from diaries, newspapers, and periodicals. These and other data suggest that until the late 19th century, the region was cool and somewhat wet, but was affected by individual years of intense drought and occasional decades of prolonged drought. Overall, the year-to-year and decade-to-decade climate was highly variable and not unlike that observed in the latter 20th century. After about 1880, the area warmed gradually. Climate variation decreased until the latter 20th century. For the entire record, the longest drought extended from about 1850-1873, although the most severe prolonged drought occurred in the 1960s. The reconstruction evidence suggests that ENSO events have a significant effect on the hydrology of the Mid-Atlantic Region, although comprehensive work on this subject has yet to be done. In general, the climate patterns from these paleoclimate reconstructions are consistent with other regions of the eastern United States and the North Atlantic basin.

D. CONCLUSIONS

Climate varies on many space and time scales, with regional variations at interannual, decadal, and century time scales being of most immediate importance to society. Knowing how a region's climate has varied in the past provides a baseline against which future regional climate change can be compared.

Analysis of the Mid-Atlantic Region's climate shows that variations have been considerable. For example, each year in the 1960s was cool and very dry, while the 1970s possessed a more variable temperature regime, but were very wet. Other decades, such as the 1980s and first half of the 1990s, were distinguished by relatively extreme year-to-year variation in all climate variables. These interannual and decadal climatic variations were closely associated with the atmospheric circulation over the region, and were also related to United States and global variations. Longer time scales of climate variation for the Mid-Atlantic Region are only crudely documented and understood, but some facts are known. For instance, the 1960s appear to have been the driest decade of the last few centuries, while the extreme interannual climate variation of the 1980s and 1990s are not unprecedented.

Despite its ecological and socioeconomic importance (and the concentration of climatologists that live in the region), the Mid-Atlantic Region's climate variation is surprisingly poorly understood. Yet, to determine if climate is changing, and to discern how climate affects the region's ecosystems and society, it is crucial that such an understanding be improved. Thus, more research is needed on interannual, decadal, and century-scale climate variation of the Mid-Atlantic Region. Specifically, research that promotes clearer answers to the following questions should be addressed:

- Is the Mid-Atlantic Region climate becoming warmer or cooler, wetter or drier, or more variable or extreme?

- Are these trends consistent with trends observed in other regions or globally?

- Are these trends unusual? That is, are these trends consistent with previous variations experienced in the region, or are they suggestive of human-induced climate change?

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PROJECTING CLIMATE CHANGE, BY ERIC J. BARRON

A. INTRODUCTION

To what extent will the human-induced increases in greenhouse gases and atmospheric aerosols influence future climate? The answer to this question has become linked to issues of economic vitality and national security because of potential impacts from climate change on natural ecosystems, agriculture, water resources, human health, energy utilization and human migration. The record of observations based on meteorological instruments is too short to determine the degree to which humans are responsible for the general warming trend over the last century. The only recourse to answer this question is to construct mathematical models of the Earth system and attempt to predict future change. Climate models are the principal tools available to predict how the climate will respond to increases in greenhouse gases. These models point to significant global warming, with large changes in the continental water balance, over the next decades and centuries. In every case, the climate models suggest that the familiar global and regional environments on which society has come to depend are in danger of changing. Many of the predictions imply serious stresses on society and have prompted discussion of sometimes costly mitigation and adaptation response measures. Are the predictions of climate models accurate enough to warrant such measures?

The complexity of the climate system is a major obstacle to predicting the details of future climate change. Neither the physical relationships described by climate models nor the available climatological observations are sufficient to project with certainty how climate will change. Consequently, society is left with a difficult decision. What steps should we take when the best predictions from state-of-the-science models suggest that climate change due to human activities will be large and significant, yet the predictions themselves have large uncertainties? The scientific debate over these uncertainties has truly entered the public arena, providing considerable confusion even in cases where the conclusions from climate models are robust. To be useful for policy development, the degree of certainty associated with the different elements of climate predictions must be evaluated and ranked. The credibility of the full range of climate model predictions must be described in order to elucidate the aspects of climate model predictions that are highly uncertain as well as those that are robust. Such an analysis not only guides policy development but focuses attention on the areas of research that are most likely to benefit society. Accurate long-term climate forecasts would most certainly have tremendous economic value.

B. A FOUNDATION FOR DISCUSSION

Many aspects of future global change, and particularly the topic of global warming, are far less controversial in scientific circles than they are in public discussion. For each of the following seven points there is no real credible debate or controversy. These points, which are based on a spectrum of scientific investigations, provide foundation and context for discussions of future climate change.

First, laboratory experiments demonstrate that greenhouse gases– also referred to as radiatively important gases– absorb and re-emit energy in the infrared wavelengths emitted by the Earth's land, oceans, and clouds. The most important of these so-called greenhouse gases are water vapor, carbon dioxide, methane, and nitrous oxide.

Second, because of their infrared absorption, increased concentrations of greenhouse gases exert a global warming influence. The role of greenhouse gases as agents to promote warming is not in question; rather the issues of uncertainty involve only the timing and the magnitude of the warming.

Third, the atmospheric concentrations of carbon dioxide, methane, nitrous oxides, and chlorofluorocarbons are significantly above their pre-industrial levels. These increases can be tied directly to human activities involving fossil fuel consumption, deforestation, agriculture, and some industrial processes.

Fourth, carbon dioxide levels are now about 30% above pre-industrial levels. A draw-down of carbon dioxide to near its pre-industrial level would take centuries even if emissions were substantially reduced in the near future. This conclusion stems from the fact that the sinks (e.g., deep ocean) for carbon dioxide operate on long time scales. In addition, since substantial reduction in global carbon dioxide emissions below current levels is unlikely over the next decades, atmospheric concentrations of carbon dioxide are expected to continue to increase.

Fifth, atmospheric aerosol (dust and soot) concentrations are also significantly increased in source regions over pre-industrial levels. The primary natural sources include windblown dust, hydrocarbons from vegetation and forests, and soot from forest and grassland fires. Increased aerosol concentrations are also found downwind from regions of high fossil fuel combustion and biomass burning.

Sixth, laboratory and atmospheric measurements demonstrate that sulfate aerosols from volcanic eruptions and from fossil fuel combustion exert a cooling influence on the climate. However, the magnitude, trends, and extent of induced cooling effects are uncertain.

Seventh, global average surface air temperatures are about 0.4-0.6°C (~ 1°F) higher than average temperatures in the nineteenth century. Because of natural variations in climate, this warming cannot yet be attributed definitively to human activities. Although, recently the Intergovernmental Panel on Climate Change (1996) agreed that there is a discernable effect of anthropogenic greenhouse gases on climate.

These seven conclusions indicate that scientists have a strong basis for stating that human activities are modifying the energy balance of the Earth system. The uncertainties center on the magnitude, timing and distribution of the associated climate changes. It is these three characteristics of climate model predictions that are the subject of considerable debate.

C. CLIMATE MODEL PREDICTIONS FOR THE FUTURE

Mathematical simulations or models of the atmosphere and ocean systems are the primary tools used to predict the future response of the climate system. The most sophisticated models are called General Circulation Models (GCMs), which attempt to include a comprehensive treatment of the physics that govern the behavior of the atmosphere and oceans. These models are designed to calculate changes in the winds, temperatures, pressures and moisture budget given a specific set of "external" boundary conditions. External boundary conditions represent any specified variable, like the position of the continents, the amount of energy received by the sun, or the composition of the atmosphere. The power of these models lies in their ability to simulate systems that are too complex for simple, intuitive reasoning. The models are not without limitation. Obviously not every molecule of the atmosphere can be incorporated into a model. Since they are computationally very intensive, many simplifications are employed– one of which is to simulate the climate at a very coarse spatial resolution (for example the Susquehanna River Basin may be represented by only one or two grid points in a global climate model). In other cases, complex relationships such as the characteristics of land vegetation are turned into simple functions designed to approximate these relationships. The key is to incorporate all of the critical processes and feedbacks, while maintaining a tractable model.

We have a growing number of independently derived GCMs. These models have become the basis for intercomparisons as a means of evaluating the potential range of future climate change. More and better observations are available to test the capabilities of the model predictions and, with increased knowledge about how the climate system operates, we can provide a more critical assessment of climate model predictions. Figure 3 provides the range of predicted changes in global-mean surface temperature for the next eighty years from seven different GCMs, each assuming an increase in carbon dioxide of one percent per year (the standard scenario for the Intergovernmental Panel on Climate Change). Figure 4 gives an example from one model (Manabe and Stouffer, 1994) of the increase in annual-mean global surface temperatures predicted for a doubling of the present day amount of atmospheric carbon dioxide 50 to 100 years from now. This figure shows the coarse resolution of the global model predictions, while suggesting that the Mid-Atlantic States will be 4 to 5°C (7-9°F) warmer than at present. The predicted change is large. For context, the summer heat wave of 1988 was less than 1°C warmer than average in the Mid-Atlantic Region.

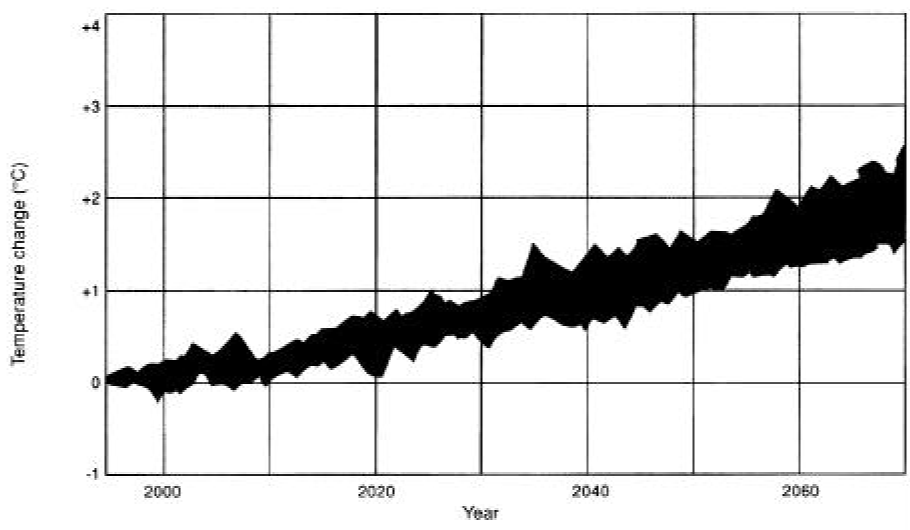

Figure 3. The range of predicted changes in global-mean surface temperature, in degrees C, for the next eighty years, shown as a band bounded by the upper and lower extremes of seven different GCMs, each of which assumed an increase of 1 percent per year in CO_2

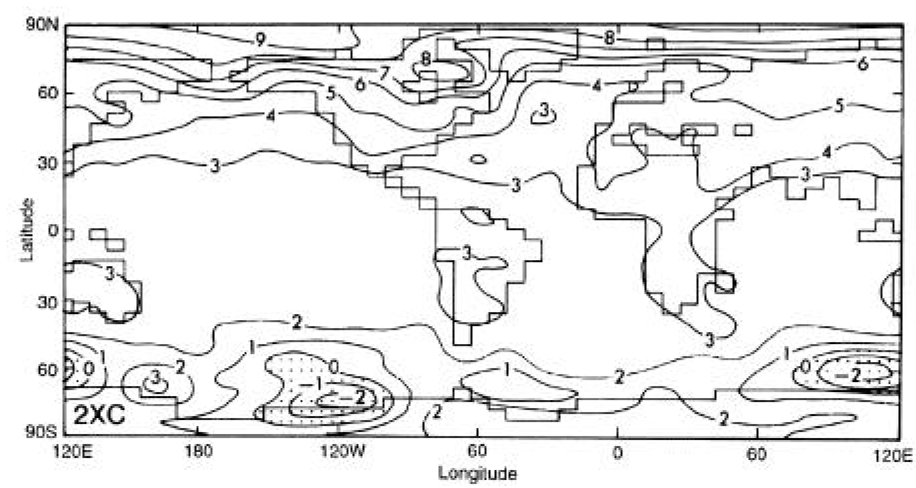

Figure 4. An example of the expected geographical distribution of an increase in annual-mean global surface temperature that would result from a doubling of the present amount of CO_2 in the atmosphere. Contours are in degrees C. From the GCM simulation of S. Manabe and R.J. Stouffer, Journal of Climate, vol 7, pp 5-23, 1994, with permission of the American Meteorological Society.

Predictions from GCMs are imperfect because they are limited by our knowledge of natural variability, our inability to predict future greenhouse gas and aerosol emissions accurately, the potential for unpredicted or unrecognized factors such as volcanic eruptions or new or unknown human influences, and our incomplete knowledge of the climate system. With this point in mind a large group of climate modelers gathered (USGCRP, 1995; Barron, 1995) to assess the levels of certainty associated with climate model predictions. The intent was to provide a list, ordered by degree of certainty, assessing the major policy-relevant predictions of climate models. This list, of necessity, is consistent only with known facts and is based only on the “best” current knowledge. Such a list also must include assumptions on the rate of growth of greenhouse gases. In this case, a scenario of a 1% per year increase in the concentration of carbon dioxide is assumed, which mimics the radiative forcing of the projected increase in the concentrations of all greenhouse gases.

The ordered list presented below is characterized in terms of probabilities, as virtually certain, very probable, probable and uncertain.

<u>Virtually Certain:</u>

(1) The increases in carbon dioxide and the decreases in stratospheric ozone will result in a large cooling in the upper atmosphere.

<u>Very Probable:</u>

(2) The global mean surface temperature will increase between 0.5 to 2.0°C (0.9 to 3.6°F) over the period of 1990 to 2050. The best estimate for a climate change resulting from a doubling of pre-industrial carbon dioxide is a warming of 1.5 to 4.5°C, with 2.5°C being the most probable estimate. The estimated warming will be reduced if sulfur emissions are not controlled and the actual temperature change may even be outside the range described here if natural climate variations are large.

(3) A warming of the surface temperature of the globe will lead to an increase in global average precipitation because evaporation rates are closely tied to surface temperature.

(4) Northern Hemisphere sea ice will be reduced. Changes to the Southern Hemisphere are less certain.

(5) Arctic land areas should experience amplified wintertime warming associated with the reduction in land surface snow cover.

(6) Global warming will influence sea level. The most reasonable estimates are a sea level rise of 5 to 40 centimeters by 2050, compared to a rise of 5 to 12 centimeters if the rates of rise over the past century continue. These estimates ignore the long-term response of the ice caps or any potential catastrophic collapse of the West Antarctic ice sheet, which are the subjects of considerable debate.

(7) Solar variability over the next 50 years will not induce a prolonged climate forcing that is significant in comparison with the effects of the increasing concentrations of carbon dioxide and other greenhouse gases.

Probable:

(8) Summer Northern Hemisphere mid-latitude continental dryness will increase.

(9) The increase in the amount of atmospheric moisture will produce regions of higher rainfall, including at high latitudes.

(10) Some regions may experience warming that is smaller than the global average, particularly in oceanic regions where surface waters are mixed downward or where deeper waters upwell.

(11) Historical records suggest that a few explosive volcanic eruptions are likely to occur during the next half a century. These transient events will result in some short-term relative cooling.

Uncertain:

(12) There is the potential for multifaceted and complicated, even counterintuitive changes in climate variability, hence predictions of changes in climate variability are uncertain. This aspect of climate change includes many possibilities, such as changes in winter storminess, changes in El Niño frequencies, and variations in thunderstorms.

(13) At present, there is only very limited capability to estimate how the climate of various regions will respond, although regional scale (from the scale of large metropolitan regions to the scale of states) changes are likely to be different from the global average changes.

(14) An increase in tropical storm intensity is plausible due to higher sea surface temperatures associated with global warming; however, there are too many unresolved issues to be certain.

(15) The details of climate change over the next twenty-five years are also uncertain. Uncertainties in the factors that control natural variability, in the model simulations, and in the changes in atmospheric chemistry make it extremely difficult to predict or even suggest decade-to-decade changes in climate. In any given decade, the changes in temperature and related variables could be substantially less than or more than the trend predicted by a climate model. Warming estimates in terms of degrees per decade and their use to analyze a single decade are unwarranted and misleading.

(16) Climate-biosphere feedback relationships may modify the magnitude of climate change. Whether the feedbacks will amplify or moderate climate change is not known.

The level of confidence in the results of climate model simulations depends very much on time scale and spatial resolution. Note that the greatest confidence is assigned to ranges predicted for the Earth as a whole and for the longer time periods over which greenhouse gases will double. Regional predictions and projections on a decade-by-decade basis are far less certain. Equally important, simulations of phenomena at very high resolution, such as the formation of hurricanes, are also less certain. A direct implication of this assessment is that uncertainties grow at the critical boundary where climate models intersect policy– at the spatial and temporal resolution of climate impacts on human and ecological systems. Yet the predictions by climate models are suggestive of substantial change with large impacts.

D. OPPORTUNITIES FOR REDUCING UNCERTAINTIES

The ranked order of the assessment of climate model capabilities provides a framework for focusing national and international research efforts. Over the last few decades, progress in reducing uncertainties in climate model predictions is clear. However, the issues and problems highlighted above are in many cases quite complex or require long-term consistent measurements in order to reduce current uncertainties. For these reasons, significant reductions of uncertainties in projecting changes and trends in climate will require sustained efforts that are very likely to require a decade or more. Much of the research effort of the U.S. Global Change Research Program and related or partner international programs are designed to address uncertainties in cloud-radiation-water vapor interactions, ocean circulation, aerosol forcing, natural climate variability, land surface processes, including vegetation changes and chemical cycling, the frequency and intensity of extreme, high impact events such as hurricanes, the potential for surprises, and the interaction between chemistry and climate. Several areas have been identified as priority research topics with substantial potential to reduce uncertainties over the coming decades.

(1) Many of the uncertainties associated with climate models can be attributed to their coarse spatial resolution. At higher resolutions, storms and circulation patterns are much better represented. Improvements in weather forecasts suggest that intensified efforts to tailor global predictions to specific regions using both finer-scale models and empirical techniques will lead to significant improvements in assessing regional vulnerability to climate change.

(2) Climate changes at the surface can be better represented by including significantly better representations of the boundary layer between the atmosphere and the surface and of vertical motions associated with features like thunderstorms.

(3) Substantially improved observations and representations of water vapor, a major greenhouse gas, will reduce a major source of uncertainty in model predictions.

(4) Improvement of the linkages that couple the atmosphere, ocean, and land surface will result in better and more comprehensive simulations.

(5) Better representation of the land surface, including vegetation, soil characteristics, and carbon dioxide and ozone effects on plant function, will reduce uncertainties in estimates of soil moisture, summertime continental drying, and in regional climate change.

(6) The development of new data sets and expectations for new, long-term, consistent observations from NASA's Earth Observing System, the European Space Agency and the Japanese Space Agency, as well as current efforts to compare the full spectrum of climate models, suggest that model comparisons against observations and other models can accelerate the rate of model improvement.

(7) Successfully demonstrating the capability of models to simulate climates different from the present day (i.e., past climates) would contribute substantially to our confidence in model predictions.

(8) Changes in the concentration of non-greenhouse gases, in vegetation, and in aerosols may indirectly influence greenhouse gases. Improving the representation of these processes in climate models should improve prediction of climate change by incorporating the indirect mechanisms that influence the earth's energy budget.

Progress is occurring on all of these fronts, and research on these topics is already yielding information of use in regional climate change assessments, which will help in assessing climate change for the Mid-Atlantic Region.

E. HIGH-RESOLUTION PREDICTIONS OF FUTURE CLIMATE CHANGE

The coarse resolution of GCMs is identified as one of the major drawbacks for regional assessments. For this reason, the development of high-resolution predictions is identified above as a priority research opportunity. This importance of high-resolution predictions is most clearly illustrated by considering precipitation. If a GCM has a spatial resolution in which each model point is nearly the size of Pennsylvania, convective precipitation (thunderstorms) or frontal systems are not going to be well represented. Two innovative procedures allow us to use coarse resolution climate model predictions to overcome this problem and assess the potential climate impacts in specific regions of the globe. The first technique, nesting of model grids, couples global models with higher resolution regional models. The second technique, downscaling, relates particular states of the GCM atmosphere to specific patterns of weather at a regional level.

In model nesting, the GCM is used to compute the global circulation under conditions different from today, for example higher carbon dioxide levels. Then the results of the GCM (temperature, pressure, winds, moisture) are used to drive a high-resolution climate model over a limited area. The high-resolution model includes a better representation of topography and of numerous physical parameters. The promise of this technique is demonstrated in Figure 5, in which the United States precipitation observations for spring 1980 (Figure 5a) are compared first with the prediction from a GCM (Figure 5b) and then with the prediction from a higher resolution model nested within the GCM (Figure 5c).

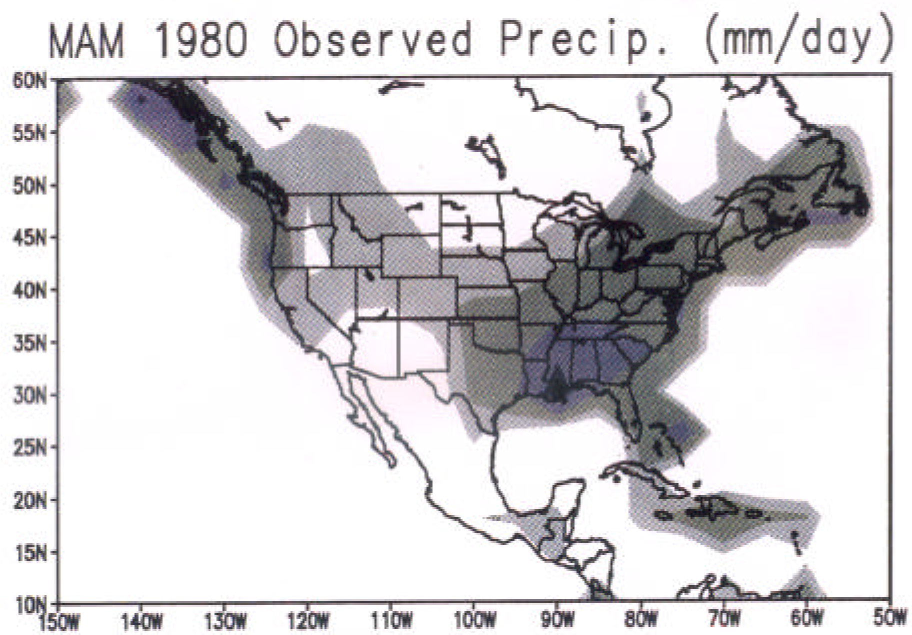

Figure 5a. March, April, May 1980 observed precipitation.

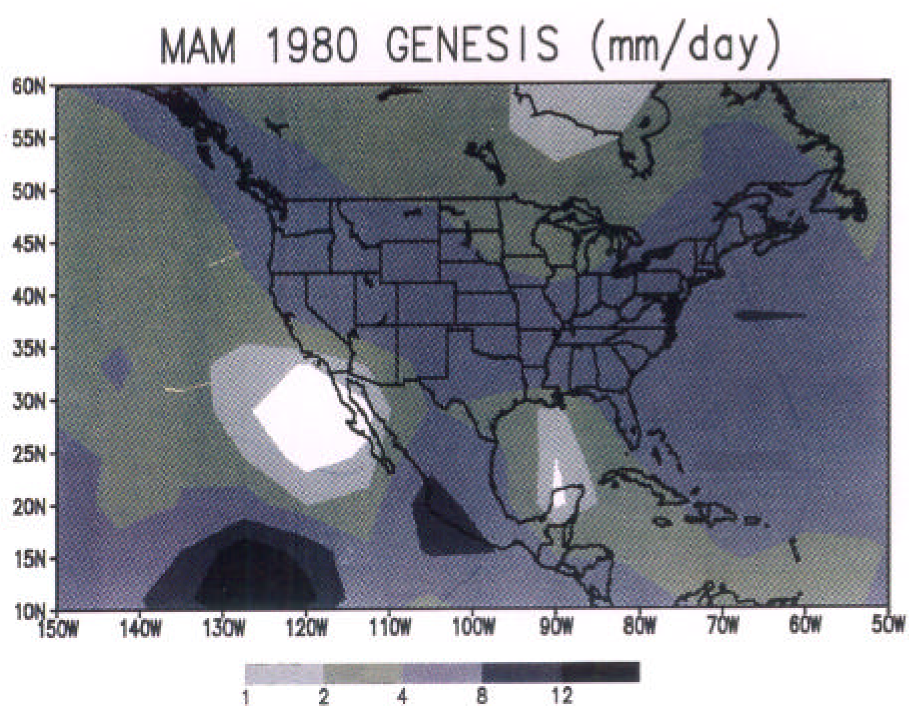

Figure 5b. March, April, May 1980 GCM predicted precipitation.

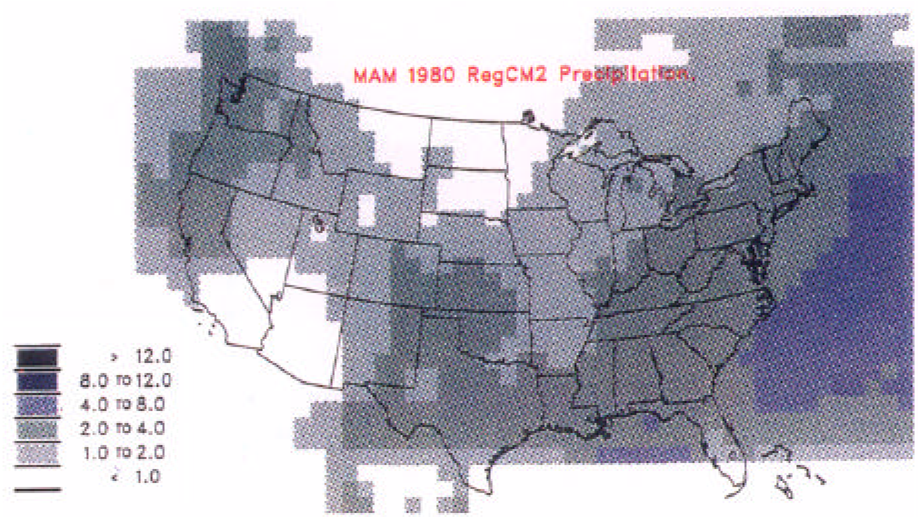

Figure 5c. March, April, May 1980 nested GCM-mesoscale model predicted precipitation.

In Figure 5b, the GCM's coarse resolution is clearly evident by its failure to produce much of the detail for the United States precipitation pattern. In Figure 5c, the results from the same GCM simulation are portrayed, but the U.S. precipitation is derived from the higher resolution model nested within the GCM. The high-resolution model has a horizontal resolution of 108 km. The improvement is dramatic. The nesting technique can also be employed using several nested grids at 36km, 12km, and 4km resolution. A proof-of-concept experiment compared predictions of a single storm passing over the Mid-Atlantic Region, in which the high-resolution model is driven by observations at the boundary, and then the high-resolution model attempts to reproduce the observations. The match is excellent. This same technique of nesting has provided a higher resolution prediction for a doubled carbon dioxide planet. In this experiment, the Mid-Atlantic Region is characterized by a substantially wetter winter (DJF-December, January, February) under higher carbon dioxide conditions, but a very similar pattern of summer (JJA - June, July, August) precipitation. Such results must be viewed with caution, as the technique is still under critical evaluation. As yet an appraisal of strengths and weaknesses of this technique remains a research topic.

The second technique (downscaling) assumes that the GCM is providing reasonable large-scale predictions. Using empirical relationships derived between the observed large-scale circulation and the temperature and precipitation in a region, the analysis predicts regional climate. The formulation can be optimized by writing a model that "learns" from trying repeated examples. Using this technique specifically for the Susquehanna River Basin, Penn State researchers Robert Crane and Bruce Hewitson found increases in precipitation under conditions of higher atmospheric carbon dioxide. Only March had lower precipitation in comparison with present conditions. The largest increases were in May and June.

The two techniques described above employed different GCMs and were very different in terms of resolution and focus. Although still in their infancy, these techniques have potential for translating global climate predictions to resolutions useful in developing policy and examining human systems.

F. SUMMARY AND CONCLUSIONS

Three major conclusions are evident from this examination of the capabilities of climate models. First, the radiative properties of greenhouse gases are well known, the concentrations of these gases are increasing due to human activities, and these increases should result in some global warming. At issue is not the fact that increases in greenhouse gases will force climate change, but rather the magnitude and timing of the climate change. Second, the degree of certainty associated with the results of climate models is a strong function of both spatial and temporal detail. The greatest certainty is associated with ranges given for global predictions. Regional predictions, predictions on a decade-by-decade basis, and predictions of higher resolution phenomena, such as hurricanes, are associated with much greater uncertainty in GCMs. This spectrum of confidence associated with the level of detail that is predicted provides a reasonable guide to policy decisions. Third, substantial opportunities, given consistent and long-term research efforts, exist for improving climate model predictions. These opportunities include efforts to enhance spatial resolution, to improve coupling of the components of the climate system, and to better represent some of the indirect effects of climate change. The nesting and downscaling techniques illustrate the potential of applying these approaches to assessments for specific regions, such as the Mid-Atlantic Region.

The sense of the climate model simulations, while recognizing the uncertainties, is one of significantly higher mean annual temperatures for the Mid-Atlantic Region under doubled carbon dioxide conditions, with increased precipitation in winter. Changes in summer precipitation appear less certain. The pattern of winter precipitation in the Northeast appears to be significantly different, but summer precipitation patterns appear similar to the present day. Of course, with higher temperatures, evaporation rates will also substantially increase.

Much additional research is required to assess changes in the nature of natural variability under higher carbon dioxide conditions, analyze the full spectrum of hydrologic variables, compare a variety of climate model results and improve the coupling of atmospheric models with other components of the Earth system. Future efforts must be directed towards the research and analysis that are critical for linking climate prediction to human endeavors.

Interestingly, the current focus on the policy relevance of climate models has largely been negative: a view that climate models are far too uncertain to be used in setting costly economic or national security policy. Certainly, the scientific debate over these uncertainties has resulted in considerable confusion even where the conclusions from climate models are robust. This section helps define the degree of certainty associated with all the different elements of climate predictions in order to provide a more useful basis for policy decisions. However, the current focus on climate models as potential drivers of costly national policy is one-sided.

Accurate long term climate forecasts could also have tremendous economic value, as shown by recent use of improved forecasts in limiting the impact of El Niños on food production and fisheries in developing countries. More accurate predictions may lead to warnings if associated with societal vulnerabilities, and will clearly contribute to economic vitality.

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CHAPTER 2: IN WHAT WAYS IS THE MID-ATLANTIC REGION ESPECIALLY VULNERABLE TO CLIMATE CHANGE AND VARIABILITY?

A. INTRODUCTION

Today's climate, including heat waves, cold spells, floods, droughts, severe storms, and other phenomena, helps determine how individuals, societies, and ecosystems function. The human and natural worlds generally adapt to the prevailing climate and to climate change, particularly if change is gradual. In the coming years, natural climate variation and human-induced climate change may place increased or new pressures on natural systems, human communities, and individuals. Even if climate change presents a more benign future, climate may be profoundly different, thereby demanding costly adaptations. The risks of and possible adaptations to climate variation and change are difficult to assess because it is unclear when, where, and how climate change will be manifest. Effects on primary production (agriculture, forests, fisheries), the economy, water resources, human health, recreation, and the occurrence of natural hazards are virtually certain, although the magnitude (and sometimes the direction) of these effects remains uncertain.

This uncertainty is especially large at the regional and daily-to-annual scales, precisely the space and time frames in which most decision-makers operate. Although they account for the known, tangible socioeconomic and environmental stresses that exist today, many decision-makers also need to consider the uncertain, abstract threat of climate change. Decision-makers who know that climate influences their operations should find out if and how climate change might affect present and future problems in their jurisdiction. They need to know what climate impacts are possible, who is vulnerable to these impacts, and how possible adaptation measures might reduce impacts and vulnerability. They must assess the availability and costs of alternative adaptation strategies and consider their priorities for implementation.

This chapter explores the Mid-Atlantic Region's vulnerability to climate impacts, in the context of issues such as economic growth, water resources and human health. The next chapter considers possible regional adaptation strategies for reducing negative impacts and taking advantage of opportunities created by climate change. It is followed by a chapter on what we still need to learn so that the region's citizens can make effective decisions in the face of climate change. The concluding chapter summarizes what we know about the potential for Mid-Atlantic climate impacts, what we need to know, how to make sure research results are useful to the region's decision-makers and accessible to them, and plans for the next steps.

Sensitivity, adaptability, and vulnerability

The impacts of climate variation and change are a function of a system's or an individual's sensitivity, adaptability, and vulnerability. *Sensitivity* indicates the degree to which a system is responsive to a variation or change in climate. For example, Mid-Atlantic states' ski resorts are sensitive to within-winter and year-to-year variations in snowfall. It is possible that climate change will mean shorter snow seasons on average and more years with no appreciable snowfall. Thus, these resorts are sensitive to the impacts of climate change. *Adaptability* defines the extent to which individual or systemic adjustments are possible in response to climate variation or change; such adaptations can be reactive or planned. For instance, Mid-Atlantic Region temperatures are still low enough during most winters with low snowfall to permit regional resorts to produce artificial snow. Such an adjustment is planned. If future winter temperatures were to become too high, this technical adaptation would not work. *Vulnerability* delimits the extent to which climate may damage or harm individuals or systems. Vulnerability depends on both sensitivity and adaptability. To complete the skiing example, the most vulnerable ski resorts are those that are especially sensitive to snowfall variations or that cannot adapt by making snow (e.g., the owners cannot afford snow-making machines, or the organizational structure prevents management from reacting quickly enough to climate).

In 1995, the Intergovernmental Panel on Climate Change (IPCC) Working Group on Impacts, Adaptations, and Mitigation of Climate Change concluded:

- Climate impacts are difficult to establish and quantify at the regional scale because model projections are too coarse and uncertain.
- If future climate variations extend beyond documented impacts of past climate variations, then it is likely that actual impacts will include surprises.
- Most systems are sensitive to both the magnitude and rate of climate variation and change.
- Climate variation and change add an important stress, especially on individuals and systems that are most sensitive and least adaptable to climate.
- Most systems are subject to multiple climatic and non-climatic stresses.
- Vulnerability increases as adaptive capacity decreases.
- Successful adaptation depends on technological advances, institutional arrangements, availability of financing, and information exchange.
- Enhanced support for research and monitoring is essential.

B. POTENTIAL IMPACTS OF CLIMATE VARIABILITY AND CHANGE IN THE MID-ATLANTIC REGION

Some potential impacts from climate change cut across many of the region's resources or sectors. (For this discussion, sectors include fresh water, coastal areas, human health, agriculture and forestry, industry and commerce, and related activities such as recreation.) The major cross-cutting issues are economic growth and ecosystems. What we know about vulnerability to potential cross-cutting impacts is described first, followed by a discussion of vulnerability for specific sectors.

Economic growth, industry and commerce

Economic growth is broadly defined as the change in the region's overall level of economic activity (as measured by incomes, spending, or the number of jobs). Because it occurs over time, economic growth is a dynamic process. Catalysts include population growth, investment, increases in skilled and educated labor, technological innovations, improvements in productivity, institutional innovations, and changes in government policies.

Sometimes outside forces alter the basic structure of an economic system. The speed of and expectations about these structural changes are important. Growth is most dramatically affected by relatively quick and unexpected changes (e.g., a hurricane) because it is difficult to adapt fully in a short period of time. In addition, immediate adaptation may require that resources be reallocated away from productive, growth-enhancing uses. On the other hand, slow and expected change (e.g., a rising sea level) allows for gradual adaptation with only a slight impact on growth.

Adaptation not only mitigates damages (or exploits benefits) resulting from structural changes, it often fuels the development of new innovations and also may provide firms with incentives to look for more efficient ways to operate under current technology. In turn, innovations and increased efficiency in production are likely to spur economic growth. Thus, while climate change may adversely affect the status quo, society is capable of adapting to take advantage of new opportunities as they arise.

Climate change will undoubtedly influence economic growth in the Mid-Atlantic region. This workshop did not address regional effects of national and international policies to reduce global greenhouse gas emissions. Instead, its focus was on how the region might be affected if scientific projections of climate change are realized. However, the potential economic impacts are largely uncertain. Because the Mid-Atlantic region is not a closed system, it is difficult to predict future growth patterns. Prediction becomes even more difficult when the uncertainties of climate change are considered. Any economic impacts would be the result of changes in this region's climate as well as relative to other regions. Adaptation may require a reallocation of production and trade practices across regions and may influence people's migratory patterns, depending on changes in the region's climate relative to other regions. In addition, policies in effect elsewhere may influence adaptation and growth in the Mid-Atlantic region. For example, beach protection and restoration projects in the Carolinas could induce emigration from Mid-Atlantic beaches to avoid the impacts of a sea level rise. In this case, tourism would decline in the Mid-Atlantic, reducing growth for the region. Alternatively, economic growth would increase if the Mid-Atlantic region became a relatively more desirable place to live as a result of climate change.

Gross domestic product (GDP) in the Mid-Atlantic region has increased steadily over the past several decades. Investment along with increases in a skilled and educated work force are likely to be the most important economic growth forces in the region, as evidenced by the fact that the finance, insurance, and real estate (FIR) sector, services, government, and manufacturing are the largest current contributors to GDP in the Mid-Atlantic region (U.S. Department of Commerce). These forces could be influenced by climate change. For example, an increase in natural hazards (such as an increased frequency of hurricanes or flooding) would increase property damage and accidents and thus increase the demand for insurance and payouts. The effects on the insurance industry will depend on how well it can adapt to changing conditions. While rebuilding after a natural hazard may spur economic growth in construction, this would require that resources be reallocated from other uses, potentially slowing economic growth in other sectors.

Other effects on industry and commerce from climate change and variability include how snow, wind, rain, and fog affect the speed and safety of air, land, and water transportation. Weather influences the operation of tourist facilities, mining and construction sites, communications, power transmission, thermal power generation, and water-dependent and other types of manufacturing processes. Roads, bridges, parking lots, buildings, pipelines, power lines, sewers and other private and public infrastructure are constructed for operation in seasonal climatic norms and with specific expectations about the frequency and severity of extreme weather events.

Direct effects of climate change and variation on commerce and industry can be positive and negative. For instance, increased winter temperatures may reduce damage to highways from freeze-thaw cycles yet reduce economic activity dependent on cold weather outdoor recreation. Increases in the frequency and severity of extreme weather events that impair travel, manufacturing, construction, mining, and other activities will adversely affect economic productivity. Infrastructure costs may also increase as buildings, roads, bridges and other structures are constructed to withstand more extreme weather.

Real estate markets could be negatively affected by a rise in sea level resulting from climate change. Manufacturing dependent on water availability or having carbon emissions could be negatively influenced by climate change if water becomes more scarce or if government policy becomes more stringent with respect to carbon emissions. However, manufacturing in the region may actually benefit if it becomes relatively more costly to operate in other regions as a result of the same influences.

Industrial and commercial activities with forward or backward market linkages to climate-sensitive sectors are also potentially vulnerable to climate change and variation, particularly electricity and fossil fuel production. Increases in summer temperatures increase the demand for electric power for cooling, while increased winter temperatures reduce the demand for heating. Depending on the net effect, the demand for fossil fuels and optimal power generation capacity may increase or decrease.

How climate change and variation will affect industry and commerce in the region depends on the direction and pace of change, the vulnerability of these sectors in the region, and the pace and impact of adaptation. Although these sectors are generally considered to be less vulnerable and more readily adapted to climate change than natural resource-based activities such as agriculture, fisheries, forestry, and natural ecosystems, current understanding of vulnerability is extremely limited.

Agriculture, forestry, and fisheries are more likely to be directly affected because their productivity directly depends on climate. Impacts to these sectors are more likely to affect economic growth in rural areas where these industries are important (e.g., in southern Maryland where watermen harvest oysters, crabs, and fish from the Chesapeake Bay). However, the growth impacts for the region as a whole are likely to be small because agriculture, forestry, and fisheries combined contribute less than 1% to the region's GDP (U.S. Department of Commerce). In addition, producers and consumers will adapt (to some extent) to any change that occurs. For example, agricultural adaptations may include switching to crops better suited to the new climate, altering the growing season, or changing pesticide usage. Input and output markets could be influenced as a result, altering prices and possibly influencing growth. New policies could be implemented to help mitigate damages. Ultimately, management practices, market responses, and policies will determine economic impacts.

Ecosystems

Ecosystems in the Mid-Atlantic Region will continue to be affected by climate variability as well as by the stressors accompanying economic development and changes in land use and land cover. Climate change may exacerbate some of these trends. Changes in average temperature and precipitation as well as increased frequency of extremes in climate variability (unusually wet or dry periods, unusually hot or cold spells) may overwhelm the resiliency of particular species of plants or animals. Their loss may be replaced by exotic species, but the characteristics of the ecosystem will be different both during the transition period and when the area approximates a new equilibrium.

For example, projected increases in global temperatures are expected to move the range of forest types northward, so that the Mid-Atlantic Region could have fewer sugar maples, and perhaps more of other species, such as southern pines. Such a change is expected to affect the region's bird populations, as migration corridors are disrupted when some tree species die off faster than suitable replacements grow. Dieback of forest prior to repopulation by species adapted to a new climatic regime could have other impacts on wildlife, forestry, and terrestrial hydrological processes. Changes in fire regimes and pest populations could similarly affect the natural and economic value of forests, causing impacts in recreation, hunting, and fishing in woodland streams. Forest fragmentation could be a major impediment to species migration and forest regeneration after dieback. Because of their role in pollination, changes in insect and bird populations could decrease agricultural productivity.

For freshwater streams and lakes, climate changes would affect runoff (and thus erosion, sedimentation, and pollutant transport), the magnitude and frequency of high and low flow events, stream acidity, and oxygen availability. Projected increases in intense precipitation events will scour stream banks, decreasing the reproductive success of aquatic insects (which serve as food for fish as well as birds and waterfowl) and of fish that lay eggs near the edges of streams. This currently happens when there is an intense rain event during the critical reproductive period, but the relative infrequency of stream scouring gives the susceptible populations time to recover. More severe and frequent extremes under climate change could cause some local extinctions, with repercussions for predators of the lost species. Increases in intense precipitation also are likely to flush more contaminants into streams, adversely affecting sensitive species.

Warmer winters could lead to more abundant insect pest populations. This may be offset by larger populations of predators such as warblers and the eastern phoebe, which might have an expanded range due to milder January temperatures.

For coastal ecosystems, climate variability and change could alter the frequency and magnitude of storm surges, alter the volume of freshwater inflows, change temperature and salinity, increase sea level and thus lose marsh habitat to flooding, and increase anoxia (lack of dissolved oxygen) and eutrophication (excessive fertilization of aquatic ecosystems). All of these could affect species composition and reproduction, affecting the commercial harvest of aquatic resources as well as recreation and tourism.

Many of the same human and climatic effects as in the coastal and freshwater areas would occur in wetlands and riparian zones. Many of these areas already are stressed by drainage and restoration of wetlands.

In forested areas, climate change could affect fire frequencies, pest ecology, species dominance, secondary wildlife effects, soil processes, and forest productivity.

Relic landscapes are an important feature of the Mid-Atlantic Region, contributing to erosion and sedimentation, acid mine drainage, disruption of ground water, and suppression of natural ecological succession. Climate changes affecting precipitation and runoff could exacerbate these problems as well as change potentials for land restoration.

The workshop's discussion group on this topic noted that ranking of ecosystem impacts would be "very difficult" at best; subjective value judgments would make such a ranking almost meaningless. For example, there are huge uncertainties associated with the non-market valuation of the resources in the region. However, it is clear that some ecosystems may have greater economic value to society than others; relict ecosystems might have lower or even negative value.

Uncertainty associated with the available regional predictions of future climate change make it difficult to specify, at this time, the greatest ecological vulnerabilities to climate change. Based upon a dynamic forest model driven by output from five different global circulation models (GCMs), one view was that the net impacts on forest would be negative. All of these GCMs indicated a decrease in the availability of moisture during the growing season. Recent Penn State downscaling research indicates that the region may actually experience an increase in precipitation and a less dramatic increase in temperature relative to the results from earlier GCMs. Furthermore, the omission of the climatic effects of aerosols in the earlier GCMs also may have significant implications for the use of these GCMs in ecosystem modeling. The discussion group agreed that there is significant uncertainty in the predictions of future climate and that even the sign of climate change is not clear at a regional level.

The group also perceived significant uncertainties in our knowledge of the current state of the region's ecosystems. It may be more possible to identify the types of regional vulnerabilities that exist rather than the magnitude of those vulnerabilities.

Water resources and water quality

Recent climate variation has produced a moisture regime in the Mid-Atlantic that has varied dramatically, as described in Chapter 1: Setting the Stage. The 1960s was perhaps the driest decade in centuries, while the 1970s may have been the wettest. In the recent years, the region not only suffered significant droughts (1986, 1988, 1991, and 1995), but also experienced record snow packs (1996) and rainfall totals (1996), local flash floods (1996), and region-wide billion-dollar floods (1996). Model projections of greater climate variability and a more active hydrologic cycle mean that variations in water will be fundamental parts of climate change. Recent hydrologic variation could be an early expression of climate change.

Climate-induced variation in hydrology creates havoc for the region's water users, from agriculture to industry, and households to institutions. For example, little of the Mid-Atlantic Region's agriculture is irrigated, and drought frequently has significant impacts on yields and income. Significant losses accrued during the short, intense drought of 1995. Ironically, other years can be too wet for farmers in the region to carry out normal, timely mechanical operations, and this excess precipitation can cause crop damage associated with fungus and pests. The very next year after the drought, 1996, produced these problems throughout the region. Furthermore, dry years reduce the dilution of agricultural runoff, while exceedingly wet years and floods release more manure and associated pathogens into the region's waters. Climate change could make the situation worse. For instance, if the future brings more frequent droughts, then farmers will have to consider investing capital in irrigation equipment. Such a switch to irrigation would also require major investments in regional water supply infrastructure.

Regional water supply and demand and their management are also greatly affected by climate variation and may be influenced even more by climate change. For example, drought and water withdrawals could lead to saltwater intrusion in coastal aquifers. Salinity intrusion would be exacerbated by sea level rise. Current water management practices have been developed to adapt constantly to the present range of climate variation, but during recent decades numerous cases of supply problems have been evident. Still, water supplies would probably allow future users to meet their needs if there were no changes in the economic, cultural, regulatory, or climatic environments. However, it is likely that none of these environments will remain static, and that the impacts of economic growth, lifestyle change, and safe drinking water regulations may be as large or larger than the effects of climate change. Successful adaptation of water supply systems to climate change must focus on increasing flexibility through demand management and institutional adaptation. It is important to consider that many technological adaptations to climate change, such as reservoir construction, require large investments and long lead times.

Regional climate change predictions are still uncertain, but climatologists are confident about the likelihood of some changes. Changes in average temperature and, especially, precipitation totals are potentially large. Sea level will rise and more intense rainfall events appear likely. Higher temperatures would increase water demand for irrigation, outdoor domestic use, and cooling; higher water temperatures and altered lake levels and stream flows would have ecological impacts. Coastal zones will be at risk of increased storm losses, inundation, and salt-water intrusion of aquifers. The impacts on runoff, and therefore the region's renewable water supply, are uncertain, but could be great.

Nevertheless, workshop participants expected population, technology, economic conditions, institutions, politics, lifestyle, and the values that society places on alternative water uses are likely to have greater impact on the region's water supply than climate change. Social scientists presently cannot project accurately how these factors will influence water supply and demand over the useful life spans of water projects or the time scales of climate change.

In short, climate has a huge influence on regional hydrology, and water is fundamental to most economic and all environmental systems. Therefore, climate variation and change touch a broad range of water quantity and quality issues.

Agriculture, forestry and fisheries

Most of the land in the Mid-Atlantic region is devoted to the production of agricultural products or is forested. The region includes some of the nation's most productive non-irrigated agricultural lands, and in the Amish of Pennsylvania, a unique agrarian culture. It also includes some of the highest quality hardwood resources in the world. Beyond the direct contributions of commercial agriculture and forestry to income and employment, agricultural and forest lands shape the landscape and provide valuable open space and rural amenities for this highly populated region. They are important resources for outdoor recreation activities and tourism. These lands and the ways that they are used also have significant impacts on water supply and quality, wildlife habitat, and other resources throughout the region.

There has been less integrated climate change assessment research for forestry and fisheries than for agriculture. Changes in climatic variables can directly affect growth and production of crops, livestock, forests and fisheries. For plants and forests these variables include temperature, solar radiation, soil moisture, and atmospheric CO_2; for animals, the direct effects of weather and extreme events; temperature and precipitation also influence fisheries. For agriculture and forests, changes in climate-affected soil processes (e.g., nutrient leaching, salinization, erosion) and in weeds, insects, and diseases that are affected by climate and atmospheric constituents could be important.

Biophysical responses of crops, livestock, forests, and fisheries to direct and indirect effects of climate include both positive and negative effects. Increased CO_2 concentrations would increase the yields of most crops, corn being the only noteworthy exception, and possibly increase the primary productivity of the temperate forests found in the Mid-Atlantic region. For annual crops, increased temperatures tend to speed development but may reduce yields and increase the potential for moisture stress. Warmer temperatures could increase agricultural productivity because of the longer growing season. Forestry growth will increase particularly at the higher elevations because of the longer season, provided there is no water stress. Primary productivity may increase with elevated CO_2 concentrations and nitrogen mineralization rates, again except in drier regions. Increased variability could also adversely affect productivity. For example, season reversal (fuzzy seasons) may have a negative effect on perennial crops (fruit trees, forests) by interrupting winter dormancy. Agriculture and forestry in low-lying areas, such as the Delmarva peninsula, could suffer economic losses and resource degradation due to sea level rise. Warmer temperatures could increase the range of pests for both crops and forests. Increased temperatures may expand the suitable habitat for some commercial fish species but reduce it for others. Extreme weather events can cause severe damage to crops and livestock.

In general, freshwater fisheries in small rivers and lakes are highly vulnerable to large changes in temperature and precipitation; freshwater fisheries in larger rivers and lakes are less so. Globally, marine fisheries are least vulnerable and are not generally expected to be significantly affected by climate change; the vulnerability of estuaries may be less than that of freshwater fisheries but greater than that of marine fisheries. At the regional level, though, estuaries like the Chesapeake could prove to be highly vulnerable to changes in temperature, freshwater inflow, and salinity. The global generalization also may not apply to anadromous species (i.e., species that spend time in both fresh and marine waters), such as striped bass and American shad, which are economically important in the region. In assessing impacts on fisheries and forests, note that economic importance and adaptation options and costs are not necessarily correlated to biophysical vulnerability.

Recreation

Tourism and a wide range of outdoor recreation activities are important to the local economies of the Delaware River Basin and Chesapeake Bay Region. Some of these activities depend directly on temperature and precipitation, such as snow skiing. Others have a less direct relationship. For example, warmer summers might encourage more people to go to the beach. But increases in salinity and temperature in the Delaware and Chesapeake Bays might cause more algal blooms so that the beach experience is less pleasant. These conditions also could foster increases in cholera bacteria, leading to beach closings and subsequent decreases in the patronage of motels, shops and restaurants that cater to people vacationing at the beach. Sea level rise, exacerbated by an increasing number of sediment-trapping dams, will contribute to beach erosion, imposing costs for beach enhancement, erosion control, or from lost vacation revenues in resort locations.

The demand for many forms of outdoor recreation may decline if there is an increase in the number of extremely hot, cold, or cloudy days; outdoor recreation simply is not as much fun when weather conditions are less appealing.

Other recreation effects may derive from ecosystem impacts. For some people, recreational fishing may be less enjoyable when the species mix changes. Current research suggests that climate change will cause a decline in cold-water game fish in the Mid-Atlantic Region. However, research in Pennsylvania found that anglers tend to care more about catching "something" than catching a target species. This suggests that sport fishing in the Mid-Atlantic Region could become more attractive, because total fish populations might increase (even though the species mix would be different than today). However, cold-water fishing may be more economically valuable than cool- or warm-water fishing, and thus be threatened more by warmer water conditions. Habitat changes will also affect hunting; for migratory waterfowl, habitat changes along migratory routes outside the region could affect hunting opportunities even if local habitat changes were to prove less significant. Increasing winter temperatures could pose a threat to the viability of skiing, either through shortened seasons or increased snow-making costs. Other winter sports would be similarly affected: ice fishing, skating, snowmobiling.

Natural hazards/extreme events

Severe storms, floods, drought and heat waves are the principal natural hazards in the Mid-Atlantic Region today; each may become worse with climate change. For example, the enhanced climate variability of the 1990s has included more frequent, powerful, and unusual winter storms and greater snow accumulations and impacts. The January Blizzard of '96 dumped record snowfall throughout much of the Mid-Atlantic. It was followed a week later by a storm with spring-like characteristics, including high rainfall totals and--most important--the ability to melt the thick snowpack in a half day. The resulting flood losses were approximately $1 billion. Two of the region's three biggest floods this century (March 1936 and January 1996) were associated with this scenario. If climate change means more powerful winter storms, greater snowfall accumulations, and more rapid snowmelt, then such floods and their impacts could become more commonplace.

The dozens of heavy thunderstorms during the summer of 1996 contributed to the Mid-Atlantic Region's record precipitation total for the year. For instance, State College, PA received more than 5 inches of rain in 40 minutes on June 17, while Gettysburg, PA had nearly a foot of rain in 10 hours on June 19. Exactly one month later, five western Pennsylvania counties were declared federal disaster areas from a storm that contained 17 tornadoes and caused record flash flooding. More deadly thunderstorms and floods hit the state in August. Localized flash floods from thunderstorms were ubiquitous throughout the Mid-Atlantic and occurred almost daily that summer.

By definition, a natural phenomenon cannot be a hazard unless it intersects with the human world.

Table 4 shows that the region's managed ecosystems and socioeconomic (i.e., human) systems currently under stress are further stressed by the region's weather and climate-related natural hazards. Several socioeconomic forces drive the interaction between these hazards and society. Economic, population, technological, institutional, political, behavioral, and cultural development and change work together to put people and their managed systems in harm's way. For instance, land-use decisions, such as building in one of the region's river valleys, result from the interaction of several socioeconomic drivers. However, building in a floodplain puts the structure and its inhabitants at risk. If a flood occurs, destroying a house and perhaps injuring the inhabitants, then the region's health and emergency services, social services, and insurance systems are stressed.

Table 4. Natural Hazards Impacts on Currently Stressed Managed Ecosystems and Socioeconomic Systems

Managed Ecosystems & Socioeconomic Systems	Droughts	Floods	Severe Weather	Tropical Storms	Heat Waves	Cold-Air Outbreaks	Pestilence/ Infestation
Fisheries	✓	✓	✓	✓	✓		✓
Water Resources	✓	✓	✓	✓	✓	✓	✓
Agriculture	✓	✓	✓	✓	✓	✓	✓
Transportation		✓	✓	✓	✓	✓	
Energy Distribution		✓	✓	✓	✓	✓	
Financial Services	✓	✓	✓	✓			
Government & Private Insurance	✓	✓	✓	✓		✓	✓
Social Services	✓	✓	✓	✓	✓	✓	
Health Services & Emergency Response		✓	✓	✓	✓	✓	✓

The Mid-Atlantic Region's socioeconomic drivers will change as its economy develops, and its population alters in both numbers and location. Social scientists cannot predict the exact trajectory of future socioeconomic systems, but it is certain that these systems will face challenges and stresses. One of these stresses will be weather- and climate-related natural hazards.

Observations have shown that the frequency of severe thunderstorms with excessive rainfall is becoming more common in the region; theory and modeling suggest that climate change should bring more of these events.

Human health

Human health risks are governed by many factors, ranging from socioeconomic status, to the availability of clean water and nutrition, to the quality of the health care infrastructure. Over the last decade, climate and climate change have become recognized as significant factors influencing health risk. Climate change and variability can affect health directly, through extreme heat waves and cold episodes, and through severe weather such as hurricanes and tornadoes. Climate change can also influence human health indirectly, through (1) changes in the range and activity of vectors (disease-carrying insects), intermediate hosts (such as animal reservoirs) and infective agents; (2) changes in water- and food-borne infective agents; and (3) altered food (especially crop) productivity. Examples of human health vulnerability in the Mid-Atlantic States illustrate the nature of this issue.

Summer 1995 brought a strong early-summer heat wave to the Mid-Atlantic Region and resulted in high mortality in Philadelphia, PA. Mid-latitude cities, already characterized by large urban heat island effects, appear to be the most susceptible to heat waves. The heat-related mortality that has occurred in cities such as Chicago, St. Louis, Washington D.C., and New York City disproportionately affects the young, elderly, the economically disadvantaged, and the ill. Because many of these deaths stemmed from socioeconomic factors and were preventable, there is considerable hope for adaptations to help check the impacts of heat waves.

Phenomena such as El Niño are associated with changes in rainfall, producing flooding and droughts in different regions. Based on climate model predictions, climatologists have speculated about whether anthropogenic warming will produce more intense or more frequent hurricanes along the East coast of the U.S. Severe weather, of course, has well-known potential to kill and injure.

Vector-borne diseases are a major cause of illness and death across the world. Disease vectors and reservoirs (e.g., mosquitoes and rodents) are strongly influenced by climate. For example, Dengue fever is transmitted by the bite of a mosquito (*Aedes aegypti* and *Aedes albopictus*). Both mosquitoes are currently present in Florida and Texas (an outbreak of Dengue occurred in south Texas in 1986). But U.S. cases are uncommon, probably because of high standards of housing, and adequate water, sewer, and waste management systems. The mosquitoes that transmit Dengue are strongly controlled by winter temperatures. Warming, particularly in terms of minimum winter temperatures, could substantially increase the range of this Dengue vector, including the Mid-Atlantic States. Malaria, caused by the protozoan parasites of the genus Plasmodium and transmitted by *Anopheles* mosquitoes, also would extend its range and activity under conditions of global warming. One type of adaptation would be to use pesticides for controlling vectors that expand their range. However, there may be public health risks associated with using pesticides for vector control, similar to current concerns about agricultural pest management.

Wet-dry cycles also influence human health risks because of their influence on predator-prey relationships. Historically, moving into a wet period following a few years of severe drought provides advantages to rodent populations which can reproduce faster than their predators (e.g., owls). Population explosions of rodents eventually lead to invasions into human habitats and human food stocks, increasing the risk of disease. Lyme disease, caused by a bacterium, has a strong climatic association as well. Lyme disease is transmitted by the bite of a tick (*Ixodes scapularis*) which feeds on the white-footed mouse, the white-tailed deer, and other mammals. The number of Lyme disease cases is strongly correlated with the size of the deer population, and in turn, the size of the deer population is correlated with the severity of winter conditions in the northeastern U.S.

Increases in water temperatures and salinity elevate the risk of cholera in the Delaware and Chesapeake Bays, especially from recreational contact.

Increased precipitation, especially if it occurs in intense events, could flush contaminants, including *Cryptosporidium*, into private wells and public water intakes. This protozoan is difficult to control because of its resistance to the typical water treatment technologies that rely on chlorine disinfection; filtering can be effective, but tends to be expensive and difficult to maintain properly. Children are at higher risk of infection, partly because of their relative inattention to proper hygiene. People with compromised immune systems are particularly vulnerable because they have difficulty clearing the protozoan from their systems; there is no cure for the (usually self-limiting) illness, cryptosporidiosis. Secondary infection is not unusual for health and child care-givers or from exposure at public swimming pools. The effectiveness of boil-water advisories in reducing infection from contaminated water depends on issuing them quickly and on the public following them properly. The potential magnitude of impacts is suggested by the 1994 *Crypto* contamination of public water supplies in Milwaukee, where more than 50 percent of those exposed to contaminated water became ill– a total of 400,000 people.

The U.S. is less susceptible to malnutrition and food shortages compared to much of the world because of the breadth of food production and our capability for technological adaptations. Nonetheless, climate change and variability may result in the need to change crops and planting practices and may also influence the activity or emergence of crop diseases. Costs associated with these changes may have eventual nutritional impacts on the poor.

Reducing health risks associated with climate change and variability will require (1) surveillance efforts, (2) increased research on changes in range and activity of vectors associated with climate change, (3) disease prevention programs, (4) education for medical and public health communities, and (5) public outreach.

C. REDUCING VULNERABILITY

This chapter has described several potential vulnerabilities to climate change impacts in the Mid-Atlantic Region– even though there is substantial uncertainty in our current knowledge of how large the impacts might be. The chapter also suggests that the region might be quite resilient to some of these impacts, either because they would affect a small part of the region's resources or activities, or because the region could adapt to the impacts. The next chapter further explores strategies that could adopted in the near term to increase the region's resiliency.

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CHAPTER 3: IMPROVING RESILIENCY AND CAPTURING OPPORTUNITIES

A. INTRODUCTION

The previous chapter describes what we currently know about potential impacts in the Mid-Atlantic Region from increased climate variability and climate change. But the region's actual vulnerability will depend largely on how its people and ecosystems react to those impacts. Thus disadvantageous sensitivities can be moderated by adaptation (negative feedback) while beneficial sensitivities can be enhanced by taking advantage of the opportunities presented (positive feedback).

An important task, then, is to identify strategies that would be effective in moderating undesirable impacts and amplifying desirable impacts. But identifying and implementing strategies takes resources so the question becomes "Is it worth it?" Existing knowledge and approaches can help answer this question in instances described in this chapter. Research is needed for other facets, as described in Chapter 4.

In the Mid-Atlantic Region (and elsewhere), some actions make sense for reasons other than climate change, and have additional benefits in terms of mitigation or adaptation. Obviously, identifying these actions is a top priority, but considering only those strategies that are desirable for other reasons could preclude considering strategies that might ameliorate some important regional climate change impacts (or take advantage of new opportunities). In either case, informed decision making depends on 1) assessing the risks, 2) identifying components of natural and human systems that are vulnerable to the risks, 3) determining how important impacts are to the vulnerable components, 4) estimating the benefits and costs of strategies to offset--or for those that are beneficial, capture--the impacts, and 5) determining the distribution of these impacts and costs across society, space, and time.

Risk assessment

Identifying the types of impacts and their likely severity is difficult for some of the possibilities described in Chapter 2. Consider assessing the human health risks from *Crypto*, for example. We can use downscaling models to project regional increases in precipitation. But there are many steps between that projection and an estimate of the potential increase in illness resulting from it. These steps include estimating how many water intakes would be inundated and how many defective well casings would be subject to overland flows; the concentrations of *Crypto* in the water at the intake (or well casing); the effectiveness of filtration or other *Crypto* removal techniques; how much the "finished water" is diluted by mixing from other water sources; the promptness of a boil-water advisory (BWA) if the water treatment system cannot remove *Crypto* effectively; how many people potentially would be exposed to contaminated water; the number of consumers who become aware of the BWA and follow it effectively; the dose of *Crypto* for those who fail to follow the BWA; and the dose-response function to indicate what share of that group is likely to experience symptoms. Similar event-trees can be described for other types of impacts. Understanding of linkages often is poor, and data often are sketchy for conducting such risk analyses.

Vulnerability

The particular system elements affected may differ greatly across the topics discussed in Chapter 2. Continuing the *Crypto* example, wells and surface water intakes in low-lying areas tend to be more vulnerable to contamination, particularly in areas where livestock is raised. Children may be more vulnerable because of their relatively poor hygiene. People working with animals (that are likely to be *Crypto* carriers) and those caring for people who are ill are more vulnerable because of higher exposure levels. The elderly and those with compromised immune systems may be more vulnerable because their bodies are more likely to react to a given exposure level.

Environmental valuation

Relatively little research has been conducted on the societal importance of ecosystem changes, although rough approximations can be made for a few specific impacts. For example, farmers commonly import bees to pollinate their crops, so an increase in this expenditure could be estimated if pollinating bird and insect populations were expected to decline. But for most ecosystem impacts, value estimates currently are not available. Continuing the example of bees, the farmers' increased costs (to import bees to pollinate their crops) account for only some of the values lost to society when an ecosystem is affected. An important component is the value people place on just knowing the ecosystem is there (and undisturbed), regardless of whether they ever expect to visit or otherwise "use" the ecosystem. This component often is called "existence value." Information on the value of ecological impacts is improving, partly because of the potential transferability of research done for natural resource damage assessments (which are conducted after oil spills for publicly owned recreational resources). It may be feasible to use data or estimates from such studies for comparable privately owned facilities that would be affected. Research specifically related to valuing the ecological impacts from climate change in the Mid-Atlantic Region is underway at Penn State and Carnegie-Mellon universities.

Benefit-cost analysis (BCA)

This approach examines all the benefits and all the costs of a proposed action or strategy. Measurement issues often are important, as suggested immediately above. In examining how much impacts are worth, we also need to consider offsetting changes. For example, increased storminess could reduce the number of beach vacation days. We need to recognize that the loss to the motel owners may be offset by an increase in revenues to the supplier of some other type of recreation. There still are some societal losses when people who would have preferred to vacation at the beach end up taking at it at an indoor arcade. Issues also arise because many mitigation and adaptation strategies would impose costs now to prevent adverse impacts far in the future. Conventional discounting, a common practice in business and public policy decisions, would reduce distant future benefits to very small amounts, thereby making it unlikely that decision-makers would adopt mitigation and adaptation strategies on economic grounds alone.

Distributional effects

Smart resource management decisions also depend on understanding of the distribution of risks, vulnerability, and benefits/costs across society, space, and time. A commitment to social equity requires analysis of which groups in society (defined by age, gender, ethnicity, or economic status, for example) benefit and which suffer losses as a result of climate change, and defining ways in which impacts (positive and negative) can be equitably shared. Both among and within regions, changes, impacts, and adaptations will occur in different ways in different places, as a result of their different physical and human geography. And the same changes, impacts and imperatives for adaptation will occur with different urgency across society and through space and time. Understanding social, spatial, and temporal distribution effects can help to set priorities for policy and for sequencing public and private investment related to climate change.

B. IDENTIFYING NEAR-TERM ADAPTATION STRATEGIES

Economic growth, industry and commerce

Businesses continually adapt to changing conditions. Developing innovations to exploit opportunities and finding more efficient ways to operate under current technology both improve their bottom line and stimulate economic growth. Households also adapt to improve their standard of living at affordable costs. An example would be the increased use of home insulation to enhance comfort and reduce home heating and cooling bills.

Stressors and sources of vulnerability that affect the region’s economy and environment include land use, infrastructure, growth, the aging of regional population, income distribution, race relations, global competition, deregulation, education, and the availability of capital. Society, the economy, and industry also are affected by direct environmental factors such as water quality, water supply, and air quality. The workshop's discussion group for this topic perceived many of these factors to be more important than climate change to the region's economy and the decisions faced by individual firms.

The insurance industry has an important role in adapting to climate change. Insurance allows people to trade a large uncertain loss for a smaller certain loss (i.e., the premium). The uncertainty associated with climate change impacts on property will increase premiums, compared with risks for which the premium can be based on historical records. The insurance industry adapts easily to gradual changes, but the potential for larger abrupt changes is a cause for concern. Actions such as "storm hardening" of homes in coastal areas would protect groups now as well as those potentially affected by climate change. It also would moderate increases in insurance premiums in coastal areas.

Some working group member felt that business is unlikely to consider possible climate change when making decisions, because current knowledge about impacts and related uncertainties is inadequate. That judgment is consistent with Penn State research results. A limited survey of water-dependent industry managers in the Susquehanna River Basin finds that they are not planning for climate change because of the uncertainty about climate change, issues of more immediate concern to plant operations and profitability, and the long time scales of climate change relative to industry planning cycles (Maynard et al., 1997). Typical equipment replacement cycles offer industry ample opportunity to respond to change. This survey and Yarnal et al. (1998) found that vulnerability to both climate change and variability in municipal water supply were declining through adaptation to water quality protection regulations. The resulting resiliency would help industry and commerce as well as residential water users.

Because of the dominance of other sources of change, strategies to improve the general economic resilience of the region will go a long way toward minimizing adverse economic impacts and maximizing the advantage from opportunities caused by climate change. Stressing that flexibility is crucial, the discussion group suggested several strategies that could help both the regional economy and individual business managers:

1) Upgrading infrastructure to make it more adaptable

2) Paying more attention to land use policy, including metropolitan planning and transport planning

3) Streamlining government operations

4) Retraining displaced workers

5) Sharing technology

The working group preferred incentives-based regulation and tax incentives for shaping policy compared to prescriptive measures. Continual reevaluation of policy, in response to technological innovations and to policy successes or failures, is another way to increase flexibility. Some felt that policy should be formed at the national level, due to the interdependence of regions within the United States, while encouraging regional flexibility in implementation. The working group agreed that clear, visionary goals must be established and communicated to all interested parties.

Some participants believed marginal changes to existing strategies and institutions may be the best regional adaptation strategies for industry and commerce, partly because they perceived existing industrial and public infrastructure as too inflexible to respond to climate change. During drought conditions, for example "competitive use policies" restrict water use by some industries in the Chesapeake Bay watershed. This can create near-term difficulties, but responses can be directed at new infrastructure through the normal capital replacement cycle. Excluding existing operations from more stringent regulations or policy would slow adaptation to climate change, but reduce businesses' compliance costs. Strategies could be intensified if climate change effects become more apparent. This sub-group viewed radical change as unnecessary at this time. Others disagreed with the assessment that infrastructure is too inflexible, but considered marginal change strategies to be useful given the uncertainties involved. Still others were skeptical that marginal strategies would prove sufficient for adaptation and mitigation, believing that greater changes will become necessary.

In summary, industry relies on natural resources and infrastructure, which vary in their vulnerability to climate change (e.g., through water shortages or increased likelihood of blizzards). The discussion group expressed strong support for planning and structural changes that affect future growth patterns, such as land use policy, which could be accomplished at moderate cost. Because they considered industry to be capable of adapting to climate change, some participants advocated a cautious approach including more localized research that will be useful to firms and local authorities. The group supported modest changes to existing strategies and institutions as appropriate immediate means of adapting to climate change. Many participants believed that technology can be relied upon as a significant source of long term adaptation options. The need for more significant restructuring of existing infrastructure and industry, however, divided group opinion.

Ecosystems

Although ecosystems sometimes have surprising resiliency, simultaneously they sometimes are surprisingly vulnerable. This section suggests ways that human actions might buffer ecosystems, giving them more chance to adapt to both current stresses and those induced by climate change.

In the coastal region, strategies to help ecosystems adapt could include new zoning laws on setback and elevation of structures and wetland restoration. Shoreline hardening could preserve beaches and waterfront for human use, but might be a barrier for migration of ecosystems. Here as in freshwater systems, genetic engineering, hatcheries, and aquaculture could be developed, but attention should be given to their potential to push "natural" ecosystems toward local extinction. For freshwater streams and lakes, adaptation strategies could include fish management as well as modification of water management strategies and structures. Protection of riparian zones as well as wetland restoration could be important adaptation strategies.

Protection (or establishment) of forest corridors, propagation of seedlings, and changes in forest and wildlife management could help forest ecosystems become more resilient.

Urban regions are already strongly changed by human forcing. Climate impacts will include changes in water quantity and quality, pesticide and toxic chemical loading from urban land, and transportation of toxic wastes. These changes could have effects on urban forests and other ecosystems similar to those in natural forests and ecosystems.

Fresh water quantity and quality

Several regional adaptation and management strategies are recommended for adjusting to or counteracting the impacts on freshwater from climate variability and climate change. Flexibility is a key. Institutions and management practices that facilitate adaptation will best be able to handle changes in water supply and demand. Examples include integrated basin and watershed management of water facilities, conjunctive management of surface water and groundwater, and inclusion of conservation incentives, water quality protection, habitat protection (wetlands, riparian corridors), and supply reallocation options in water management.

Government agencies play an important role in gathering information, including the important task of monitoring the nation's water supply. At the same time, government agencies should provide industries and consumers with incentives to change use patterns and develop technologies that mitigate human impacts on the climate and facilitate adaptation to climate change. Institutional conflicts, such as the inability to enforce legal regulatory powers, also require more attention.

Industries will respond by self-regulation and take a longer-term perspective concerning these issues if financial incentives exist. It is important that industry take part in land use planning and management, including the use of economic incentives, to moderate the costs of climate change impacts. For example, most of the Mid-Atlantic Region has been able to withstand recent droughts– although certain areas have fared poorly during these events– but the region is not prepared for a very severe drought at current usage levels. Standardized data collection would improve the development of alternatives and management decisions.

Both education and the use of economic incentives are useful to develop effective strategies. Interdisciplinary, multimedia education strategies are needed at the local level, for officials and managers and for the public. All parties– government, industry, non-profit and nongovernment organizations, and the media– have important education roles.

Finally, “win-win” strategies and actions that are cost-effective even without climate change are much more likely to succeed. Projects initiated because of other concerns could add “enhancing resiliency to climate change” to their list of benefits, often at modest or no additional cost. Feedback to help evaluate the effectiveness of policies and activities is also important for handling future climate change.

Agriculture, forestry and fisheries

Economic and policy adaptations to direct and indirect impacts of climate change will affect the profitability of farm, forest, and fishing enterprises. Climate impacts will induce behavioral adaptations by producers, input suppliers, processors, and consumers (e.g., changes in crops and production practices by farmers, changes in agricultural trade flows between regions, changes in consumer food purchasing patterns) and stimulate demand for techniques better suited to new climatic and economic conditions. Changes in production will lead to changes in the prices of agricultural and forest commodities. Agricultural, forest, and fisheries adaptations may happen faster if agricultural research and extension can enhance technological response capabilities and disseminate research findings. However, policies such as product price supports, input subsidies, agricultural trade barriers, and payments for crop failures could hinder adaptation by encouraging the production of climate-sensitive crops, the use of cropping systems ill-suited to the changed climate, or limiting incentives for relocation or innovation.

Assessments need to distinguish between economic impacts and changes in physical variables. Economic impacts depend on price changes and substitution possibilities, as well as on changes in the underlying productivity of the biophysical systems. Prices are determined by national and international forces and may move in ways that blunt or amplify the biophysical change. For example, yield reductions do not imply an economic loss to farmers, foresters, or fishermen if the prices they receive for their products increase sufficiently. Similarly, because agriculture and forestry in different regions are linked physically by the movement and management of weeds, pests, and diseases, and economically by prices, policies, and commodity flows, regional impact assessments require understanding of climate change, direct and indirect impacts, and adaptations in other regions.

Several studies have explored the impacts of climate change on agriculture, mainly on large spatial scales. Results vary according to factors such as the climate scenarios considered, the modeling techniques used, and the extent to which economic and technological adaptations are considered. These studies generally indicate that global economic impacts of projected climate change on agriculture will be small. Projected climate change is expected to have little impact on the overall U.S. economy and domestic food production. However, impacts of climate change on agriculture at the regional level are highly speculative. Both positive and negative impacts have been predicted for agriculture in the Mid-Atlantic States, with the results differing according to the methodology.

It is clear that adaptation can greatly reduce the negative impacts of climate change on agriculture. For example, farmers can shift to less climate-sensitive crop cultivars, or to less climate-sensitive crop and livestock production systems. The workshop discussion group for this topic expected that well-informed commercial farmers and foresters would adapt to climate change and variation through shifts in species, crops, livestock, and management practices. Foresters can assist migration of forests through, for example, tree planting strategies. Foresters have identified species that display broader tolerance to environmental conditions. Fast growing species may be better adapted to continual change, and foresters could rely less on natural regrowth of forests and more on planting, perhaps using hybrid species. These adaptive responses would be driven by the direct impacts of climate change on agricultural and forest enterprises, and by changes in agricultural and forest product prices induced by climate change impacts in other regions. This region’s agricultural economy could be more affected by changes in prices for commodities, induced by changes in other U.S. regions and the world, than by direct impacts on agricultural productivity from changes in the region’s climate.

Public education and technology transfer programs that provide farmers, foresters and fishermen with information on future weather and technical options would facilitate adaptation. The Cooperative Extension Service is an example of a system that could be used to deliver this kind of information. In addition to public information systems, increased development of private sector information services (weather forecasting) can facilitate adaptation.

Improved monitoring and early warning systems could help avoid losses from extreme events. Improved monitoring of current weather would help farmers avert losses associated with frost, particularly in the fruit industry, and increase the effectiveness of pest management strategies, particularly integrated pest management (IPM). Long-term monitoring of forest inputs (e.g., nitrogen, acid precipitation, air quality) linked to forest productivity and health are needed to understand how forests are changing and how these changes are affected by changes in environmental conditions.

Income and employment in agriculture, forestry and commercial fisheries in the Mid-Atlantic region are small, so large impacts on the regional economy are unlikely. On the other hand, local impacts, such as in the relatively small portion of the region where commercial fishing occurs, could be substantial. The discussion group for this topic had relatively little expertise for fisheries, so felt less certain about potential impacts and adaptation strategies for commercial fishing.

Overall, the group concluded that predicted climate change does not represent a significant threat to the region's agriculture or forests in the next 50 years. Competition for land, environmental regulation, and competitiveness will remain the key stresses in agriculture. Similarly, other external stresses, such as land-use change and the chemical environment (ozone, nitrogen deposition, acid precipitation) will be continue to be more important than climate change in the forest sector. Agriculture appears to be more resilient than forests, in part because of its shorter production periods, greater commercial character, and value of output. Many forest values are unmarketed and the use of money to protect value and take adaptive actions has not been a priority. Public sector responses to protect nonmarket values are much more critical for forests than for agriculture.

Recreation

Many types of recreation adaptation can be envisaged. For example, increased risk of contamination at freshwater or marine beaches can be offset by more use of swimming pools. Warmer average evening temperatures may tempt more night-time outdoor exercise, especially if daytime temperatures are uncomfortably warm. Similarly, an increase in hot weather might lead to more requests for golf tee times very early in the morning or the installation of more water fountains. Golf course owners may need to irrigate more, an illustration that some forms of outdoor recreation may become more costly.

Many of the potential recreation impacts--and thus adaptation strategies--are tied to other topics discussed during the workshop. One example would be bird watching. Ecological changes that modify the distribution of birds would affect people's ability to observe particular bird species. Thus management actions to protect bird migration corridors also would help preserve this recreational opportunity.

Some types of adaptation initially seem obvious. For example, if the projected decline in cold water recreational fish is more than offset by increased populations of warm water species, trout anglers could switch to fishing for (say) largemouth bass. But the recreational experience may be sufficiently different that former trout anglers suffer a decline in well-being even when they catch more fish. It is an empirical question whether adaptation (e.g., a large increase in bass fishing days) more than offsets the decline in well-being associated with a decrease in the earlier preferred recreational activity (e.g., a smaller number of trout fishing days).

Natural hazards/extreme events

The types of adaptation that would reduce vulnerability to increased frequency or severity of extreme weather events are the same as those frequently proposed for reducing vulnerability to current patterns in extreme events. Among others, these strategies include:

- Bringing more communities (and their residents) into the Federal Flood Insurance Program, and enforcing its requirements.
- Planning more sensibly to restrict development in flood-prone areas.
- Reducing subsidies that encourage development and rebuilding in areas likely to have flooding or severe winds.

Some of this adaptation may require more reliance on the insurance industry for private insurance to reduce individuals' and businesses' financial risk from extreme events. Possible avenues for adaptation include incorporating more knowledge about actual risks when setting premiums, expanding available funds through further pooling and accumulation of funds (which may require significant changes in practices and institutional cooperation), as well as proactive efforts to reduce the likelihood of damage from extreme weather.

Human health

Current information is sufficient for suggesting specific near-term strategies that would have positive net benefits now because of climate variability and in the future when faced with climate change. Judicious use of analogs based on past events can suggest management strategies. For example, early warning and buddy systems can be combined with the provision of cooled shelters to reduce heat mortality. Improved filtration, detection, and effective boil-water campaigns can reduce exposure to vector borne disease. People can be encouraged to move away from the risk of injury, drowning and contaminated water in flood plains by removing flood insurance subsidies and limiting government flood recovery assistance in locations prone to frequent flooding. The appropriate extent of these near-term strategies can be determined (on a sub-regional basis) by examining both their benefits (e.g., reduced health and property damages) and costs (e.g., for heat wave warning systems, restricting land uses, protecting and improving water supplies). Strategies such as removing subsidies for inappropriate behavior are relatively low-cost. Low-cost options such as removing federally subsidized flood insurance can be difficult to implement at a regional level without national action. Others are easier to implement at regional and sub-regional scales.

The following table proposes a variety of adaptations and management strategies to aid in adjusting to and counteracting negative health impacts of climate variability and change:

Table 5. Improving Regional Infrastructure for Climate-Related Health Impacts

Heat Related Illness	**Pollution Related Illness**	**Vector-Borne Diseases**	**Extreme Weather Events**
Identify areas at risk Develop early warning systems Education/outreach to public health officials/systems Improve building practices (e.g. paint roofs, install roof sprinklers)	Education Monitoring and surveillance	Monitoring and surveillance (e.g. making more diseases reportable so that they can be tracked) Vector control (e.g. integrated pest management) Environmental modification (e.g., removing old tires) Disease ecology (upstream information)	Remove populations in high risk areas (e.g. remove incentives for living in flood plains) Strengthen water supplies against contamination (public and private) Educate water managers

Monitoring for climate-related disease is important, but there is debate about the best way to do so. Looking for indicators (e.g., precursors or vectors) of the potential presence of the disease may lead to prevention strategies, but such monitoring and prevention can be both costly and uncertain. In instances where the number of cases is likely to be small, it may be cost effective to focus on treating people who become ill, rather than monitoring precursors.

Illness related to climate change provides more opportunity for preventive measures because its nature is environmental exposure, compared with illnesses with larger genetic or behavioral components. At this time we cannot resolve the preventive versus treatment issue; the more cost-effective method may vary by disease and depends upon disease ecology and the degree of exposure to disease pathogens. A priority should be promoting interdisciplinary work and collecting data.

Education and communication with stakeholders are essential. Stakeholders include groups that could be affected by, or who have the potential to influence, health impacts from climate change. These stakeholders must be identified, along with their information needs and the most effective information delivery system(s). For instance, the medical community must be educated in environmental health and be made aware of what diseases might occur. Effective strategies are unlikely to be implemented unless government (federal, state, local) and funding officials understand the potential size of regional health impacts of climate change. Thus these officials are another example of stakeholders. The largest stakeholder groups, of course, are among the general public. Educational/informational programs can help them make informed decisions about adapting to health threats from climate change.

CHAPTER 4: RESEARCH NEEDS

A. INTRODUCTION

The previous chapter suggested near-term strategies to address problems already recognized or that represent a "win-win" approach to climate impacts in the Mid-Atlantic Region. Closer examination of their potential effectiveness and costs can be expected to reveal gaps in our knowledge that can be filled by information gathering and research. Even more compelling reasons for research are the substantial uncertainties about just how the region's climate is likely to change over the next century, how this will affect both managed and unmanaged ecosystems, and how individuals and communities will respond and adapt to these changes. This chapter brings together suggestions about research judged to be most useful for helping the region's citizens make wise decisions related to the impacts from climate change.

B. DIVERSE RESEARCH NEEDS

Economic growth, industry and commerce

Workshop participants perceived climate impacts to be a limited threat to the Mid-Atlantic region's wide range of industry although there might be substantial impacts on other economic activity. They were not confident in these perceptions, because of the lack of information on the local climatic impacts that business may face, as well as how likely such climate change risks are relative to other risks facing the economy.

Whether risks are short or long term is important for business planning, especially for long term capital investment, plant location, and raw material availability. Thus, studies of possible climate change impacts should involve risk comparisons, including the time horizon of these risks. Because of its vulnerability to climate change, the insurance industry is particularly interested in risk research.

Options developed in the past to minimize business risk, such as flexible input sources, support the perception that industry generally can adapt. Because such observed adaptability makes many future scenarios seem less threatening, extreme case scenarios can be a useful planning tool. The chances of such events are remote, but their disastrous consequences would be beyond the means of adaptation and amelioration by current institutional frameworks. Research that identifies institutional vulnerabilities and remedies would be valuable to society in general, as well as to industry in particular.

Assessing the importance of climate variability and climate change on industry and commerce requires information on a much finer scale than currently available, a scale that can be used by water managers and individual firm-level decision-makers. Thus workshop participants perceived research at the localized level to be much more beneficial than continued research on global scale general circulation models (GCMs). Such research is likely to be most effective if focused on sensitive sectors and areas within the region. Historical data, including data collected by industry, may be useful in this regard. The dissemination of information from climate change studies, such as the IPCC reports, also can aid industry decisions. The business community's expectations about climate change and variation are important because current investment decisions influence the region's future vulnerability.

Research is needed to determine how increased frequency of extreme weather events and changes in water supplies (e.g., because of their use in production processes and for diluting chemically and thermally contaminated effluents) could affect the region's economic productivity and competitiveness. We also need research on the effectiveness of existing and new technological, economic, and public policy adaptations that could ameliorate adverse impacts.

Recreation is expected to be an increasingly important economic activity in this region and elsewhere. Substantial research is available on recreation in the Mid-Atlantic Region, but it may not cover all forms of recreation potentially affected by climate change. Relatively little of this research has been tied to factors that might be influenced by climate change. An assessment of which types of recreation are likely to be most affected and the importance of these activities to the region could suggest near-term adaptation strategies as well as further recreation research priorities.

Ecosystems

Workshop participants agreed that climate variability and change could have profound effects on natural and human-modified terrestrial and aquatic ecosystems, in conjunction with other driving forces of ecological change. Yet the specifics of those profound effects are unclear. As a first step, we need to synthesize existing information to determine which species in the Mid-Atlantic Region are especially vulnerable to exacerbated climate variability and likely trends in average precipitation and temperature. Along with a preliminary assessment of the ecological roles of vulnerable species, this synthesis will allow identification of gaps in available data and suggest priorities for a research agenda.

Differing time scales of climate change as well as the intrinsic nature of these changes directly and indirectly affect ecosystems, ranging in time from short-term stochastic events to major long-term eras such as the Pleistocene glaciation. We need to understand more about the directions and rates of climate change anticipated in the region before we can understand how ecosystems might respond to these changes in comparison to their responses to the spectrum of other events that will occur.

An example might be coastal engineering strategies, such as integrated coastal sediment management. Research could examine the ecological effects (and effectiveness) of enhancing sediment to increase the rate of vertical growth and avoid consequences from sea level rise.

As mentioned earlier, climate-induced changes could have significant economic impact, as well as affecting inherent ecosystem values. Evaluating future ecosystem impacts requires: (1) determination of the direction and magnitude of climate change (as well as the speed of its onset) in the region; (2) improvements in the duration and spatial/temporal resolution of ecological monitoring; and (3) improved theoretical models of ecosystem functioning. Greater understanding of the present extent, density, composition and dynamics of ecosystems in the region is needed for assessing the impacts of human, natural, and climate driving forces.

Water resources: quantity and quality

Because most of the stresses on the Mid-Atlantic Region's water resources are directly or indirectly associated with population and economic growth, additional research that aids in projecting the region's economic growth and population would be especially helpful.

To assess how great the stresses on water resources from climate variability and climate change will be, better information is particularly needed for: accurate regional climate modeling; understanding how climate and water resources interact; how climate affects unmanaged ecosystems; how climate change will influence natural and agricultural vegetation and runoff; how ecosystem changes will affect water quality and quantity; and how to reduce scaling mismatches between climate model output and input information necessary for water management and planning.

Choosing wise adaptation and management strategies requires good information on how climate change could affect water supply, both on average and in terms of variability. Water demand information is important because climate change could affect both instream and withdrawal uses. Information also is needed on the effectiveness and costs of alternative demand management and water supply strategies.

Other information needs include projections of land cover change, the frequency, magnitude and distribution of extreme events, evapotranspiration rates, and how climate change will affect potential demand for water use in agriculture. Some of this information is particularly important to water management because of the reliance of water managers on historical data in planning future infrastructure. For example, the region currently has very little reliance on irrigation, which could be an inappropriate signal for future irrigation demands.

Communication between researchers and politicians, in particular, must be strengthened so that researchers develop tools that are useful to managers.

Agriculture, forestry and fisheries

The major stresses for the Mid-Atlantic region's agriculture are economic factors (e.g., competitiveness, taxes), regulatory issues (e.g., labor, environment), and land-use pressures (land competition). These are more important determinants of the viability and vitality of agriculture in the region than climate variations per se. For forestry, climate variability may interact strongly with other environmental stresses (insect pests, ozone, nitrogen deposition, acid precipitation) on forests. The working group lacked detailed information on how humans use and enjoy forests, and the forest economy, thus making it difficult to understand how climate change and variation will affect forest values, particularly those non-timber values, such as recreation, scenic views, wildlife habitat.

As is the case for other sectors, predictive scenarios are the largest unmet information need to facilitate adaptation in agriculture and forestry. For example, will the region's climate be wetter or more variable, and how much wetter or more variable? Short-term climate scenarios (the next few decades), including realistic transient representations of climate change, are particularly important. More research also is needed on forecasting medium run (6-18 months) climatic conditions with a focus on extreme weather events and on understanding how to prepare for these events.

Agricultural and forestry research can help farmers and forest managers adapt. For example, developing new crop cultivars could make agriculture less climate sensitive. Maintaining the genetic base for the development of crops is crucial, especially for the so-called "minor crops" that are important for this region. Similarly, forestry research can help forestry managers adapt, although forests' slower growth rates mean it will take longer than in agriculture.

Although fisheries were not well represented by the experience and expertise at the workshop, it is clear that recreational fishing is economically more important than commercial fishing in the region. This is due to the large and growing public participation in this activity and the economic impacts of recreational spending. Research needs for recreational fishing include learning more about the relative values anglers place on different types of fishing opportunities, as well as refining projections of how climate change would affect different recreational fishing opportunities.

Integrated regional-scale research on how climate change and variability will affect agriculture, forests, and fisheries is essential to understand impacts on people and communities economically dependent on these sectors. However, beyond their contributions to income and employment, each of these sectors is a source of important nonmarket services (e.g., open space amenities, wildlife habitat, ecosystem services, cultural values) that could be increased or diminished. Further research on regional climate change and variability, direct and indirect impacts on biophysical productivity, and technological and economic adaptation options and costs in Mid-Atlantic Region agriculture, forests, and fisheries is essential to understanding potential consequences for land use, land cover, water supply and quality, and other issues of societal concern.

Natural hazards

Climate change may alter the frequency and intensity of natural hazards, thereby changing this stress on natural and managed ecosystems and on socioeconomic systems.

It would be ideal to know how climate change will affect the natural hazards profile of the Mid-Atlantic Region. Regionally specific climate predictions on all time scales would help planning efforts to prevent or moderate damage from floods, droughts, heat waves, cold-air outbreaks, and other climate-related disasters. Such information would save lives and reduce economic losses. However, precise regional predictions of weather and climate may never be possible, and it is unlikely that accurate socioeconomic forecasts will ever exist. Nevertheless, there are many research and information needs that, if satisfied, could reduce current and future vulnerability to weather- and climate-related natural hazards.

Workshop participants identified four basic research and information needs for weather- and climate-related hazards:

- More must be known about the links between individual hazards and the vulnerabilities of the region, including overall vulnerability and vulnerability by socioeconomic sector. Gaining this knowledge requires research on climate impacts, hazards, and socioeconomic drivers.
- Relationships between individual events and variation in the climate system on all time scales must be clarified. For example, does a wetter summer climate over the Mid-Atlantic Region translate into more locally severe storms and flash floods? Does increased (decreased) climate variation mean increased (decreased) natural hazards?
- Climate and natural hazards data must be collected at finer spatial and temporal scales. A match between the space and time scales of natural and socioeconomic data must be developed and incorporated into monitoring networks.
- The needs and concerns of interested parties must be incorporated in weather and climate research relating to disaster mitigation.

Although it will take time to develop the first three of these items, action should be taken now to build user requirements into climate-related hazards research.

Human health

Choosing long-run regional health strategies in the face of climate change will require improved general climate information such as the nature of projected climate variability in the Mid-Atlantic Region and the impact of the North Atlantic Oscillation (e.g., the distribution of rainfall and temperatures, including freezes that reduce disease vectors, etc.). Thus reference radio sondes (the weather balloon instruments that broadcast their measurements of temperature, humidity, air pressure, etc.) should be supported.

More must be learned about how climate change would affect genetic mutations and diseases resistance, as well as how ecosystem changes would affect disease vectors. Research on changes in the dynamics of transmission, distribution and resistance of disease agents (ranging from environmental factors such as temperature, humidity, and rainfall that affect survival of the disease organism, to vectors such as insects that carry the disease to people, to the human host that actually experiences the disease) can help in projecting the potential for the emergence of diseases new to the region. For example, warmer temperatures could increase algal blooms in the Chesapeake Bay, which might harbor cholera. At the same time, other diseases may move out of the region. Increased rainfall and flooding could contaminate public and private water supplies (e.g., with *Cryptosporidium*), accompanying the property damages often thought of as the primary impacts from weather hazards. More climate variability also could lead to poor water quality during drought conditions, accompanied by health impacts for people with limited access to clean water.

A key issue in determining the health effects of climate change is understanding what will happen to the threshold level of tolerance of the population and of the region's disease agents. The threshold could stay the same if adaptation to climate change occurs. But the threshold could move, for example, if higher humidity levels cause people to be less resistant to disease-carrying insects. Climate variability may be a more important influence on health than climate change. Negative impacts of climate change would increase health care costs and stress on health care facilities.

Furthermore, knowledge of sociological response to physical stress is important (i.e., will people move or adapt; and if they do adapt, what is the adaptation process?) in addition to understanding how the risk and cost of climate change will be spread across the region's population. Mental health may be affected by increased precipitation (grey weather) and by dislocation of people due to extreme weather events. Thus interdisciplinary research teams that can account for the physical, biological and social interactions will be essential for projecting regional health implications. Similarly, multidisciplinary prevention planning teams can avoid trading one problem for another.

C. MOVING TOWARD A RESEARCH AGENDA

The list of research needs described in the sections above can seem overwhelming. However, research needed from one perspective or sector to enhance wise decision-making about climate change often also is needed for another sector or perspective. In addition, data or understanding from much of the suggested research would improve the region's ability to make smart decisions even in the absence of climate change. Recognizing these linkages may make it easier to a) get support for research that will have benefits for planning the region's future in general and b) setting priorities among the research topics more targeted to projecting and ameliorating negative impacts from climate change.

The research agenda outlined in Table 6 summarizes the research needs identified above. The table identifies research that would provide answers broadly applicable to the Mid-Atlantic Region's overall vulnerability to climate change, as well as research needed for the major sectors likely to be affected by climate change.

The final chapter in this report summarizes the findings of the workshop and recommendations for the next steps.

Table 6. Research Agenda

Basic research important for many sectors:

Climate research

- Regional models and scenarios
- Extreme events
- At scale useful for public and private decision-makers

Biochemical/Ecosystem research

- How nutrient cycles, plant growth, and competitive advantages for individual species within communities will be affected by increased CO_2, temperature, sea level rise, induced soil salinity, and flooding from extreme weather events
- Changes in animal populations, based on changing plant food supply, particularly for
    - hunted species
    - disease vectors
    - charismatic bird species
    - agricultural pests
- Improved techniques for ecological monitoring and collaborative ecosystem management

Socioeconomic research

- Improved predictions of human migrations and demographic changes

- Links between human demography and climate variables
- Attitudes toward and values for environmental and ecological characteristics
- Differences in risk between private and public sector activities
- Issues of environmental justice; where are impacts greatest?
- The role of information in initiating responses to minimize risks or maximize opportunities
- How institutional and technological change can diminish risks and enhance opportunities

Sector-specific research (given answers to basic research questions):

Forestry

- Clarify most vulnerable aspects of forest business
- Separate climate impacts and other human impacts along urban/rural gradients
- Link human demography with forest history and climate predictions to understand potential forest species migration

Agriculture

- Improve prediction of soil moisture, and its timing
- Clarify most vulnerable aspects of agriculture related to potential changes in plant growth
- Link human demography with agricultural history and climate predictions to understand potential for farmer willingness to adapt to climate change
- Identify best potential species under climate change

Water

- Given results of human demography studies, project location and extent of stress on water, including effects of land use/land cover
    - urban/rural gradients
    - coastal/inland gradients
- Improve predictions of climate change impacts surface and ground water availability and impacts on its quality

Health

- Link human demography, disease vector migration, water quality, and climate predictions to understand potential health changes, overall and in sub-regions
- Potential impacts on mental health and disease resistance

Recreation

- Clarify climate-sensitive aspects of recreation, especially as related to plant and animal populations
- Given human demographic and valuation research, prioritize conservation efforts

CHAPTER 5: SYNTHESIS, CONCLUSIONS AND NEXT STEPS

A. INTRODUCTION

Four questions guide the organization of this chapter:

1. What do we know about the impacts of climate change in the Mid-Atlantic Region?

2. What strategies can be considered now for reducing vulnerability and taking advantage of opportunities presented by climate change?

3. What else do we need to know?

4. How do we make sure the results of research are useful for and available to the region's decision-makers?

The chapter ends with an update on next steps for assessing impacts from climate change in the Mid-Atlantic Region.

B. FOUR QUESTIONS

1. What do we know about the impacts of climate change in the watersheds of the Chesapeake and Delaware Bays?

The Region's Unique Characteristics

The Mid-Atlantic Region has several characteristics that make its people, economy, and ecosystems sensitive to climate change. These include:

- Extensive shorelines
- Significant agricultural, forest, and fishery sectors
- A large population
- Historical settlement patterns along waterways
- An economy based on abundant water
- Unique natural resources, such as the Chesapeake Bay

The region also has features that may help to make is resilient to climate change. These include:

- A highly developed, diversified, dynamic economy.
- Significant potential to adapt through technological and institutional change

Major Findings

- **The Mid-Atlantic Region is reasonably robust with respect to climate variability.** This conclusion is based on factors such as the region's abundant water resources, varied ecosystems, diversified economy, and history of managing weather-related disasters. Working groups representing different sectors (economic growth, industry and commerce; ecosystems; water resources; natural hazards; human health; agriculture, forestry and fisheries) potentially vulnerable to climate impacts ranked climate low in importance relative to factors such as poverty, global market pressures, and water and air quality. They viewed these other factors as presenting more immediate, tangible impacts.

- **Climate change could have adverse impacts on the region's people, economy, and ecosystems**. When working groups accepted model-based future climates as indicative of the futures, climate impacts took on greater importance. Some impacts were judged to be as important as other major issues that influence the region's economic and societal well-being.

- **Potential impacts could vary widely by sector depending on the sensitivity of the sector and the potential for adaptation**. The working groups that discussed health, ecosystems, and recreation expected profound effects in these sectors. Significant sea level rise would have a marked and extensive impact in the Mid-Atlantic area. In contrast, the working group for agriculture did not consider this highly adaptable component of the regional economy to be seriously threatened under the climate change scenarios. Global markets are likely to be a greater driver for agriculture than climate. Similarly, the region's economic growth was not viewed as seriously threatened under the climate change scenarios adopted for the workshop. This conclusion largely reflects the working group's expectation that the regional economy's size, diversity, and adaptability make it resilient with respect to the impacts of climate change. On the other hand, impacts could be substantial and important on a local scale. This group expressed uncertainty about how factors governing economic growth, such as water availability and transportation infrastructure, might be affected by climate change.

- **The importance of climate change in influencing the severity or frequency of natural disasters is unclear**. In general, working groups could identify the types of vulnerabilities, but were unable to assess their magnitudes given the uncertainties inherent in future climate predictions.

2. What strategies can be considered now for reducing vulnerability and taking advantage of opportunities presented by climate change?

Despite substantial uncertainties about many potential regional impacts from increased climate variability and change, adaptation strategies can be identified for problems that are already recognized or that represent a "win-win" approach to climate impacts. These include:

- Enforcing restrictions on construction and eliminating subsidies that promote re-building within areas of high natural hazard risk.
- Expanding the use of warning systems, such as those that activate under conditions of high heat stress.
- Improving on land-use and drought planning efforts, which will address issues already of importance in the region whether climate changes are significant or not.
- Instituting flexible strategies for water management across regional or local districts.

While many strategies can be conceived that would reduce existing and expected stresses, some would have high economic or societal costs. For example, enhancing the infrastructure for water management through increased storage capacity is one logical option given the Mid-Atlantic region's propensity to drought. But increasing concerns about the environmental implications of dams and reservoirs now require closer evaluation along with the actual construction and operating costs. Additional analysis can examine the cost effectiveness of proposed strategies to address current stresses likely to be exacerbated by expected economic and population growth. Such actions offer benefits of reducing the region's vulnerability to climate as a bonus.

3. What else do we need to know?

This chapter lists relatively few identified near-term strategies for adapting to climate change. A closer look at the suggested strategies suggests important gaps in our knowledge of how to evaluate alternative approaches to implementing them. Workshop participants provided valuable perspectives on research needs, but could not be expected to represent the full range of (admittedly limited) scientific knowledge available for assessing the regional impacts of climate variability and change. The workshop discussions, supplemented by the Organizing Committee's reflections, suggest the following topics as the highest priority research needs:

Research Needs: The scientific information available for assessing regional impacts of climate change and variability is extremely limited. Assessments based on this limited information could grossly miscalculate either the threat or opportunities to the region. Essential information for improving the assessment of how the Mid-Atlantic region would be affected by climate change include:

- how climate change will affect the regional climate (i.e., frequency and intensity of severe weather, the nature and timing of precipitation events, frequency and severity of droughts);
- the rate and magnitude of climate change at the scale of public and private decision makers in climate sensitive sectors (e.g., agriculture, forestry, water supply);
- how climate change will affect the region's natural resources and ecosystems;
- how climate change will affect the productivity of agriculture, forests, fisheries and other sectors;
- differences in risk between private and public sector activities;
- differences in risk for different population segments;
- the role of information in initiating responses to minimize risks or maximize opportunities;
- how institutional and technological change can diminish risks and enhance opportunities;
- the current state of Mid-Atlantic ecosystems, and the associated monitoring and modeling of ecosystem changes; and
- expected regional demographic changes.

4. How do we make sure the new knowledge is useful for and available to the region's decision-makers? (A summary of workshop rapporteur Baruch Fischhoff's insights)

- Who wants or needs to know?

The region's decision-makers range from individual citizens to heads of interstate compacts. They can be grouped into three categories with respect to regional impacts from climate variability and change. These categories include those decision-makers who are 1) likely to experience direct negative impacts, 2) concerned about costs of policies to reduce the impacts from climate change, or 3) potentially able to benefit from climate change. The first group includes the energy and chemical industries, government officials, environmental groups, health care managers, casualty and non-casualty insurers, infrastructure managers, the travel/recreation industry, and coastal land owners. It also includes the disadvantaged, who may be more vulnerable to negative impacts. Actions by many of these same groups could contribute to or complicate the problem, so they might be part of the second group that is especially concerned about the costs of policy proposed to reduce greenhouse gas emissions or moderate its impacts. People in the third category might be able to take advantage of new economic opportunities, including those in agriculture, engineering, and industrial associations.

- What is worth knowing?

A plan for producing and disseminating information on climate variability and change starts by noting that information needs differ among members of a very diverse audience. “Broad-band” dissemination can be helpful for a wide audience with general needs, but “narrow-band” information may be more helpful for a targeted audience with specific needs. Communication planning should start with a needs assessment that determines what people already know, explores their trust in scientific and social sources, and evaluates whether they need information simply to feel informed or for structured decisions (e.g., to choose an action). If the goal is informed decisions, a value-of-information analysis can help identify what information will be most useful to the decision-makers.

Research shows that decision-makers often are aware that research is available, but cannot figure out how to make use of it. This suggests the need for affirmative answers to four questions:

1. Is the research relevant for decisions?
2. Is the research available to decision-makers?
3. Is the research compatible with their existing decision models?
4. Are decision-makers receptive to research?

- How do we make information useful?

Going beyond “business as usual” will be essential to develop an effective regional strategy for responding to both challenges and opportunities from increased climate variability and change. It would be easy for climate researchers to say, “too bad we can’t give them the data they want” when people express discomfort about the many uncertainties in projecting climate variability and change and their potential impacts. Policy makers must recognize the need for coordinated research and analysis to fill holes in the incomplete picture of the climate issue. They also need integrated management plans so that solutions to one public problem do not exacerbate another. An important component of a regional strategy is a communication and collaboration infrastructure, such as that initiated for the Mid-Atlantic Workshop.

This communication and collaboration infrastructure should:

- Clarify the costs and benefits of climate change
- Show interconnections among different impacts of climate change
- Have the people who will use the information help plan the research, so that the impacts they care about will be included
- Use multiple communication channels to
  - give people reasons to think about and make sense of an issue
  - show the links between research results and actions they can take.

C. NEXT STEPS AND UPDATE

What does this all mean for assessing climate change impacts and adaptation strategies for the Mid-Atlantic Region? We know that climate change will bring ecological and social impacts, some positive and many threatening, and that these impacts call for anticipation, evaluation, and amelioration or adaptation. How do we proceed from here?

The complex linkages among causes and regional consequences of climate change suggest the need for an *integrated* regional assessment, but integrated assessments easily can become unmanageable. Thus we need to choose the key elements and linkages for each assessment component. The bigger the potential costs from climate change, the greater the value of conducting a careful assessment to avoid poor choices. The long time scales associated with climate change inherently involve uncertainties about changes in technology and socioeconomic factors. This suggests an initial focus on climate impacts and corresponding strategies that might make sense even without climate change.

The September 1997 workshop participants anticipated that the U.S. Global Change Research Program (USGCRP) would collaborate with federal agencies (represented in the National Assessment Working Group, NAWG) to sponsor several regional assessments. They also anticipated that an interdisciplinary National Assessment Synthesis Team (NAST), with members in academia, government, and the private sector, would draw upon the assessments to account for regional differences in its synthesis report due to Congress by January 2000.

With encouragement from USGCRP and the U.S. Environmental Protection Agency (EPA), Penn State began assembling a multi-disciplinary team of faculty members to lead the first Mid-Atlantic Regional Assessment (MARA) of Climate Change Impacts. The region to be assessed was expanded beyond the boundaries of the Chesapeake and Delaware Bay watersheds, and now includes all or parts of eight states (NY, NJ, PA, DE, MD, WV, VA, and NC) and the District of Columbia. A draft preliminary MARA report will be ready by April 1999 to meet the NAST schedule.

Penn State's approach is based on a framework developed by its Center for Integrated Regional Assessment (CIRA), as shown in Figure 6, and models such as the one they developed for the Susquehanna River Basin assessment. NAST and NAWG are recommending specific global climate models (GCMs) and socioeconomic projections, to enable aggregation across the regional assessments. Penn State also will use its own empirical downscaling and nested GCM/mesoscale models, which provide finer resolution for regional assessment. The CIRA framework accommodates an iterative approach, with increasingly complex quantitative analysis for important components.

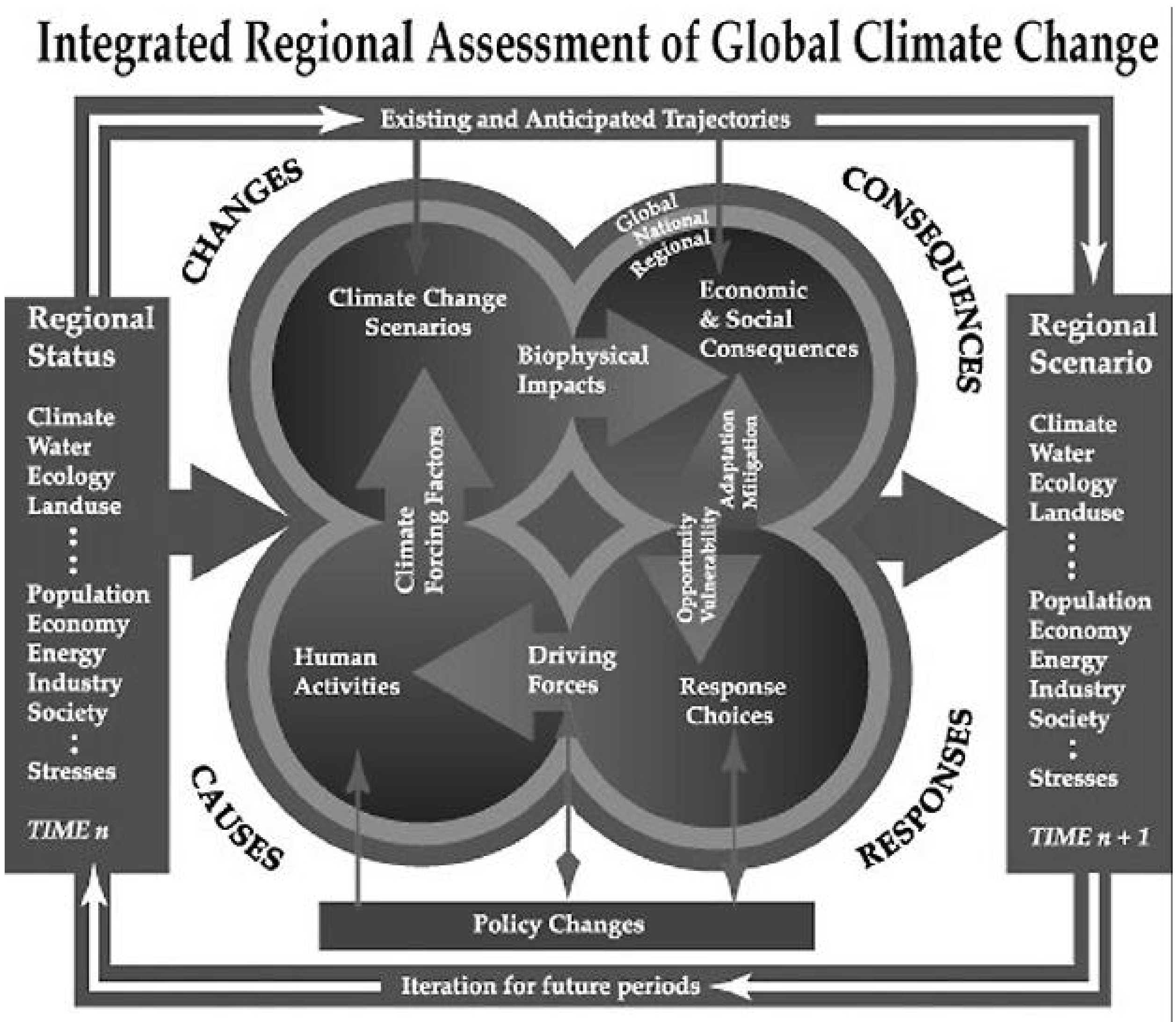

Figure 6. Framework for integrated regional assessment.

The basic questions posed for the September 1997 workshop also will guide MARA:

1. What are the region's current stresses and issues?

2. How would climate change and variability affect these stressors, or create new ones?

3. What new information is needed to better answer questions 1) and 2)?

4. What are the options for coping with climate-induced stresses?

A major MARA objective is to identify strategies for increasing the region's resiliency to climate variability, actions that would reduce negative impacts and take advantage of opportunities created by climate change. Another objective is to identify research needed for evaluating adaptation options.

A June 8-9, 1998 researchers' meeting explored questions raised during Penn State's September 1997 workshop and identified available databases and current research useful for MARA. As a result of this open process, MARA is addressing all five topics being emphasized in the national synthesis– forests, agriculture, water, coasts, and human health– as well as cross-cutting issues such as ecosystems. The MARA report will provide an overview of baseline conditions and how they might be affected by climate change. In-depth case studies will illustrate how impacts will vary within the Mid-Atlantic Region. For example, the assessment is examining potential consequences of forest changes for the timber industry as well as for campers or hunters who use forests for recreation. Farming practices might change with the climate, which could affect the health of waterways, or the safety of water supplies. Examples of other case studies include: potential impacts on fishing; ecological and land-use linkages that might increase mosquito-borne or tick-borne diseases; community water supply managers' information needs for coping with more variability in water sources; and the potential for increased damages from sea-level rise combined with possibly more frequent, more intense storms.

Working groups for each of the five topics include collaborators from other universities and government. The assessment report will bring together information about diverse beneficial and detrimental impacts into a picture of the effects on the region as a whole. More detailed information can be found at http://lumen.deasy.psu.edu/mara/.

To maximize is usefulness, the assessment must go beyond researchers analyzing data and summarizing results. Input from stakeholders (i.e., potentially interested or affected parties) can improve the assessment's usefulness by 1) indicating what information they need to make more informed decisions related to regional impacts of climate change, 2) ensuring the assessment is responsive to climate-related concerns most important to the people who live and work in the region, 3) identifying relevant data not otherwise available to the assessment team, and 4) recognizing that their knowledge of regional and local social, cultural, and political institutions may help prioritize options for building resilience and flexibility within the region.

To tap this resource, Penn State has set up an Advisory Committee with 45 diverse stakeholders, 20 representatives of local, state, and federal government, and 12 researchers (in addition to 15 research collaborators who are working with the core Penn State team). Many of them participated in an October 19-20, 1998 meeting, during which they commented on Penn State's assessment plans and began to explore effective ways to display future results and strategies for disseminating results. About 20 members of the Advisory Committee responded to our December 1998 request for feedback on draft outlines for the working group reports. Their input is helping to shape the continuing stages of the assessment. At a May 2-3, 1999 meeting, the Advisory Committee will review draft preliminary assessment results and recommend specifics about how to display and disseminate the findings. The draft preliminary MARA report, a more complete report drafted after an additional year of assessment, and supporting documents will be circulated for review, revised and submitted to the NAST.

The regional assessment is still in its early stages. Much work remains and the collective wisdom of stakeholders has only begun to be tapped. Still, the focus on the unique elements of our region is leading the MARA team to clear assessment and research priorities. Understanding these linkages can reduce the uncertainties in assessing impacts within the region. Assessment and research have the potential to identify cost-effective, socially acceptable amelioration and adaptation strategies that will help maintain and enhance the economic and societal vitality of the Mid-Atlantic Region.

APPENDIX

Web Site

Much of the material in this report also is available on our web site for the September 1997 workshop:

www.essc.psu.edu/ccimar

(The "essc" stands for one of our sponsors: Penn State's Earth System Science Center. The last acronym can be remembered as representing "Climate Change in Mid-Atlantic Region.") The printed report integrates material on the web site and adds background material about the watersheds for the Chesapeake and Delaware Bays.

In turn, the web site has information not printed in this report. The web site information has been set up so that it is easy to download for your use. Major additions in the web site include summaries of agenda presentations:

- Kent Mountford, "Chesapeake: History from a Different Perspective"
- Plenary Session on Variability in Today's Climate
- Plenary Session on Climate Change and Regional Impacts
- Plenary Session on How the News Media Report on Environmental Issues
- Synthesis Plenary Session

Perhaps most important, the web site has the complete text and figures from the workshop's Public Address by Joel Scheraga, "Climate Change: What Does It Mean For You?"

Other web site items include:

- Titles of the posters presented by workshop participants. Abstracts are on the web site for many of the posters, with full text for a few of them.
- A photo gallery showing most of the workshop organizers and participants, in working group and plenary sessions
- Video clips of the campus and four workshop speakers
- Letter from Vice President Gore
- Links to related sites

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Working Group Questions

For all participants:

1. How important is climate variability compared to other current stresses and sources of vulnerability?
2. What kinds of physical, social, and economic changes and consequences do you expect if current climate projections are correct? Are the impacts positive or negative? How important are these changes relative to other future sources of stress and vulnerability?
3. Is adequate information available to assess the importance of climate variability and change for the sector(s) and to form adaptation and management strategies? What are the most important unmet information needs?
4. What regional adaptation and management strategies would help in adjusting or counteracting the impacts of climate variability and climate change?
5. Which strategies are most cost effective? Best for social equity? Robust to the uncertainty concerning where, when, and to what degree climate change and variability will occur?
6. What public policy actions or other outside assistance could help implement these strategies?

For leadership teams (long set):

1. Past and current climatic impacts

How important have the effects of climate variability and climate change been on the sector(s) over the last few decades and how important are they currently?

What major changes (i.e., social, economic, technological, and other environmental issues) in the sector(s) are occurring that are not related to human-induced climate change and variability?

How do current climate variability and climate change compare in importance with other current stresses and sources of vulnerability?

2. Future climatic impacts

What major future changes (i.e., social, economic, technological, and other environmental issues) in the sector(s) are expected but are not related to human-induced climate change and variability?

What kinds of physical, social and economic changes and consequences in the sector(s) do you expect as a result of human-induced climate change, if current climate projections are correct?

If current climate model projections are correct, how important is future climate change for the sector(s), relative to other future sources of stress and vulnerability?

Evaluate the degree to which the climate-induced impacts and consequences may be positive or negative for specific groups and for society as a whole.

3. Information issues

What kinds of information are needed to ensure a reasonable assessment of the importance of climate variability and climate change for the sector(s)?

What kinds of information are needed to form adaptation and management strategies in the face of possible climatic variability and climate change?

Do you believe that this information is available but poorly communicated or that new research or partnerships are required to obtain it?

How can the media contribute to greater public understanding of scientific study results about climate change? How can the media contribute to public understanding of long-term trends (in contrast to extreme events)? How can government agencies contribute in these areas? The scientific community? Private industry?

4. Strategies and policy issues

What regional adaptation, management, and economic strategies can be used in the sector(s) for adjusting to or counteracting the impacts of climate variability and climate change? Can climate variability be buffered to reduce impact severity?

How are the strategies affected by uncertainty concerning where, when, and to what degree climate change and variability will occur? Are there any “no regrets” or “low regrets” strategies?

How cost effective are the strategies?

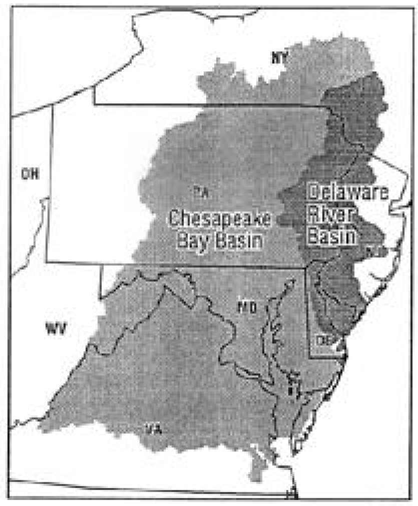
What are the societal impacts of the strategies? Who will benefit and who will lose?

In what ways are existing institutions well, or poorly, structured for facing potential climate change? Are there significant institutional or other barriers to these strategies? How could these be removed? Are there significant public policy actions or other outside assistance that could ease implementation of these strategies?

Workshop on

Climate Change Impacts In the Mid-Atlantic Region

THE PENNSYLVANIA STATE UNIVERSITY
SEPTEMBER 9-11, 1997
Nittany Lion Inn



Sponsored by: The United States Environmental Protection Agency; Penn State's Earth System Science Center and Center for Integrated Regional Assessment in the College of Earth and Mineral Sciences, Department of Agricultural Economics and College of Agricultural Sciences, The Environmental Resources Research Institute, and Office of Research.

The workshop will focus on the watersheds for the Chesapeake and Delaware Bays. Three short white papers will be prepared and distributed to participants in advance.

Final Program

Tuesday, September 9, 1997

[4:30 pm Preliminary meeting of working group chairs, co-chairs, and rapporteurs Colonial II Room]

6:00 - 9:00 pm Registration, reception/mixer, poster session, welcoming address
Board Room and Mt. Nittany Room

7:00 pm **Speaker: Kent Mountford, Chesapeake Bay Program, "Chesapeake: History from a Different Perspective,"** *slide presentation*

8:00 pm **Speaker: Brent Yarnal, Penn State, "The Susquehanna River Basin,"** *slide presentation*

Followed by discussion, and perusal of posters

Wednesday, September 10, 1997

7:30 am	*Registration continues* (continental breakfast)
8:00 am	*Workshop purpose and goals* Assembly Room
8:30 am	*Plenary Session:* Variability in Today's Climate in the Mid-Atlantic Region **Chester Ropelewski, NOAA/National Weather Service**
9:00 am	Perspectives on Current Impacts and Adaptation to Climate Variability in the Mid-Atlantic Region **Panel: Tom Cronin, Office of Science and Technology Policy** **John Carberry, Dupont** **Joanne Denworth, Pennsylvania Environmental Council** **Jonathan Patz, The John Hopkins University**
10:00 am	*Break*
10:15 am	Our Changing Climate: Observed and Expected Future Changes in the Region's Climate **Eric Barron, Penn State University**
10:45 am	Linking Projected Climate Changes to Regional Impacts - Integrated Regional Assessment Overview **Rosina Bierbaum, Office of Science and Technology Policy**
11:15 am	Perspectives on Regional Vulnerabilities to Climate Change **Panel: Larry Kalkstein, University of Delaware** **George Segelken, Cigna Corporation** **John Reilly, U.S. Department of Agriculture/Economic Research Service** **Benjamin DeAngelo, Natural Resources Defense Council** **John Topping, The Climate Institute**
12:30 pm	*Working Lunch* Ballroom C
2:00 pm	*Working group sessions:* Group discussions, led by a session chair, co-chair, and rapporteur will consider both the Chesapeake and Delaware Bays and their drainage basins and will emphasize: ▪ what we know now from the science, ▪ how this is related to identified vulnerabilities, ▪ major gaps in information (e.g., data, scientific understanding), ▪ what coping measures might be used and barriers to adopting them, ▪ priorities for research • to improve estimates of regional consequences from climate change • to identify adaptation and resource management strategies for reducing regional vulnerabilities to climate change impacts

Topics and leaders

- economic growth, industry and commerce (including energy and transportation) Ballroom D
  Jon Plaut, Joanne Denworth, Dave Schwarzwaelder
- ecosystems Mt. Nittany Room
  Dan Botkin, Tom Cronin, Barbara Levinson
- water resources (quantity and quality) Colonial I
  Gwynne Schultz, Irene Brooks, Ken Frederick
- natural hazards Assembly Room, Ballroom A
  Dick Halgren, Peter Eisenberger, Wanda Haxton
- human health Writing Room 3, Ballroom B
  Jonathan Patz, Lynne Carter, Lewis Gilbert
- agriculture, forestry and fisheries Ballroom E
  John Reilly, Pierre Crosson, Charles Krueger

3:15 pm *Break*

3:30 - 5:00 pm Working group sessions continue

[5:15 - 6:00 pm Meeting of working group, chairs, co-chairs and rapporteurs
Assembly Room]

7:30 pm *Public Address:* **Joel Scheraga, EPA**
"Climate Change: What Does It Mean For You?"
26 Hosler Building

Thursday, September 11, 1997

7:30 am *Continental Breakfast*

8:00 am *Plenary Session:* How the News Media Report on Environmental Issues
Ballroom C
Panel: **Bud Ward, National Safety Council, Chair of Panel**
Tom Horton, Baltimore Sun
Jeff Lawson, WVEC-TV, Newport News, VA
Brad Bell, WJLA-TV7, Washington, D.C.

9:30 am Reinforce charge to groups: to develop recommendations about (a) research agenda for the region, (b) follow-up activities in the region, and (c) regional input/results to support national assessment of climate change impacts.

9:45 am *Break*

10:00 am *Working group sessions* continue

noon *Working Lunch*
Assembly Room

1:15 pm *Plenary Session:* Synthesis Panel
Ballroom C

1:15 pm Workgroup reports from rapporteurs and discussion

2:45 pm Synthesis and Future Needs, **Baruch Fischhoff, Carnegie Mellon University, overall rapporteur**

3:45 pm Concluding remarks

4:15 pm Workshop adjourns

[4:15 - 5:00 pm Working group chairs, co-chairs, and rapporteurs meet
Colonial I Room]

Letter from Vice President Gore

THE VICE PRESIDENT
WASHINGTON

September 9, 1997

Dear Participants in the Mid-Atlantic Climate Change Impacts Workshop:

I want to express my regret at not being able to participate personally in your Workshop on Climate Change Impacts in the Mid-Atlantic region. More importantly, I want to commend all of you for beginning the critical process of assessing the implications of climate change for the ecosystems and economy of the Mid-Atlantic area. It is only through the combined efforts of all concerned parties, including the university community, business leaders, state and federal government, and citizens, that we can develop the understanding we need to confront the challenge of climate change.

I am convinced of the seriousness of this global problem, and the fact that many of the most significant effects of climate change are manifested at the regional and local levels. Just last week, I visited Glacier National Park, where all of the glaciers are disappearing rapidly and are predicted to be completely melted within the next 30 years. It was an overwhelming experience to hike up to the Grinnell glacier, and walk across the hundreds of yards of rock that used to be covered by the ice. Similar retreats are taking place all over the world. This melting may be powerful evidence of the warming that we have already experienced over the last century, along with measurements of temperatures, sea-level rise, and increases in precipitation. Ice core data show that CO_2 levels are already higher than they have been in the last 160, 000 years, and if we continue along our current path we are headed for the highest levels in 50 million years by 2100. The best minds of the scientific community agree that we face a wide array of negative impacts to human health and ecosystems.

The Clinton-Gore Administration is determined to take the necessary steps to protect the environment for future generations. Developing a detailed understanding of regional consequences and texture of change is a necessity if we are to craft effective strategies that preserve environmental quality and long-term economic prosperity together. I eagerly await the final report of your Conference. It will be extremely valuable as we design future research budgets and undertake the first national assessment of climate change impacts. Thank you all for your dedication and contributions to this endeavor.

Sincerely,

Al Gore

Al Gore

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