# PREPARING FOR A CHANGING CLIMATE

*The Potential Consequences of Climate Variability and Change*

## Mid-Atlantic Overview

*A Report of the Mid-Atlantic Regional Assessment Team*


*Compiled by*

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## About this publication

This report summarizes the methods, findings and recommendations from the first 18 months of the Mid-Atlantic Regional Assessment (MARA) of potential impacts from increased climate variability and change. The MARA examines both beneficial and damaging impacts, accounting for how people and ecosystems are likely to respond to these changes.

This overview is intended for use by federal, state and local elected officials and by people in their role as citizens, employees, and members of the community. It also gives regional texture intended to complement the national overview report being prepared by the National Assessment Synthesis Team (NAST).

Our assessment includes two key features: 1) an interdisciplinary approach using the best science available, and 2) substantial stakeholder participation. Aided by financial support from the U.S. Environmental Protection Agency (EPA), Penn State's MARA team (i.e., the core faculty, research associates and assistants, and external collaborators, listed in Appendix A) is commited to an integrated assessment approach. Few studies have taken an integrated approach at the scale of a region such as the Mid-Atlantic, so our initial plan was to demonstrate the MARA approach on two or three sectors likely to be affected by climate change. Meetings with our Advisory Committee confirmed available research that suggests a broad range of potential impacts, with none overwhelming the others for this region. This convergence of scientific implications and stakeholder interests led to assessing impacts for each of the following: agriculture, forests, water resources, coastal zones, ecosystems and human health. The assessment focuses on the year 2030 because the discussion of impacts for 2100 (the other date emphasized in the National Assessment) is necessarily more speculative.

Enthusiastic teamwork has accomplished an astounding amount on a very compressed schedule. My thanks to each MARA team member for his or her work. Appendix A lists the full team as well as those on our large Advisory Committee. Synergism between researchers and the Advisory Committee has resulted in many modifications and improvements as a result of their input and feedback. On behalf of the MARA team, thanks to the Advisory Committee members for their insights and thoughtful responses. Special thanks to EPA Project Officer Janet Gamble. Thanks also to Ron Smart of Elemental Media for the report's layout and to Grabhorn Studio for the cover design.

Three features can help in getting the most from this report: 1) The glossary in Appendix D, 2) the list of acronyms in Appendix E, and 3) a broad range of information available on the MARA web site http://www.essc.psu.edu/mara/. More technical information about the MARA will appear in a special issue of Climate Research, to be printed in Spring 2000. Even more detail will be in a longer Foundations report, expected to be on the MARA web site by July 2000.

A draft of this overview was circulated widely for peer review. This revision responds to more than 40 sets of comments from a broad range of experts and stakeholders. The MARA team appreciates their constructive input. Full documentation of our responses to the comments appears on the MARA web site: http://www.essc.psu.edu/mara/.

We welcome feedback so that we can maximize the usefulness of our continuing assessment efforts (e-mail: fisherann@psu.edu; phone: 814-865-3143; fax: 814-865-3746; mail: PSU/AERS, 107 Armsby Building, University Park, PA 16802).

Ann Fisher
February 14, 2000

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# *Executive Summary*

## Purpose

The U.S. Global Change Research Program (USGCRP) and federal agencies are sponsoring 16 regional assessments across the nation—including the Mid-Atlantic Regional Assessment (MARA). The goal is to identify:

- how people and their surroundings are affected now by climate variability and how they will be affected by climate change,

- how individuals and communities can take advantage of opportunities and reduce vulnerabilities resulting from climate variability and change, and

- what additional information and research are needed to improve decision-making related to impacts from climate variability and change.

The assessments are challenging because of uncertainties in projecting both climate change and how our society will evolve – with or without climate change. These assessments rely on multi-disciplinary integrated approaches and broad stakeholder participation to ensure that the most important questions are examined and that the findings are useful.

## The Mid-Atlantic Region (MAR)

The Mid-Atlantic Region, or MAR, includes all or parts of eight states (NY, NJ, PA, DE, MD, WV, VA, and NC) and the District of Columbia. More than half of the region's 35 million people live in Philadelphia, Pittsburgh, Baltimore, Washington, Richmond, and Norfolk. (New York City is the topic of another assessment.)

The region's annual economic output amounts to about 13 percent of the nation's. Manufacturing and Services are the largest economic sectors, accounting for 26 percent and 20 percent of MAR output respectively. Agricultural production covers 25 percent of the region's land and Forests cover nearly 65 percent, but each represents only about 1 percent of the region's gross output.

The region's relatively large population (15 percent of the nation's population in 5 percent of the contiguous land area) and development have stressed many of its ecological resources, including the nation's two largest estuaries, the Chesapeake Bay and Albemarle-Pamlico Sounds, as well as the Delaware River basin.

Over the last century, the average annual temperature in the MAR has been about 52°F, and average annual precipitation has been about 41 inches. Although there have been upward trends in the last century's precipitation (of about 10 percent) and temperature (of about 1°F), the year-by-year and decade-by-decade variations in extreme events such as droughts and floods are far more noticeable than these small changes in average conditions.

## Projecting future socioeconomic status and climate

In 1900, it was difficult to predict the 20th century's dramatic socioeconomic changes, ranging from the decline in farm employment that accompanied huge increases in agricultural productivity to the dependence on computers. The picture for the year 2100 is just as unclear. Even so, socioeconomic projections are a starting point for developing plausible scenarios that establish ranges for how sectors might be affected by climate change. The USGCRP provided high, medium and low projections of population, income and employment growth for the region, assuming no climate change. These scenarios serve as a baseline for identifying incremental socioeconomic impacts from changes in climate.

The USGCRP also provided scenarios from two state-of-the-art global climate models (the Hadley model from the Hadley Centre for Climate Prediction and Research in Great Britain, and the CCC model developed by the Canadian Centre for Climate Modeling and Analysis), to enable comparisons across regions. As is the case for the socioeconomic changes, these provide plausible ranges rather than predicting what actually will happen. Both models account for increasing emissions of atmospheric greenhouse gases (which tend to increase global surface temperatures) as well as sulfate aerosols (which tend to reduce surface temperatures).

Despite these similarities, the models produce quite different results. For the MAR, Figure E1 shows their projected differences in maximum temperature and precipitation. Both show warming by the year 2030; the CCC model shows much more warming by 2100. However, the Hadley model shows substantial increases in precipitation while the CCC model does not. Two earlier studies used high resolution empirical and numerical models to extract regional information from a third global climate model (GENESIS). These studies projected an increase in MAR precipitation, similar to the Hadley results. Because of the uncertainties in projecting future climate, especially at a regional scale, we use the model results in Figure E1 to represent plausible ranges for changes in MAR temperature and precipitation, rather than predictions of what actually will happen at any particular place or time.

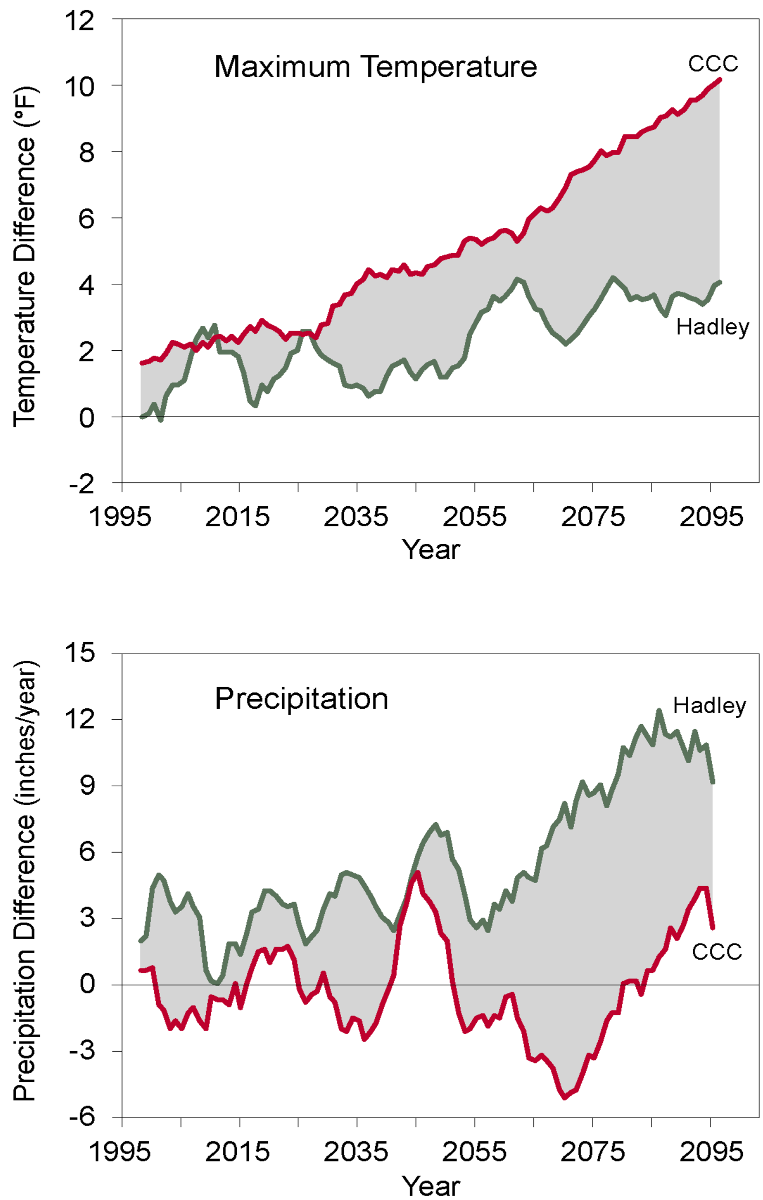



*Figure E1. Hadley and CCC model differences from the observed 1960-1989 base period, for the MAR.*

## How people and their surroundings will be affected by climate change

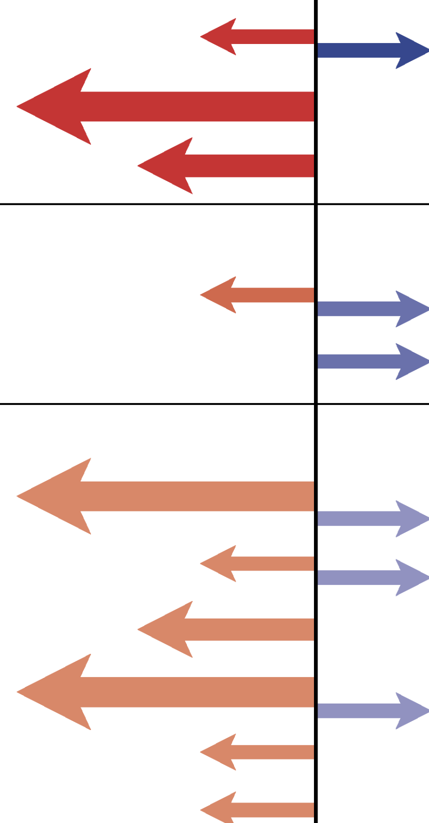
The assessment is based on the convergence of climate model projections that the MAR will be somewhat warmer and perhaps wetter, with potentially more variability in climate. Table E1 summarizes impacts from climate change that might occur in the MAR by the year 2100. Because of the large uncertainties about projecting changes in the region's climate, economy, and ecosystems, we put the impacts in categories according to their likelihood. The size of an arrow indicates an impact's expected magnitude in relative terms.

Most certain, climate change in the MAR is likely to increase slightly its **agricultural production** of soybeans, and possibly corn and tree fruits, while making tobacco less competitive. Enhanced sea-level rise almost certainly will occur, with the potential for substantial damage to the **coastal zone**'s structures, wetlands and estuaries, and to water supplies because of salt water intrusion. Increased temperatures will make urban heat stress more likely; although the change is relatively large, heat stress will remain a small factor in the region's **health status**.

In the moderately certain category, **forests** might grow a little faster, but extreme events could disrupt the pattern of revenues from MAR forestry operations. People also might experience even fewer health impacts from cold stress.

More uncertain is the potential for very large negative impacts on MAR **biodiversity**, especially because many plants cannot migrate quickly and because plants and animals may not be able to negotiate barriers such as mountains, cities, or sea walls. These negative effects might be offset

| **Table E1. Summary of MAR Impacts** | Negative Impact / Positive Impact |
|---|---|
| Most Certain | |
| • *Agricultural production* | |
| • *Coastal zones* | |
| • *Temperature related health status (urban heat stress)* | |
| Moderately Certain | |
| • *Forestry production* | |
| • *Temperature related health status (cold stress)* | |
| Uncertain | |
| • *Biodiversity* | |
| • *Fresh water quantity* | |
| • *Fresh water quality* | |
| • *Ecological functioning* | |
| • *Vector and water-borne disease health status* | |
| • *Environmental effects from agriculture* | |



slightly by faster growth in warmer, wetter conditions. Also uncertain are impacts on water quantity and quality. Additional precipitation will increase stream flows, making more water available for public water supplies in most years. If the additional precipitation tends to be from thunderstorms or rapid snow melt, runoff could make stream flows more variable. Greater year-to-year variation in precipitation combined with higher temperatures means that streams could still go dry in some years. Thus although there may be a slight increase in available water, **water quantity** may be slightly more variable because of droughts and floods. Fresh **water quality** may suffer moderately from sediments and contaminants flushed into streams or well casings by thunderstorm runoff and rapid snow melt. There also could be large impacts on **ecological functioning** as in a less diverse mix of forest species. There would be less habitat to support cold water fisheries but more for warm water fisheries. Another example is the potential for a mismatch between when birds migrate and when key food sources are available for them. Biodiversity and ecological effects could be among the region's largest impacts—but are very uncertain. Other uncertain impacts are expected to be much smaller, such as the potential for climate change to induce more **disease** carried by insects and animals or from contaminated water. Another example is the potential for nutrient leaching and runoff from livestock production to increase the **environmental damages** from agriculture.

Economic analysis suggests that the MAR ***economy*** will be resilient to projected climate change. The region's diversified, technologically advanced economy is highly integrated with the rest of the United States and the world and has relatively little dependence on climate-sensitive economic sectors. Although there are exceptions (e.g., settlement along coasts and in flood plains), economic, technological, institutional and behavioral changes generally have reduced the region's vulnerability to the prevailing climate. Examples include the huge decline in the relative importance of climate-sensitive economic activities (agriculture and forestry), the regional diversification of food and energy supplies, the climate-controlled structures in which we live, and advances in disease prevention and treatment. We expect similar adaptations to occur in response to climate change.

The MARA suggests that climate change poses diverse and potentially large risks to the region's ***ecosystems***. Lingering effects from earlier degradation are compounded by continuing pressures on many of the region's ecological resources at a time of growing societal demand for ecological resource protection, both for its own sake and for recreational uses.

Table E1 shows that the MAR can expect both positive and negative impacts from climate change. Despite efforts to identify as many positive impacts as possible, results show that benefits are fewer and smaller than potential damages. The impacts will make some of the region's citizens and organizations better off while making others worse off, so that the *distribution of impacts* is also an issue. These features—substantial overall economic resilience in concert with pressure on ecosystems and concern about inequitable impacts for vulnerable groups—are the region's starting point for taking advantage of new opportunities and coping with negative impacts from climate change. Rather than a straightforward summation of simple measures, overall social well-being is a complex agglomeration of economic, ecological and distributional considerations. Thus the MARA findings provide insights for making better decisions under uncertainty, with the goal of optimizing social well-being.

# *Setting the Stage*

## Chapter 1. Introduction

The summer 1999 widespread drought in the Mid-Atlantic region followed by the largest peace-time evacuation in U.S. history to protect people from Hurricane Floyd are reminders of how much weather and climate influence people and their well-being. Growth in population and the corresponding increase in impervious surfaces lead to more severe impacts from the same shortfall in precipitation, or from the same intensity of hurricane. It is challenging to understand interactions among influences such as population growth, changes in land use, and climate variability, to determine the seriousness of consequences from these interactions, and to evaluate options for moderating undesirable consequences. Fortunately, emerging integrated assessment techniques can help with such challenges.

Integrated assessment uses diverse perspectives and many types of expertise to focus attention on the most important aspects of a societal issue (Carter et al. 1994). Integrated assessment can identify which influences will make the situation better or worse, and accounts for the interaction among influences. It can be a starting point for evaluating individual, community and societal actions to improve the situation. It also highlights what is known and what is not known about the issue and alternative actions. The assessment process described here examines the regional implications of climate change. The results are intended as input for making smarter decisions in the Mid-Atlantic region, as related to climate change. However, the description also can be the basis for similar integrated assessments of other issues, ranging from population growth to land use change to education to health care.

### The Mid-Atlantic Regional Assessment (MARA) as part of a national assessment process

The impacts of climate variability and change will differ across regions, and people will experience these impacts where they live. Some (but not all) of the processes regulating vulnerability to climate change operate at local scales and could be missed in aggregate national and global studies. Recognizing this, the U.S. Global Change Research Program (USGCRP) has been collaborating with federal agencies (represented in the National Assessment Working Group, NAWG) to sponsor 16 regional assessments that span the nation and its territories. The USGCRP also is sponsoring nationwide assessments of five cross-cutting “sectors”: coastal areas and marine resources, fresh water, agriculture, forests, and human health.

The over-arching goal is to provide scientific information useful to society by identifying how people and their surroundings will be affected by climate change, how individuals and communities can take advantage of opportunities and reduce vulnerabilities resulting from climate change, and what additional information and research are needed to improve decisions related to impacts from climate variability and change. (Note that these assessments are not examining the need for, or ways to accomplish, reductions in greenhouse gas emissions; other activities are exploring these issues.) The assessments are challenging because of the uncertainties in projecting both climate change and how our society will evolve – with or without climate change. These assessments rely on multi-disciplinary integrated approaches and substantial stakeholder participation.

An interdisciplinary National Assessment Synthesis Team (NAST), whose members represent academia, government, and business, is summarizing the potential national impacts from increased climate variability and change. The NAST will submit a First National Assessment report to Congress in the year 2000. Appendix B has more information about the national assessment process.

## Goals of this report

This report summarizes the Mid-Atlantic Regional Assessment (MARA) methods, findings, and recommendations. Four questions guide MARA:

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

2. How could climate change and variability affect these stresses, or create new ones?

3. What actions could increase the region's resiliency to climate variability, reducing negative impacts and taking advantage of opportunities created by climate change?

4. What new information is needed to better answer questions 1) and 2) and to evaluate adaptation options?

The MARA goals are to provide information about how the region's climate might change, what the changes might mean for the region's society and ecosystems, and actions that could reduce vulnerabilities or exploit opportunities created by climate variability and change. The results also provide region-specific context for the first national assessment. Another goal is to demonstrate that substantive stakeholder involvement can help focus the assessment so that it is more useful to the people who live in the MAR. This report summarizes progress toward these goals.

## Assessment approach

The MARA approach to these questions is based on an integrated assessment framework developed by Penn State's Center for Integrated Regional Assessment (CIRA) and shown in Figure 1 (Knight et al. 1999). Assessment can begin at any point in the diagram; the logic follows a continuous loop from 1) causes to 2) climate changes to 3) the biophysical and socio-economic consequences of these changes to 4) human responses to the consequences. Dialogue with the policy community and other stakeholders helps identify the most important components and focus the framework's iterative, increasingly complex quantitative and qualitative analyses. The framework diagram also accounts for hierarchical relationships among different scales. MARA is based on the assumption that the causes of climate change are mainly outside the region, but that climate change could engender important interactions among the ecological and physical responses within the region. However, because human responses include actions that in turn generate climate change at a national or global scale, the national synthesis needs to account for the aggregate effects of similar actions across regions.

The first step for the MARA has been to describe the region's land forms, natural resources, demographics, economy and climate as they are at present, with some historical context (Chapter 2). This description provides a starting point for understanding the impacts of climate change. Next, because the region's society and economy will evolve regardless of whether climate change occurs, the second step is to envision that evolution, with special attention to components that are sensitive to climate (Chapter 3). The third step is to assess how the region's climate might change over the next century (also Chapter 3). The fourth step builds on the first three, to assess the incremental impacts from climate change on the MAR (Chapters 4-9). This step accounts for the responses by people and their institutions, as well as ecosystems, to take advantage of new opportunities or to reduce damages presented by climate change. The fourth step also identifies anticipative actions that can be taken now or in the near future that would reduce vulnerabilities or enhance opportunities for the future, plus information and research still needed to improve decisions related to the regional impacts of climate variability and change (Chapters 10-11).

The enormity of the assessment task made it necessary to choose both a set of impact categories and the depth with which each would be examined. The MARA team used several criteria, including: 1) the importance of the impact category to the region's economic, social and environmental well-being; 2) expected sensitivity of the impact category to climate variability and change; and 3) the feasibility of performing a credible assessment of each impact category, given the available time and resources. In applying these criteria, we were informed by existing knowledge about the region's environmental stresses, and expectations about which ones might be affected by climate variability and change. In addition to the team members' prior research and literature reviews, our input was supplemented by participation at the Summer 1997 Aspen Global Change Institute workshop, "Preparing for a US National Assessment," the November 1997 "U.S. Climate Forum," and the Summer 1998 and Spring 1999 workshops, "U.S. National Assessment: The Potential Consequences of Climate Variability and Change." These meetings led to interactions among the teams conducting the regional assessments, the sectoral assessments, and the National Assessment.

Crucial input also came from extensive interaction with stakeholders - those who might be affected by climate change in the MAR or who might make decisions based

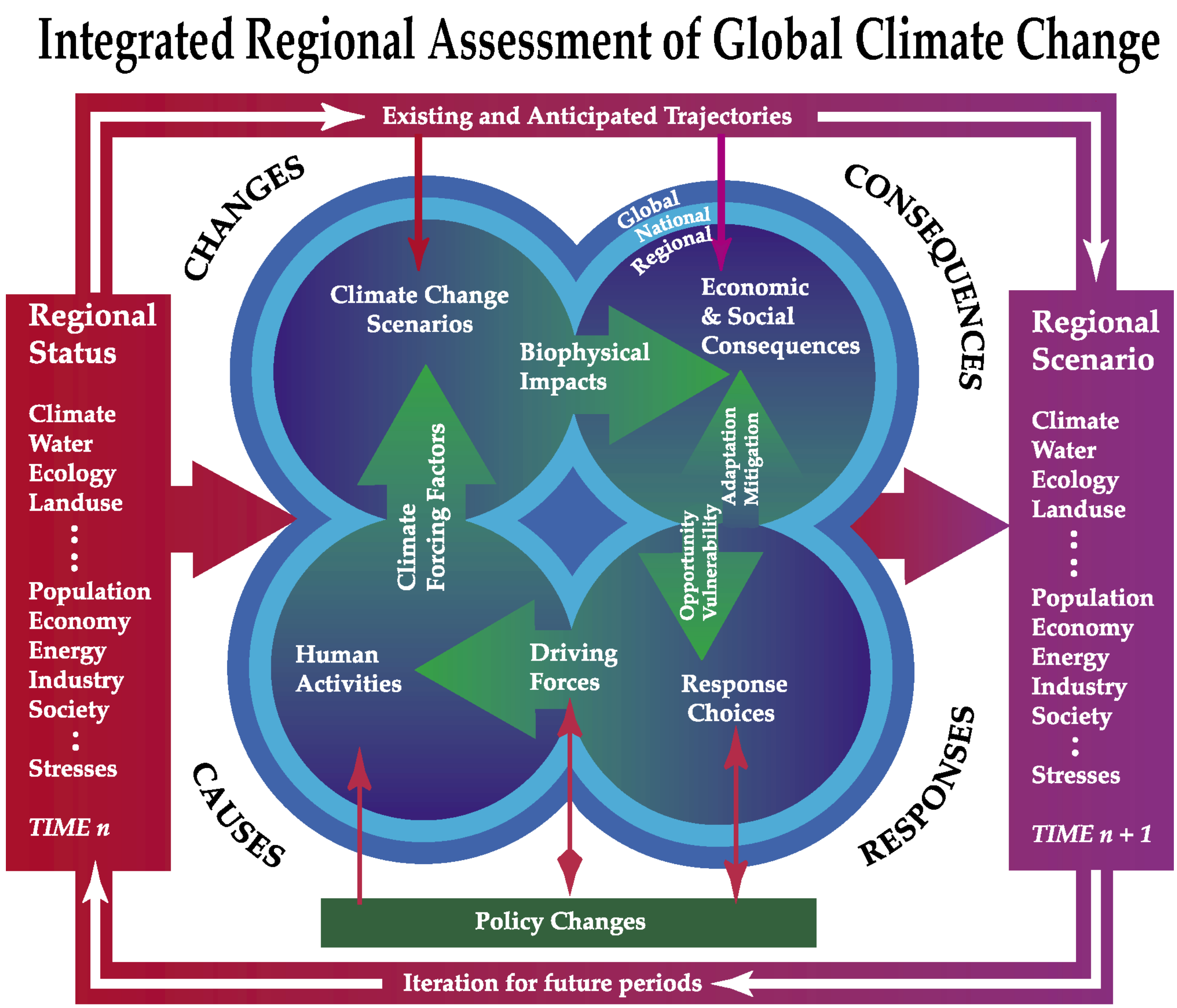



*Figure 1. Integrated Regional Assessment Framework*

on output from the assessment. Much of this interaction has been with the MARA Advisory Committee, which has more than 90 stakeholders and experts. The Advisory Committee has met 4 times for interactive dialog on the MARA plans and progress. Its members also have provided input and feedback on draft outlines, scenarios, an April 1999 draft of preliminary assessment findings, and an earlier draft of this *Overview*. Their diverse perspectives emphasized the need to cover more impact categories than originally planned, often using information for which they had special access or knowledge. Evidence of the MARA team's responsiveness to stakeholder participation is shown by the fact that more than 40 of them took the time to prepare comments on the overview draft. Its revision is more accurate and more useful as a result of their thoughtful feedback. The MARA team particularly looks forward to working with stakeholders to develop messages and dissemination strategies that will make it easier for people to understand how climate variability and change in the MAR might affect their family, their employment, and their community—and what they might do to adapt to negative impacts or enhance positive impacts. Appendix C includes additional information about stakeholder participation in the MARA process.

This report summarizes the methods, findings and recommendations from the first 18 months of MARA activities. The MARA team now is filling gaps in the assessment. Some of these gaps are for components that simply could not be completed during the initial activities; other are for issues identified during the assessment process as potentially more important than anticipated. These include more attention to a) interactions among sectors, b) feedback effects that could strengthen or weaken impacts, and c) consequences for special populations and special places.

## What can we do now?

MARA findings suggest win-win actions that have substantial benefits even if climate stays the same, plus a bonus of making the region more resilient to climate variability and change. The most important actions are to:

- Use a watershed perspective to reduce flood and drought damages and protect water quality (in streams and rivers, lakes and reservoirs, and ground water).
- Remove incentives for practices (e.g., that promote building in areas vulnerable to erosion and flooding) that place people, investments, and (especially coastal) ecosystems at greater risk to climate variability.
- Set up communication and learning tools and programs that help the region's people identify how they can capitalize on benefits and reduce damages from climate change.

The first two strategies would reduce risks from several causes—including climate change. They imply actions (such as preserving forests and wetlands, minimizing urban and agricultural runoff, protecting stream habitat and reducing the release of toxic chemicals) that also reduce ecosystem stresses; although less certain than the large threats to the coastal zone, threats to ecosystems also could be quite large.

## What do we still need to know?

People in the MAR can make better decisions if they know more about potential impacts from climate variability and change and the effectiveness of alternative actions. Knowing more also would reduce uncertainty about the direction and size of impacts in Table E1, making it less likely that the region would face major surprises. The most important information and research needs are to:

- Improve projections for frequency, timing and intensity of average and extreme weather (especially precipitation), at a regional level.
- Improve projections of how average and extreme weather affect agriculture, forests, fresh water quantity and quality, coastal zones, ecosystems, and human health, and how adaptation would moderate negative impacts and enhance opportunities.
- Improve models to evaluate the benefits and costs of alternative adaptation options, so that economic efficiency can be considered in management and policy decisions.
- Improve methods for evaluating how proposed shifts in policy (e.g., health policy, land use policy, agricultural policy) might affect vulnerability to climate variability and change.

More specific recommendations about what can be done in the near-term and the needs for information and research are listed in Chapters 10 and 11.

# *The Mid-Atlantic Region: Present Status and Potential Futures*

## Chapter 2. The Mid-Atlantic Region's geography and economy

### Defining the MAR

Figure 2 shows that the Mid-Atlantic region (MAR) includes all or parts of eight states (NY, NJ, PA, DE, MD, WV, VA, and NC) and the District of Columbia. Several factors influenced the choice of regional boundaries. A primary consideration was the region's major watersheds (Chesapeake Bay, Delaware River basin, Albemarle-Pamlico Sounds, as shown in Figure 3), particularly because of interstate compacts that enable management across political boundaries. For example, small portions of New York are included as parts of the watersheds for the Chesapeake and Delaware Bays.

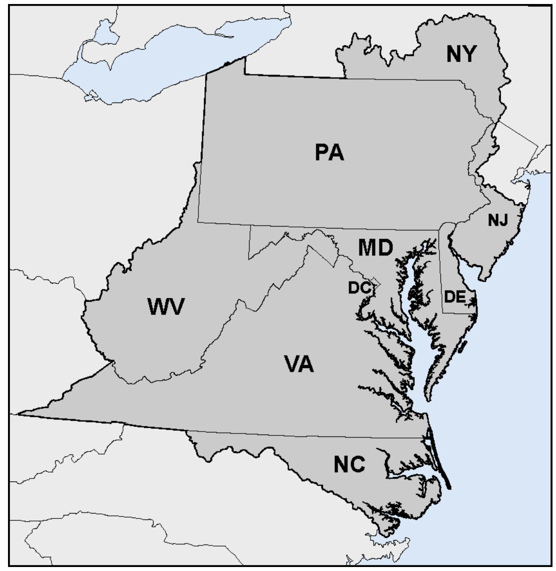



*Figure 2. The MAR, with state boundaries*

A second factor was the need for data on land use, land cover, and ecological characteristics. The U.S. Environmental Protection Agency's (EPA's) Mid-Atlantic Integrated Assessment (MAIA) and Mid-Atlantic Highlands Assessment (MAHA) provide baseline data on the environmental status of PA, WV, MD, DE, VA (and the District of Columbia) (Jones, et al. 1997). Given the economic linkages between the Chesapeake Bay watershed and the areas to its west, and the fact that many environmental and land management decisions occur at a state level, we expanded the MAR to cover all of the MAIA territory.

Third, NJ's western counties are in the MAR as part of the Delaware River basin. We added the southeastern NJ counties to ensure their inclusion among the regional assessments. Remaining portions of NJ, NY and NC are being covered by other regional assessments.

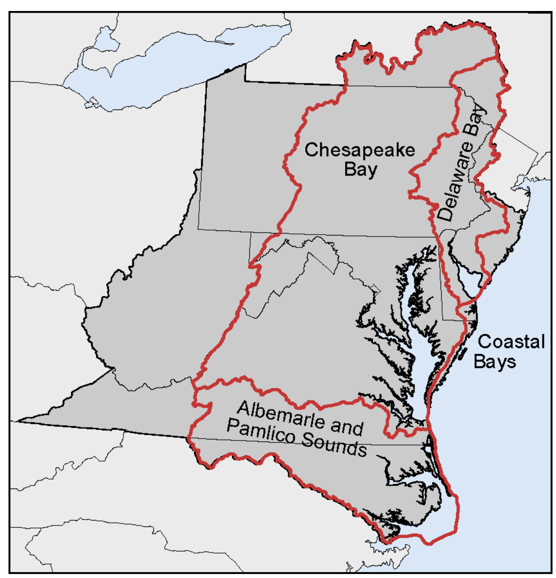



*Figure 3. The MAR, with major watersheds and highlands*

## MAR land forms and land cover

The MAR's 358 counties are in four geographic regions (Cuff, et al. 1989), as shown in Figure 4. The relatively flat Coastal Plain extends inland, traversing all of DE and parts of NJ, MD, VA and NC. The MAR's foothills of the Appalachian Mountains are in the Piedmont Plateau, covering north-central NJ, southeastern PA and central portions of MD, VA, and NC. From northwestern NJ to the southwest through PA, MD, and VA, the parallel eroded mountains are called the Ridge and Valley zone. The Appalachian Plateau extends from the NY portion of the MAR, through northern and western PA, the western edge of MD, and most of WV. This subregion varies from rolling hills to relatively flat areas, with meandering waterways throughout.

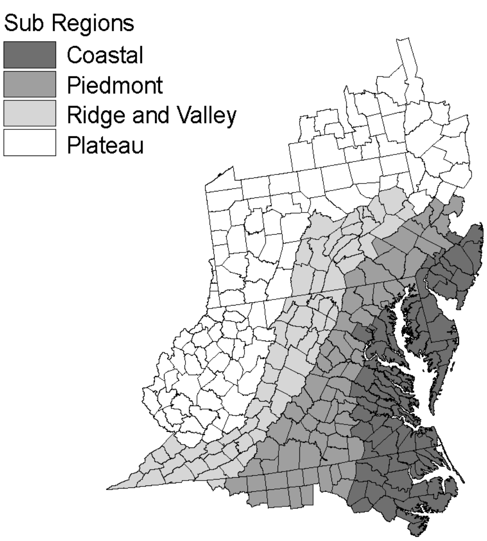



*Figure 4. Geographic subregions of the MAR*

Figure 5 shows the regional distribution of major land cover categories. Going inland, the landscape becomes less agricultural (25 percent of total MAR land cover) and more forested (nearly 65 percent of land cover).

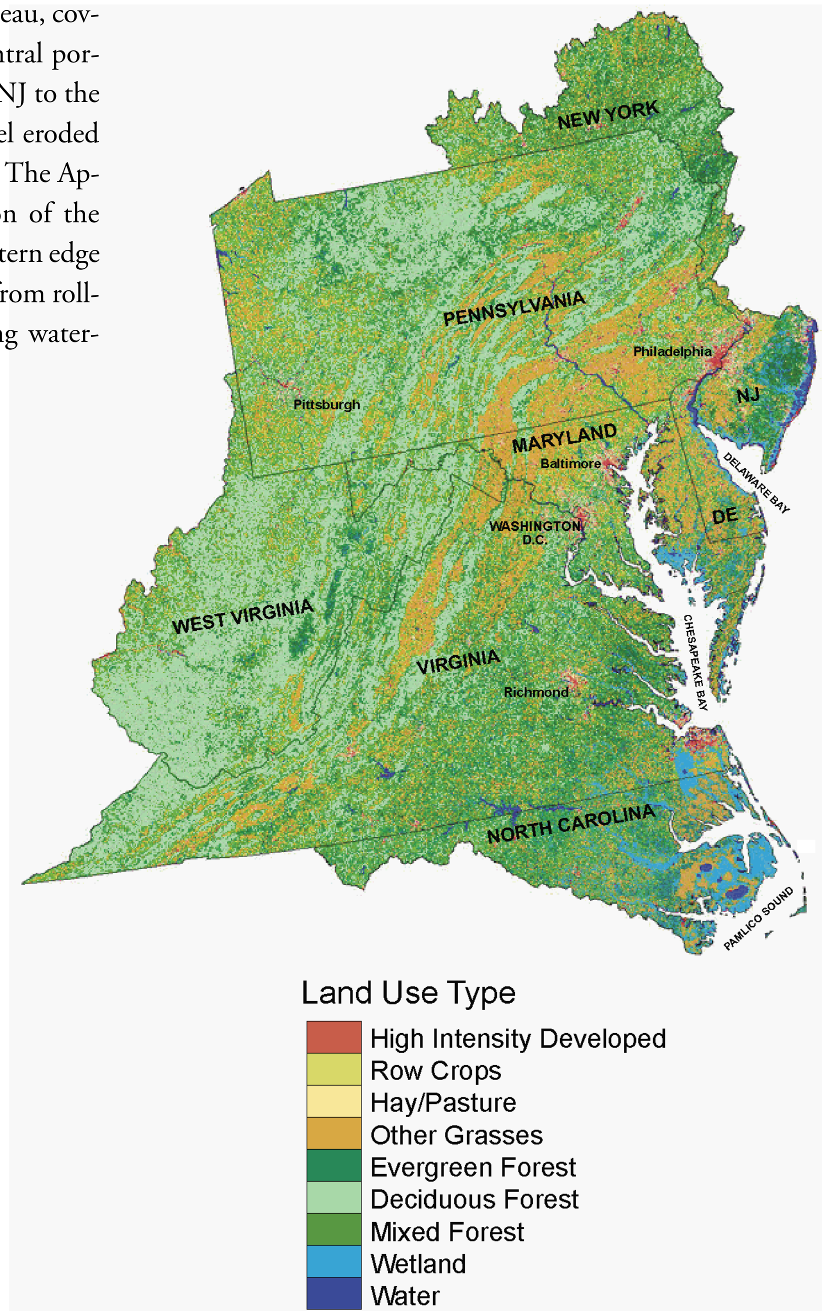



*Figure 5. Mid-Atlantic land cover*

## The MAR population and economy

Less than 4 percent of the MAR's land is urban (Figure 5), but more than half of the MAR's 35.2 million people live in its six largest urban areas: Philadelphia, Pittsburgh, Baltimore, Washington DC, Richmond, and Norfolk (U.S. Bureau of the Census 1998). The region's population growth of nearly 20 percent between 1967 and 1995 (the most recent year for which information is available) is more modest than the nation's growth of 33 percent. Regional growth has been fastest in the retirement-age category (with a decrease in the proportion under 20); 14 percent of the region's population is 65 or older (compared with 13 percent for the nation), with higher shares in the Ridge and Valley (15 percent) and Plateau (16 percent) subregions. About two-thirds of the working-age population, jobs and incomes are in the Coastal Plain and Piedmont subregions (NPA 1998a). For the entire region, jobs increased by 55 percent over the 1967-1995 period, and real per capita income increased by 82 percent.

The region's annual output ($1.67 trillion in 1995) amounts to about 13 percent of the nation's (IMPLAN 1997). Manufacturing and Services are the largest economic sectors, accounting for 26 percent and 20 percent of MAR output respectively. Sectors directly sensitive to climate—Agriculture and Forestry—each represent about 1 percent of the region's gross output.

Input-output analysis shows strong linkages among economic sectors in the MAR, with all industries except Agriculture and Mining (at the broad 1-digit Standard Industrial Classification or SIC level) purchasing between 50 and 80 percent of their intermediate inputs within the region. This means that activity in one part of the region's economy can have ripple effects in other sectors. The region also is highly integrated with economies in the rest of the nation and the rest of the world. For example, imports are 32 percent and exports are 28 percent of the region's total gross output. Agriculture, Mining, and Manufacturing account for the largest shares of this trade. The region's economy also is affected by migration, tourism, and communications. These linkages to other regions provide a buffer against impacts within the MAR. They also transmit impacts from other regions to the MAR.

## Human stresses on the environment

The region's relatively large population (15 percent of the nation's population in 5 percent of the contiguous land area) and economic development have stressed many of its ecological resources, particularly the nation's two largest estuaries: the Chesapeake Bay and Albemarle-Pamlico Sounds. These estuaries, along with the Delaware River basin, are stressed by nutrient runoff from agricultural and urban areas. The region's forests, wetlands, and fresh water streams are affected by habitat loss and degradation, pollution and nonnative invasive species. The primary habitat threats for these ecosystems are forest fragmentation and loss, wetland drainage, stream channelization and dams. Existing and future ecosystem stresses are described more fully in Chapter 8.

## MAR climate

Over the last century, the average temperature in the MAR has been about 52°F and average annual precipitation has been about 41 inches.

### Box 1 Weather and Climate

*Distinguishing clearly between weather and climate can improve understanding of this section. **Weather** is the hour-to-hour and day-to-day state of the atmosphere, such as being rainy or sunny, warm or cold, windy or calm. **Climate** can be thought of as average weather, and encompasses a locale's typical weather patterns as well as the frequency and intensity of storms, cold outbreaks, and heat waves.*

*Some reports define climate variation as natural variation in climate, and climate change as those variations and trends in climate attributable to human activity. For this report, whether the cause of an impact is natural or anthropogenic is less important than whether it has to do with long-term trends or shorter patterns of variation. Thus we use more intuitive definitions: **climate variability** refers to day-to-day, year-to-year, and decade-to-decade patterns of weather and climate. **Climate change** refers to longer term trends in average weather and climate, usually measured by temperature and precipitation.*

Identifying whether climate is changing is difficult because of the complexity of the climate system and the large variations in year-to-year and decade-to-decade weather, the climate system's tendency to change slowly because of the basic physics that determine a locale's climate, and because the record of climate measurements is relatively short—only about 100 years. Over this period, there has been an upward trend in precipitation amounting to about a 10 percent increase. There also has been an upward trend of nearly 1 degree Fahrenheit in temperature. Still, the year-by-year and decade-by-decade variations in extreme events such as droughts and floods are far more noticeable than these gradual trends (Polsky et al. 2000).

From 1901 to 1998, the average number of very hot days per year—at least 90°F—decreased slightly from roughly 20 to 18 in the MAR. Over the same period, the average number of very cold days when temperatures dipped below 0°F increased from 1 to nearly 4 per year. Thus although average temperatures are rising, the MAR is experiencing fewer really hot days yet more really cold days. Variation in the region's climate also shows up in seasonal patterns. For example, the three coldest winters on record were 1976-77, 1977-78 and 1978-79, while some of the warmest winters occurred in 1982-83, 1994-95 and 1997-98.

If we express extreme precipitation events as occurring when precipitation exceeds two inches in 24 hours, then the MAR has slightly fewer of these events now than it did 100 years ago. Precipitation is increasing, but it does not seem to be because of more frequent severe rainfalls and snowfalls.

### Box 2 Climate History in the Mid-Atlantic Region

*Even the short record of measurements can help in understanding climate. For example, observations of winds up to 10 miles above the Earth's surface have been available only since World War II. These show that changes in atmospheric circulation can explain variations in MAR climate. A strong west-to-east atmospheric flow prevailed over North America through the late 1940s and early 1950s (Yarnal and Leathers 1988), producing average to slightly above-average temperatures and variable precipitation over the MAR. Then the circulation shifted to a weaker north-to-south flow that became entrenched by the 1960s. A deep trough of continental polar air and a storm track southeast of its long-term position prevailed during this decade, so that precipitation often fell off the Atlantic coast. This regime led to a relatively cool, dry MAR climate. The MAR experienced higher temperatures and more precipitation when the trough migrated westward during the 1970s. Since the late 1970s, large variations in the shape and positioning of the month-to-month and year-to-year jet stream flow over North America have produced a highly variable surface climate.*

*Insights about earlier climate can be gleaned from cores taken from sediments of the Chesapeake Bay (Cronin et al. 2000), from tree rings (Cook and Jacoby 1977, 1983), and from diaries, newspapers and periodicals (Baron 1995). Such paleoclimate reconstructions suggest as much climate variability in the MAR during the 16th-19th centuries as observed during the 20th century. Especially noticeable are "megadroughts" in the 16th and 17th centuries that were more severe than 20th century droughts, as well as very wet periods that occurred once or twice every century and lasted nearly 20 years. The effects of El Niño-Southern Oscillation events and the North Atlantic Oscillation also are observed in the record (Cronin 1997).*

# Chapter 3. Envisioning the MAR's socioeconomic, environmental and climate future

By definition, regional climate change impact analysis involves comparing what the region would be like "with" and "without" climate change. Climate impact research typically generates climate scenarios using a range of assumptions about changes in emissions of greenhouse gases and other forces that drive climate change. Then societal and other impacts are analyzed, based on the climate scenarios. Because climate change is a long-term phenomenon, this exercise requires consideration of potential economic, demographic, technological, institutional and ecological conditions many years into the future. The MAR, like other regions of the United States and the World, has changed dramatically over the last century, and there is no reason to expect slowing in its pace of rapid economic change. The region undoubtedly will be substantially different in the future than today, in terms of its sensitivity to climate change and potential for response and adaptation. Therefore it is important to envision the impacts of climate change in an evolving society that will differ in many ways from the current society. Our limited ability to forecast reliably beyond just a few years implies large uncertainties about what the future will be like—with or without climate change.

Rather than assuming that a particular future will exist, it is more useful to explore scenarios that could exist, examining the ramifications of those "what if" scenarios. Imagining where we might be headed reduces the complexity and unpredictability, allowing decisions that can accommodate both positive and negative impacts (Schwartz 1991). Developing useful scenarios involves both art and science. The MARA team relied on broad input from experts and stakeholders in identifying crucial scenario components and the ranges that guided the assessments described in Chapters 4-9. The scenario development process and results are summarized in this chapter.

## Socioeconomic and environmental future

In 1900, it was difficult to predict dramatic 20th century changes such as the decline in farm employment that accompanied huge increases in agricultural productivity, the widespread use of computers, or the shift from horses to cars that reduced manure disposal problems in large cities but increased air pollution. The socioeconomic and environmental picture for the year 2100 is just as unclear. For example, population cannot be predicted accurately at a regional level because of the difficulty in predicting regional migration patterns. Similarly, predicting employment and income is complicated by the ease with which technology and other resources move across regional boundaries. Point estimates almost certainly would be incorrect. However, trends and expectations about future labor force participation rates, birth rates, immigration, capital investment and improvements in productivity can be used to calculate ranges for potential population, employment and income. Trends suggest a continued increase in population over the next 30 years in the MAR, with a continued shift to the Coastal and Piedmont subregions. This population growth will create additional pressures for converting agricultural land to urban and suburban uses, especially in the corridor from Norfolk to New York City. In turn, land development is likely to create additional stresses on the region's ecosystems, particularly the Chesapeake and Delaware Bays. General expectations such as these help determine the input for more formal projections provided by USGCRP and shown in Figure 6 (NPA 1998a). These calculations serve as a baseline for the region's future socioeconomic conditions in the absence of climate change. Note that the uncertainties increase dramatically as the horizon moves farther into the future.

These baseline ranges establish upper and lower bounds for socioeconomic conditions on which climate change is overlaid. Within specific sectors, these aggregate projections sometimes are less relevant than more detailed projections of land uses, demand for agricultural products, or technologies. The chapter-by-chapter assessments reflect available detailed projections where appropriate.

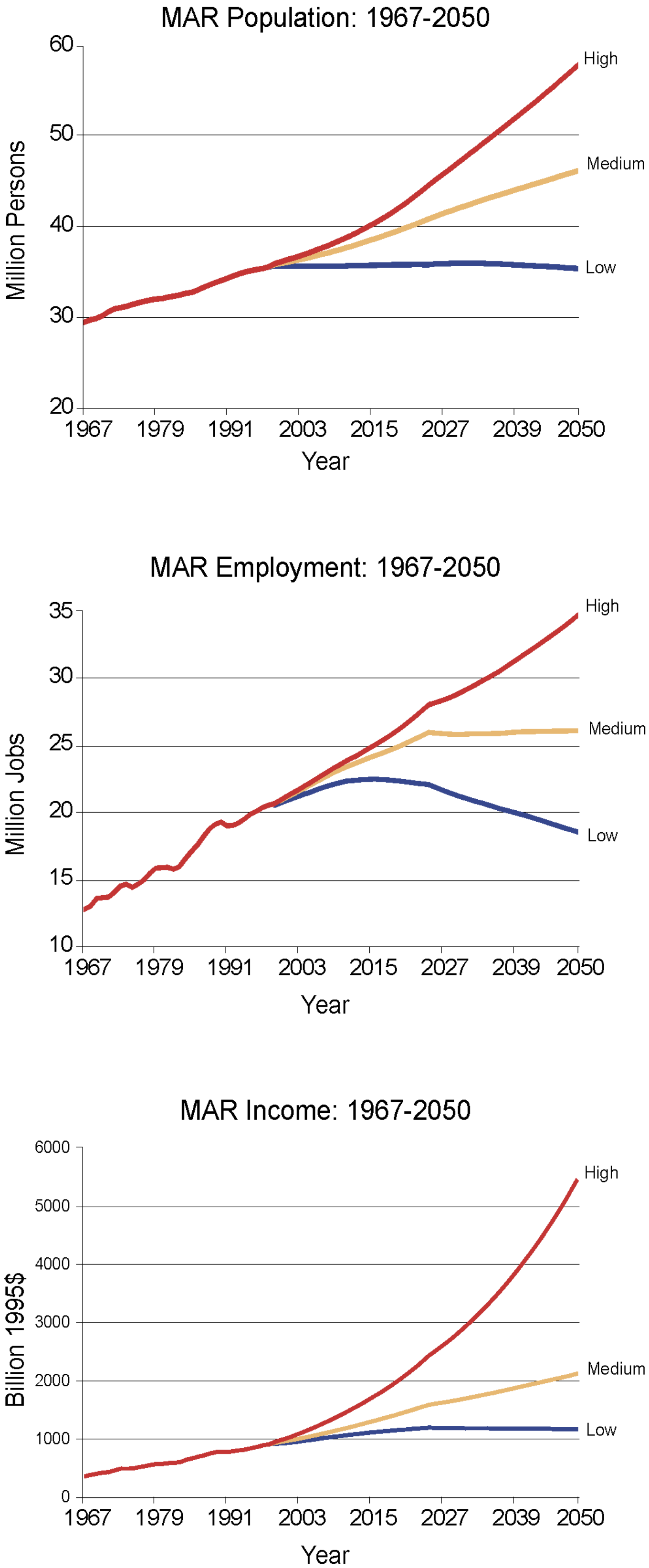



*Figure 6. NPA's Population, Employment and Income Projections for the MAR , to 2050*

The most serious risk of adverse impacts emerges from scenarios that combine the greatest increases in socioeconomic or ecosystem sensitivities with increased climate stresses and little socioeconomic and/or ecological adaptation. For a given climate change, Table 1 shows that large socioeconomic or ecosystem sensitivities to climate variability and change will have small impacts if there are large adaptive capabilities in the socioeconomic structure or ecosystem, but large impacts if adaptive capabilities are small. Similarly, reduced risks or the lower bounds for adverse climate impacts emerge in scenarios that combine reduced baseline socioeconomic or ecosystem vulnerability with substantial ability to adapt. Such tables can be a starting point for examining a range of climate, socioeconomic and ecosystem conditions. Combinations of climate and socioeconomic scenarios with offsetting effects may yield greater or smaller risks. The ranges between the upper and lower bounds could be viewed as confidence intervals.

The set of scenarios is kept tractable by first identifying sectors likely to be sensitive to climate change and then by identifying and selecting risks within those sectors. The resulting scenarios serve as a starting point for identifying incremental socioeconomic impacts from changes in climate. To illustrate, the primary climate-sensitive sectors identified for the MAR are: agriculture, forests, fresh water, coastal zones, and human health—with ecosystems as a cross-cutting issue. Within the agriculture sector, for example, we identified four key potential risks: food availability and cost, agricultural income and employment, rural landscape, and environmental impacts of agricultural production. Because food availability and cost are almost entirely determined by factors external to the region, we chose to focus on the latter three. Similar decisions were made for the remaining sectors.

**Table 1. Potential Size of Climate Impacts.**

| | Socioeconomic/Ecosystem Adaptation | |
|---|---|---|
| | ***Large*** | ***Small*** |
| **Socioeconomic/Ecosystem Sensitivities to Climate** | | |
| ***Large*** | *Small impacts* | *Largest impacts* |
| ***Small*** | *Smallest impacts* | *Small impacts* |

## Future climate

The U.S. Global Change Research Program (USGCRP) provided data from two state-of-the-art global climate models to promote a common ground for developing climate change scenarios across the country. Two models were provided because the organizers of the National Assessment preferred to have data from more than one modeling group to reflect the uncertainties in projecting future climate. They also stipulated that the models had to:

- cover both the last century and the next century,
- use a consistent set of assumptions about the rate of increase in greenhouse gas concentrations and sulfate aerosols, and
- be available prior to the start of the formal assessment process.

Given these guidelines, two models were available—the Canadian Climate Centre (CCC) model, and a model from the Hadley Centre for Climate Prediction and Research in Great Britain.

Both models have done a reasonable job of reproducing U.S. climate trends. For example, Table 2 shows the similarity between observations and model results for a recent decade. We chose 1984-1993 to represent the current situation because of the wealth of socioeconomic, ecological and climate data available for this period.

However, the climate simulations diverge as they run into the future. Both models show increasing temperatures, but with a more rapid increase in the case of the CCC model. Figure 7 shows the U.S. temperature change from

**Table 2. Observed and simulated temperature (°F) and precipitation (inches) for 1984-93. Temperatures are daily maximum temperatures and minimum temperatures.**

| | Maximum Temperature | | Minimum Temperature | | Precipitation | |
|---|---|---|---|---|---|---|
| | mean | standard deviation | mean | standard deviation | mean | standard deviation |
| **Observed** | *63.7* | *16.5* | *41.4* | *15.2* | *43.1* | *4.4* |
| **Hadley** | *63.5* | *17.5* | *41.0* | *15.5* | *42.8* | *3.0* |
| **CCC** | *63.6* | *16.7* | *41.6* | *15.1* | *45.0* | *2.8* |

both models, together with the results from several other models. The simulations tend to fall into two groups, one showing a more rapid temperature increase than the other. The CCC model falls into the former group and the Hadley model into the latter. At this point, there are no grounds for suggesting that any one model or simulation is more accurate or realistic than another, and both models produce climate changes that are possible given the projected changes in atmospheric composition. As is the case for the socioeconomic changes, the simulations produced by these models represent plausible ranges for possible climate change, rather than predictions of what actually will happen for any particular time or place.

Both models were run for the 1992 business-as-usual (i.e., unconstrained emissions) scenario of the Intergovernmental Panel on Climate Change. This scenario provides for a relatively rapid rise in the emissions of carbon dioxide and other greenhouse gases (which tend to increase global surface temperatures) and of sulfate aerosols from coal combustion (which tend to decrease surface temperatures). On balance, the warming effect is significantly larger, hence the upward trend in temperature change depicted in Figure 7.

While virtually all models show a consistent temperature response (an increasing trend with the rate of change varying among models), there is much less consistency in projected precipitation changes. This is also true of the Hadley and CCC models for the Mid-Atlantic region. Figure 8 shows the projected changes in maximum temperature (upper panel) and in precipitation (lower panel) for the MAR. The heavier lines show 9-year running averages, while the finer lines

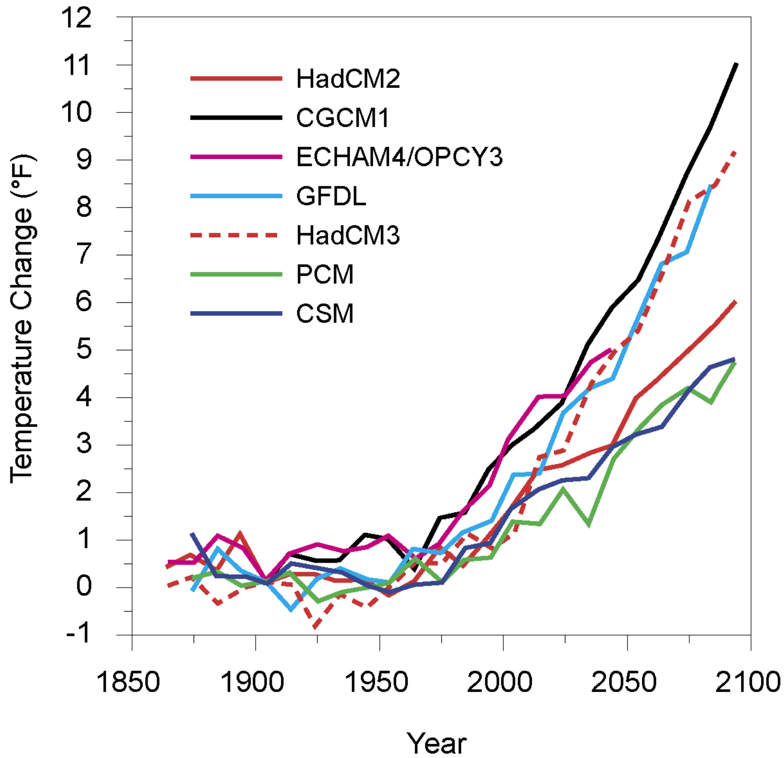



*Figure 7. Simulations for the United States of average changes in temperature from leading climate models based on historic and project changes of $CO_2$ and sulfate emissions. The Red and Black lines indicate the models chosen for use by the National Assessment.*

capture the variability likely to occur annually. Both models show warming throughout the next century. The Hadley model also shows a substantial increase in precipitation by 2100, while the CCC model does not. Two earlier studies of the region used high resolution empirical and numerical models to extract regional information from a third global climate model (GENESIS). These methodologies, referred to as "climate downscaling techniques," provide finer resolutions more appropriate for regional assessments. Both studies projected an increase in MAR precipitation similar to the Hadley results (Crane and Hewitson, 1998; Jenkins and Barron, 1997).

The CCC and Hadley simulations, when considered in the light of the additional downscaling results, suggest that the most likely MAR climate change scenario will show increasing temperatures and increased precipitation across the region. Temperature increases are likely to be on the order of 2°F by 2030 and may increase an additional 3°F to 8°F by the end of the 21st century. There is a high likelihood that average annual precipitation will increase, but the magnitude and seasonal distribution of the increased precipitation is uncertain. The MAR has experienced natural weather disasters and weather extremes at different times of the year. The current spatial resolution of global climate models is not fine enough to show thunderstorms or hurricanes, but both the CCC and Hadley models indicate slight increases in the frequency and intensity of winter storms with little change in storm track over the MAR. Because storm impacts can be substantial, Chapters 4-9 acknowledge the uncertainty and address the implications of more storminess.

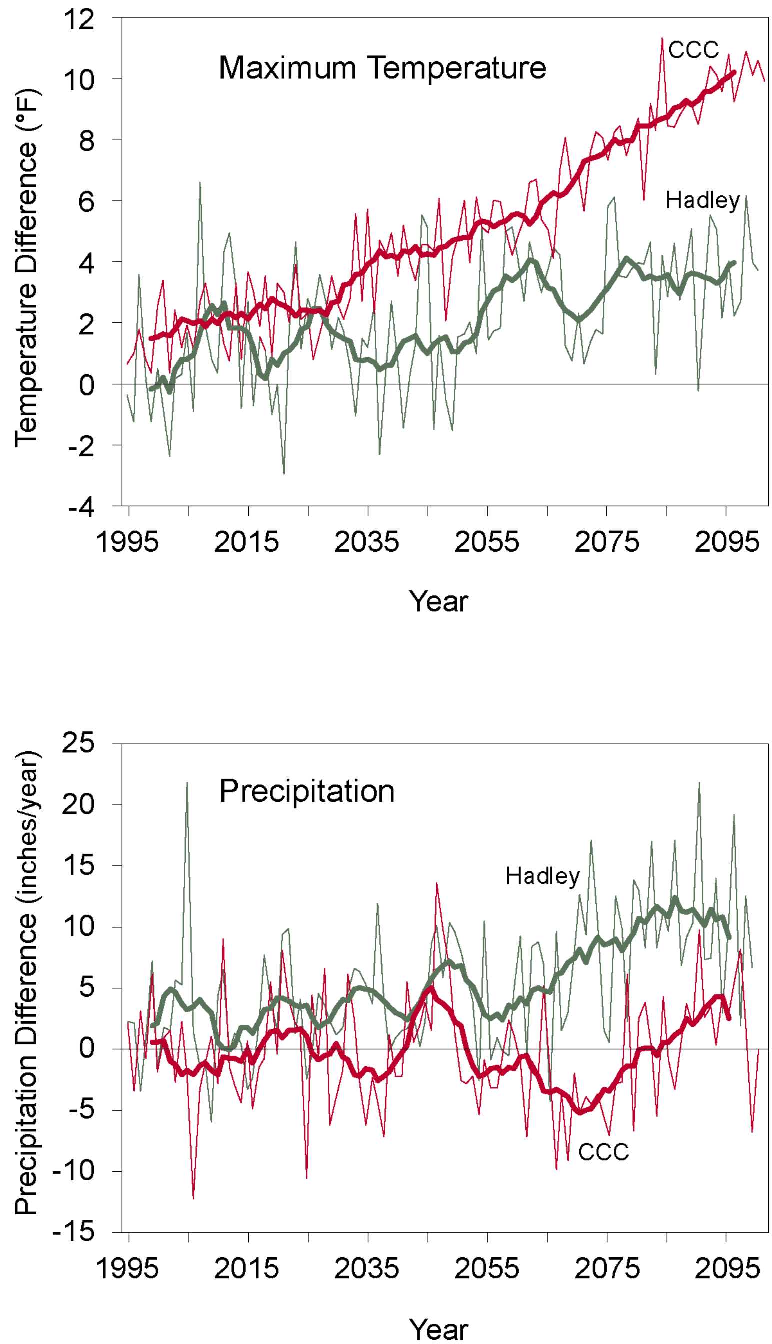



*Figure 8. Hadley and CCC model differences from the observed 1960-1989 base period, for the MAR*

It is also important to note that climate is highly variable from year-to-year and that some of this variability is due to features of the climate system (such as El Niño events) that are not well simulated by current global climate models. This variability will continue and may even increase in the future. On time scales of years-to-decades, the climate in any given period in the next century could be considerably warmer/colder or wetter/drier than indicated in Figure 8. Consequently, Figure 8 should be used only to infer the overall trend in regional climate change.

Table 3 summarizes the climate change scenarios for the MAR, together with projections of other important environmental parameters such as sea level and runoff. An indication also is given of our current confidence in these projections. The most likely change is the rise in atmospheric carbon dioxide ($CO_2$). (The great uncertainty in projections of storminess keeps this category from appearing in Table 3.) These environmental changes are linked with the socioeconomic scenarios to project potential impacts, challenges and opportunities in Chapters 4-9. The assessments in Chapters 4-9 use the scenario information in a variety of ways. Where a quantitative analysis is possible (in the case of stream flow, for example) the Hadley and CCC model projections are used to present a range of possible outcomes. Where only more qualitative assessments are possible, the judgement is based on the generalized trend of increasing temperatures and rainfall. In some cases the assessments use information from prior analyses utilizing different climate models, and details of these models are presented when relevant.

**Table 3. Important projections for the years 2030 and 2095 with respect to 1990.**

| Parameter | 2030 | 2095 | Confidence in projection |
|---|---|---|---|
| **$CO_2$** *(%)* [a] | *+20 to +30* | *+50 to +120* | *Very high* |
| **Sea level** *(inches)* [b] | *+4 to +12* | *+15 to +40* | *High* |
| **Temperature** *(°F)* [c] | *+1.8 to +2.7* | *+4.9 to +9.5* | *High* |
| **Precipitation** *(%)* [c] | *-1 to +8* | *+6 to +24* | *Medium* |
| **Runoff** *(%)* [d] | *-2 to +6* | *-4 to +27* | *Low* |

a. Range reflects IS92d and IS92f $CO_2$ emission scenarios (Watson et al., 1996).
b. Low and high projections of Warrick et al. (1996) for IS92a scenario, plus a local component of 0.008 inches per year.
c. Range given by Hadley and CCC models for the Northeast U.S. (Felzer et al., 1999).
d. For the Susquehanna River Basin, using a water balance model forced with the CCC and Hadley output (Neff et al., 2000).

Some of the assessment results rely on subregional data extracted from the models. For illustration, Figure 9 uses the Hadley model to show the pattern of temperature change for winter and summer average temperatures. The maps depict the simulated temperature change between the average temperatures for 2025-2034 compared with 1984-1993. These data are extrapolated to the higher spatial resolution of the VEMAP grid used to display present-day climate in the National Assessment data sets (Felzer et al. 1999). They do not represent downscaled regional analyses of climate change. Similar maps can be produced for other variables and for the change by 2100 (which, along with 2030, is a benchmark in the National Assessment process). The spatial distribution of the simulated temperature change in Figure 9 apparently reflects some combination of latitudinal effects and the physiographic divisions in the region. The summer-time increases are greater over the Coastal Plain and Piedmont than over the Ridge and Valley and Plateau regions. While regional patterns such as these are quite likely to occur, we can not place too much confidence in the specific grid-cell values shown in Figure 9. Just as is the case for the socioeconomic projections, uncertainties increase as the size of the region becomes smaller. Both the socioeconomic and the climate projections tend to be more reliable for general trends across broad areas than for specific changes in small areas.

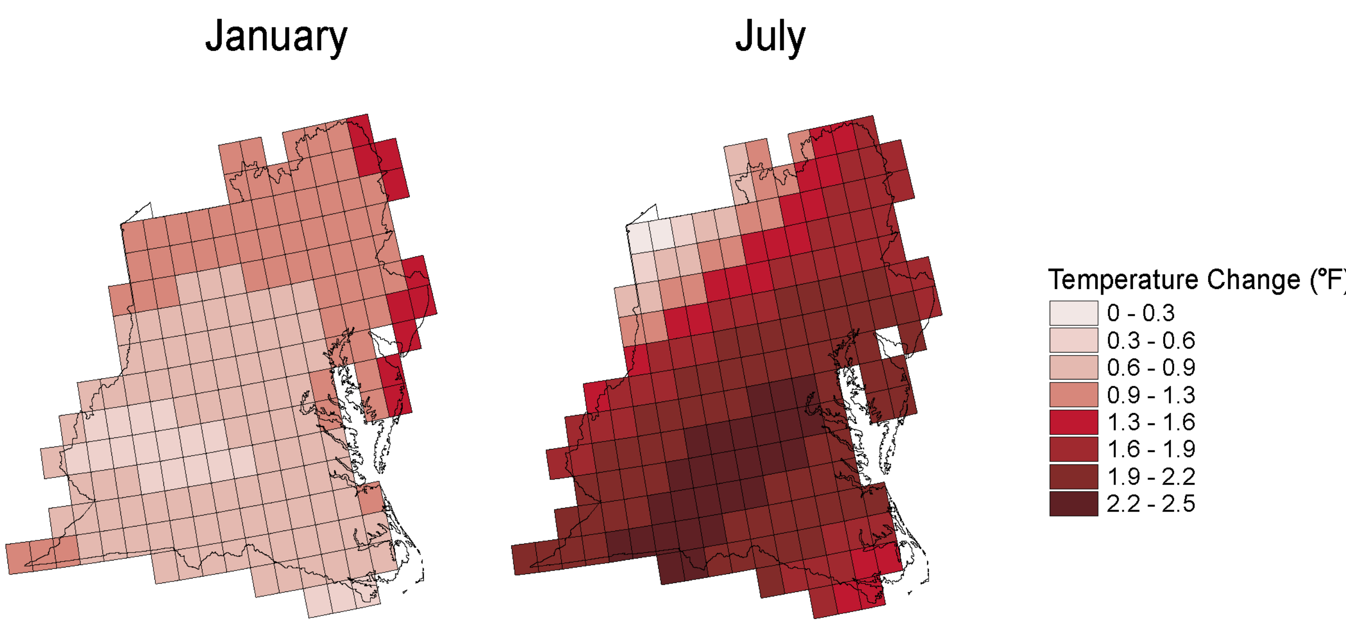



*Figure 9. January (left) and July (right) differences between future (2025-2034) and contemporary (1984-1993) average temperatures for the Hadley model*

# *Impacts, Challenges and Opportunities*

Chapter 3 describes many uncertainties that arise in projecting a) how the population, economy and environment of the MAR will evolve, b) how the region's climate will change, and c) how changes in the region's climate will affect its population, economy and environment over the next 30 and 100 years. The uncertainties are compounded by the fact that different people, man-made systems, species and ecosystems have differing capacities for adaptation to climate change. Despite these uncertainties, this assessment has produced insights about how the region's citizens and decision makers can improve near-term decisions to enhance the long-term future of the MAR. The impacts of climate variability and change summarized in Table 4 are based on climate model projections that the MAR will be generally somewhat warmer and somewhat wetter, with potentially more variability in the region's climate in the next 30 to 100 years; this implicitly presumes that the causes of global climate change will not be abated. Relatively little can be said about the timing of these impacts, except that they would occur by 2100. Although the summary in Table 4 is useful for indicating the relative direction, magnitude, and certainty of potential impacts, management decisions will need more information about the data behind these indicators. Thus sector-by-sector impacts are described more fully in Chapters 4 through 9. These chapters assess agriculture, forests, fresh water, coastal zones, ecosystems and human health. Each chapter covers current status and stresses for that topic, and how climate variability and change would affect the current status and stresses. Actions that might take advantage of opportunities or reduce vulnerabilities, and the most important information and research gaps are summarized in Chapters 10 and 11.

| **Table 4. Summary of MAR Impacts** | Negative Impact | Positive Impact |
|---|---|---|
| **Most Certain** | | |
| • *Agricultural production* | tobacco | soybeans, possibly corn and treefruits |
| • *Coastal zones* | erosion, saltwater intrusion | |
| • *Temperature related health status* | heat stress | |
| **Moderately Certain** | | |
| • *Forestry production* | extreme events | more growth, different mix |
| • *Temperature related health status* | | less cold stress |
| **Uncertain** | | |
| • *Biodiversity* | migration barriers, invasive species | warmer temperatures |
| • *Fresh water quantity* | more variability | more average streamflow |
| • *Fresh water quality* | runoff | |
| • *Ecological functioning* | forest composition, cold water fisheries | warm water fisheries |
| • *Vector and water-borne disease health status* | Cryptosporidiosis, malaria | |
| • *Environmental effects from agriculture* | nutrient leaching, runoff | |

# Chapter 4. Agriculture

Agriculture's dependence on climate makes this sector an obvious candidate for examining potential impacts from climate change. Reflecting national trends, agriculture within the MAR has declined in importance while simultaneously adapting rapidly to changes in production and processing technology and to changing demands for different agricultural products.

Compared to other parts of the nation, the MAR has smaller farms and produces a wider range of crops and livestock (U.S. Department of Agriculture 1999). Historically adequate rainfall has led to irrigation on less than 3 percent of MAR crop acreage, compared to a national average of about 13 percent. Crops account for about one-fourth of the MAR's agricultural land, with the remainder in hay and pasture. About 65 percent of MAR agricultural sales are from livestock and livestock products. However, in the context of the total value of production, which includes both sales and products consumed on the farm and thus not sold, crops are much more important (about three-fourths of total value).

About one-fourth of the MAR's land area is agricultural (Abler et al. 1999), so its presence defines many rural landscapes. Rural and urban populations within and outside the region enjoy agricultural vistas and consider them to be a valuable amenity. Agricultural land is an important habitat for a variety of wildlife species. Agriculture is also a source of negative environmental impacts in the MAR, mainly nutrient and pesticide runoff, and erosion (Kellogg et al. 1997, 1999).

Using the socioeconomic approach outlined in Chapter 3, two baseline scenarios were developed. The first one, called the Status Quo (SQ) scenario, assumes agriculture continues much like it is today in the MAR. However, it is realistic to expect that agriculture will become less important in the MAR because of a) environmental regulations, b) competition from other agricultural areas across the nation and in the rest of the world, and c) higher values for MAR land in uses other than agriculture. These expectations and the expectation that people will learn and adapt are represented in the second scenario, called the More Environmentally Friendly and Smaller (EFS) scenario. Table 5 shows the assumptions for the scenarios.

Table 6 shows how the two scenarios provide upper and lower bounds on positive and negative agriculture-related impacts from climate change. For example, the EFS assumptions provide the upper bound on increased agricultural production; even though agricultural production is smaller than under the SQ scenario, it is much better

**Table 5. Baseline Agricultural Scenarios for the Year 2030 in the Mid-Atlantic Region**

| Scenario | Scenario Assumptions |
|---|---|
| **Status Quo (SQ)** | • Agriculture as it exists today |
| **"Environmentally Friendly" and Smaller Agriculture (EFS)** | • Major decline in field crops<br>• Smaller but significant decline in livestock<br>• Substantially fewer farms<br>• Higher productivity due to biotechnology and precision agriculture<br>• Much more production per farm<br>• Much less sensitivity to climate variability due to biotechnology, precision agriculture, and improved climate forecasts<br>• Conversion of land to urban uses, but slowed by farmland protection programs<br>• Some reforestation of economically marginal agricultural lands<br>• Much less commercial fertilizer and pesticide use due to biotechnology<br>• Less runoff and leaching of nutrients and pesticides due to precision agriculture<br>• Stricter environmental regulations, especially for intensive livestock operations |

**Table 6. Upper and Lower Bounds Established by the Two Agricultural Baseline Scenarios**

| | Negative Impacts on Production | Positive Impacts on Production | Negative Environmental Effects | Positive Environmental Effects |
|---|---|---|---|---|
| **Upper Bound** | SQ | EFS | SQ | SQ |
| **Lower Bound** | EFS | SQ | EFS | EFS |

SQ = Status Quo Scenario
EFS = More Environmentally Friendly and Smaller Scenario

equipped to take advantage of positive climate developments. Correspondingly, the smaller production under EFS assumptions yields lower bounds on environmental impacts (accompanying climate-induced changes in agriculture).

Climate change impacts on each of the MAR's major agricultural products can be analyzed by applying these baseline scenarios. Potential direct impacts from climate change include increased photosynthesis (because higher carbon dioxide concentrations act as a fertilizer), reduced transpiration, warmer temperatures, increased precipitation, changes in extreme weather, and changes in weeds, insects and diseases. (Although potentially important, there is more uncertainty about the extent of changes and their potential impacts for extreme weather, weeds, insects and diseases.) The assessment also considers indirect effects due to changes in farm commodity prices (because of climate change impacts in other regions or countries) and economy-wide effects (because of climate change impacts on prices Mid-Atlantic farmers must pay for inputs, for example).

Table 7, which is part of Table 4, summarizes the assessment results. Because farmers are adaptable, climate change is likely to increase production of soybeans, and possibly corn and tree fruits. Tobacco could become less profitable, mainly because climate change will improve its growing conditions more in areas other than the MAR and thus increase competition from outside producers. The region's other two major agricultural categories, dairy and poultry, are not expected to be affected by climate change.

If livestock production continues to be as important in the MAR as it is now, nutrient leaching and runoff could increase—which could raise the risks of waterborne diseases such as Cryptosporidiosis and of ecological damages to fresh water and estuarine resources from eutrophication. Other impacts on agriculture from climate change are not expected to affect water quality, unless there is a substantial change in extreme weather events. The impacts of changes in agricultural production on rural amenities could be significant, but there has been little research to identify these threats or opportunities.

| **Table 7. Summary of MAR Impacts on Agriculture** | Negative Impact | Positive Impact |
|---|---|---|
| Most Certain<br>• *Agricultural production* | tobacco | soybeans, possibly corn and treefruits |
| Uncertain<br>• *Environmental effects from agriculture* | nutrient leaching, runoff | |

# Chapter 5. Forests

Forests cover about 65% of the MAR's total land area (Figure 5) and support a rich mix of species, from the pine and coastal wetlands regions in the south to the northern upland hardwoods (Jones et al. 1997). The top part of Figure 10 shows the current distribution of major forest types: oak-hickory (46% of forested area), maple-beech-birch (37% of area), and pine and mixed pine-hardwood forests (8% of area) (based on data in Hansen et al. 1992). Dominant hardwood species are red oaks, white oak, yellow-poplar, red maple, sugar maple, black cherry, beech and sweetgum. Softwood forests are dominated by hemlock and by loblolly, shortleaf, and white pines.

Although cut extensively for wood products in the early 1900s, the region's second-growth forests are rapidly approaching maturity. Forest area in the MAR has been relatively stable over the past 30 years, but total standing biomass has increased as forests mature (Powell et al. 1996).

Forest products in this region are primarily sawlogs, pulpwood, fuelwood, and veneer logs, and other products such as maple syrup, nuts and edible plants. The combined total gross output (sales revenue) of forest-related economic activity in 9 sectors (Forest Products, Forestry Products, Forestry/Services, Logging Camps & Contractors, Sawmills, Millwork & Plywood, Other Woodproducts, Wood Furniture & Fixtures, and Paper and Paper Products) in 1995 was $41.8 billion, or 2.5% of the $1,671.1 billion total gross output in the MAR.

MAR forests also provide important nonmarket benefits, including recreational opportunities, watershed and riparian buffers, wildlife habitat, enhanced biodiversity, and aesthetic appeal. Stresses from anthropogenic and natural factors include loss of forest land to urban/suburban development, atmospheric pollution (deposition of acidic compounds and high ground levels of ozone), disease and insects (especially the gypsy moth), deer browsing, and occasional wildfires. Urban/suburban development also contributes to fragmentation of forest tracts, reducing the ability of plants and animals to survive and migrate. Most of the forests (88% of acreage) in the region are privately owned, so management decisions rest largely with non-industrial private landowners.

Insights about potential impacts of climate change can be gleaned from current effects of climate in forests. Because most of the available information was anecdotal rather than representative of MAR forests, we designed, pretested, and revised a questionnaire to determine how weather affects forest operations. The questionnaire was sent to 592 federal and state agencies, consulting foresters, loggers, industrial foresters, and urban and municipal foresters within the MAR; 57 percent responded. Whether forests are managed for watershed protection, harvesting of sawtimber or pulpwood, or maintenance of forest aesthetics and habitat, their managers report increased operating costs when extreme weather occurs.

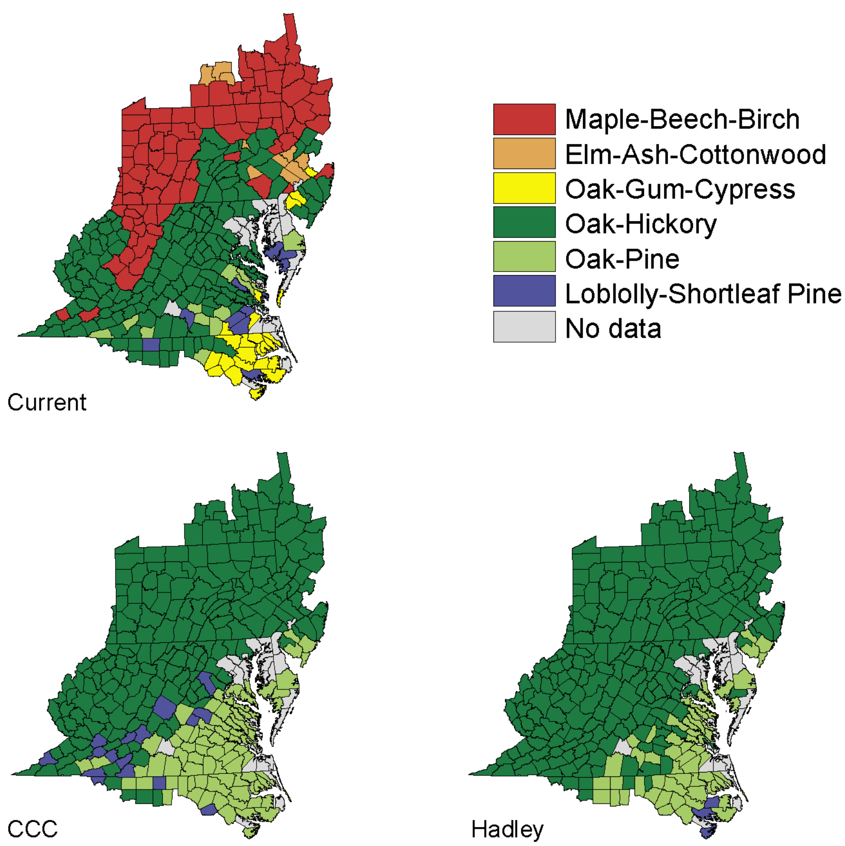



*Figure 10. Dominant MAR forest types for current climate, and potential distributions for CCC and Hadley equilibrium climate scenarios, for a $CO_2$ doubling.*

# Chapter 6. Fresh water quantity and quality

The MAR's annual precipitation average of 41 inches provides water for many purposes. These include power generation, public and private water supplies, industry, agriculture, waste treatment, aquatic and riparian habitat, and recreation on the region's streams, lakes and reservoirs. In the MAR, the dominance of forests and agricultural lands means that evapotranspiration accounts for approximately two-thirds of all precipitation. The rest moves as groundwater or surface water to streams, lakes and reservoirs; both flows are valuable for human and ecosystem use.

Approximately 95 percent of all MAR withdrawals are from surface water (Neff et al. 2000). Thermoelectric power generation withdraws more water than any other use (60 percent of all withdrawals), although much of this water is returned to the watershed rather than consumed. The second and third largest users of water are public water supplies (20 percent) and industry (14 percent). As mentioned in Chapter 4, relatively little MAR agriculture is irrigated, accounting for less than one percent of the region's total fresh water use.

Groundwater use is much smaller than surface withdrawals, but important. Within-region use of groundwater varies from 3 percent of total withdrawals in West Virginia to 15 percent in Delaware and 17 percent in Maryland. Nearly one-fourth of the region's residential water supply comes from privately owned wells. Nationally, only the southeastern United States has a larger share of self-supplied residential water.

Although the supply of fresh water in the MAR generally is adequate to meet withdrawal demands, exceptions include drought and occasional disruption or contamination by floods or pathogen outbreaks (Solley et al. 1998, Yarnal et al. 1997). Rapid development in parts of the MAR that rely on ground water wells, especially for residential use, has created stresses because of surface water infiltration, or salt water intrusion in coastal areas. Human activities have affected the region's water resources in many ways (Walker et al. 1999a). For example, high nutrient loadings from agriculture and other non-point source runoff reduce oxygen levels, which in turn reduce the habitat available for animals living in water. High nutrient loadings also increase blooms of algae, which shade deeper water and thus decrease the amount of submerged aquatic vegetation (SAV).

Impacts from climate change on stream flow were estimated using a water balance model (Najjar 1999) for average monthly air temperature and precipitation over the Susquehanna River Basin (SRB), comparing the 1900-1987 record with output from the CCC and Hadley models for 2025-2034 and 2090-2099. The model projects modest changes in annual streamflow for 2025-2034: +7 percent for the Hadley scenario and -2 percent for the CCC scenario (Figure 11). By 2090-2099, the model projects substantially larger annual changes of +24 percent for the Hadley scenario and -4 percent for the CCC scenario. Recall that the CCC model projects much larger temperature increases and much smaller precipitation increases than the Hadley model. Consequently, the offsetting effects of increased temperature and precipitation cause the water balance model to show different directions in streamflow changes for each scenario. A further complication is that elevated $CO_2$ may allow plants to use water more efficiently, thereby reducing water need and increasing streamflow (Wigley and Jones 1985). These factors highlight the difficulty in predicting future streamflow. Similar difficulties arise in pinpointing the impact of climate change on future groundwater levels.

Despite the uncertainties in projecting future water availability, insights into potential adaptation strategies can be gleaned from how water managers currently respond to climate variability. Results from a survey of Pennsylvania water managers appear in Box 3.

The potential for a wetter regional climate, punctuated by droughts, suggests higher water supply management costs to protect the quality of both surface and ground water sources and to provide more storage capacity. Increased storage capacity could buffer the region against additional flooding if extra precipitation tends to arrive in intense

# Chapter 7. Coastal zones

The Mid-Atlantic's coastal areas, especially the Chesapeake Bay, Delaware Bay, and Albemarle/Pamlico Sounds (Figure 3), have important aesthetic and economic values. In Delaware, for example, Parsons and Powell (1998) estimated that $90,000 of the value of a $200,000 home along the coast could be attributed to ocean frontage; bay frontage is worth $15,200 and canal frontage $46,200. The MAR coastal counties (see Figure 4) are densely populated, with 38 percent of the region's population in only 19 percent of its area. Five of the MAR's six largest cities (Philadelphia, Baltimore, Washington, Norfolk, Richmond) are in its coastal zone. The shore is a tourist destination; many coastal communities have more visitors than permanent populations.

Coastal communities and the natural resources that prove so attractive have been vulnerable to the inexorable forces of nature: storms, coastal erosion and beach dynamics. Despite this vulnerability, coastal development has been subsidized through federal activities such as shoreline protection and beach replenishment, federal disaster assistance, and the National Flood Insurance Program (NFIP). In the 1978-1998 period, coastal counties of four MAR states (NJ, DE, MD, VA) had 177,758 NFIP policies in effect with $21 billion in coverage (Kunreuther et al. 1999). During that time, $81 million in premium revenues were collected; $327 million were paid in 46,670 claims, $138 million of which were repetitive.

Because higher air temperatures from increases in $CO_2$ (see Table 3) are expected to warm and thus expand the oceans, climate-induced sea-level rise is very likely—and will add to the effects of local subsidence in the MAR. Sea-level rise will flood coastal regions. Figure 12 shows a rough estimate of how a 24-inch rise in sea level (which is in the range projected for the year 2095, as shown in Table 3) would affect Delaware's shoreline (Najjar et al. 2000). The areas shown in blue are less than two feet above current sea level. The actual response will depend on shoreline dynamics and wetland accretion, as discussed below. About 22,000 acres would be inundated. The largest impact would be on emergent wetlands, which account for less than 2 percent of Delaware's area. About 21 percent of this category would be inundated. The next largest impacts on land use categories are much smaller, but could be far more important economically. For example, flooding would cover less than one percent of land currently in high intensity developments, but would be exacerbated by future development in coastal areas.

Coastal water temperatures track air temperatures, especially in shallow waters that have smaller volumes to be heated or cooled and less influence from ocean circulation and mixing. Warmer inland air may encourage more visits and permanent residences at the shore, where warmer air and water will extend the recreation season. Table 3 shows

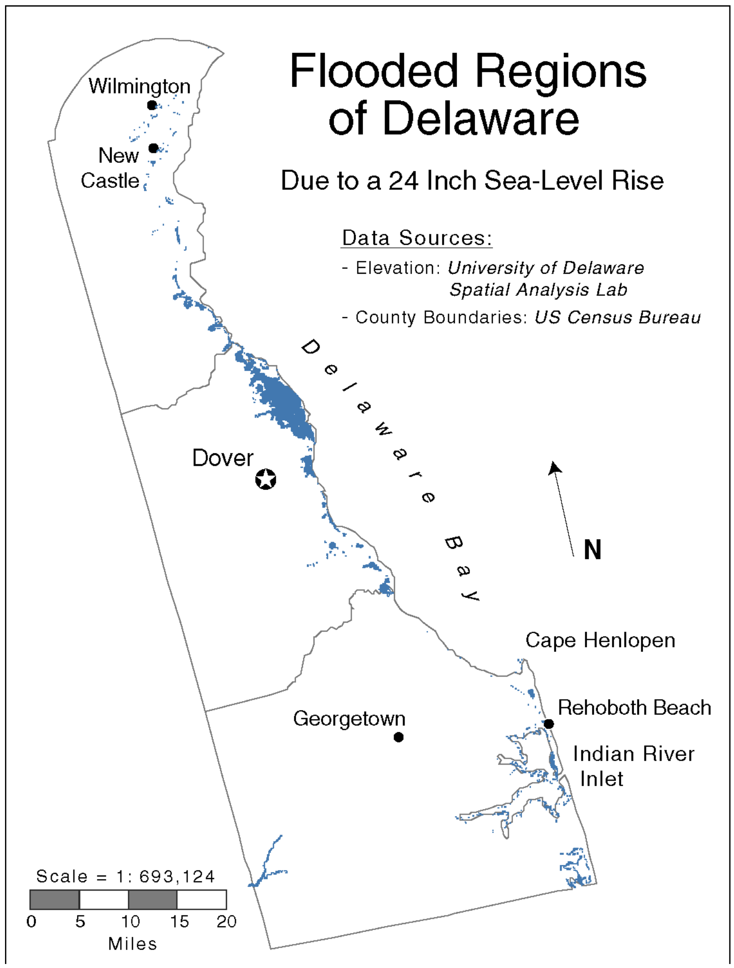



*Figure 12. Potential Flooding in Delaware from 2 foot sea-level rise.*

# Chapter 8. Ecosystems

The prominence of ecosystem discussions in the chapters above reflects their importance as well as their cross-cutting nature. Ecosystem services are "conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life" (Daily 1997, p. 3). These include actual life support functions, maintenance of biodiversity, and production of goods (including aesthetics).

The land cover diversity shown in Figure 5 signals diversity in the MAR's ecosystems, which range from natural to managed. The MAR's forested, wetland, fresh water and coastal ecosystems are on the natural side of the continuum; its city, suburban and farm ecosystems are on the managed side. This chapter highlights selected MAR ecosystems and their sensitivity to climate change.

The Chapter 5 discussion emphasizes managing forests for their products. The region's forests also include rare vegetation types, such as shrublands that provide crucial habitat for wildlife and for endangered plant species. Similarly, the coastal plain's northern pine-oak forest (known as pine barrens) form a unique ecosystem home to rare plants and animals. The region's public natural areas, such as national and state parks and forests, provide recreational opportunities and protected habitat for wildlife species and communities. Current stresses on MAR forest ecosystems include fragmentation, especially near urbanized areas and on the Delmarva Peninsula (Jones et al. 1997); pollutants such as acid rain (Likens et al. 1996); and invasion of non-native organisms and insect pests (Schlarbaum et al. 1999)

Chapter 7 describes coastal wetlands and Chapter 6 describes freshwater fish habitat. But neither chapter considers fresh water wetlands and their important roles in recycling nutrients, in providing crucial wildlife habitat, and in removing pollutants from water (Hammer 1997, National Research Council 1995). Some of these fresh water wetlands are forested; others are marshes dominated by plants such as cattails. Several unique and rare wetland ecosystems are threatened in the MAR. Losses of lowland evergreen shrub bogs and upland sphagnum bogs have exceeded 85 percent in some MAR states, and more than 98 percent of the original stands of Atlantic white-cedar swamp forest—such as those found in the Great Dismal Swamp of VA and northern NC—have been destroyed (Noss et al. 1995). Drainage is the major threat to fresh water wetlands, but they also are affected by pollution (e.g., chemical wastes) and non-native invasive species (e.g., purple loosestrife).

The MAR has substantial diversity in its freshwater fauna which helps explain the importance of freshwater ecosystems for recreation (as illustrated in Box 4). For example, the number of native freshwater fishes ranges from 70 to 201 across the MAR states (Warren and Burr 1994). The number of mussel species ranges from 12 to 80 across the region's states (Williams and Neves 1995). Like terrestrial and wetland ecosystems, freshwater ecosystems are stressed by habitat alteration, pollution, and non-native invasive species. For example, the percentages of mussel species at risk of extinction range from 46 percent to 71 percent in the MAR states.

Many ecosystem components are quite resilient, while others are very fragile. The survival, reproduction and the geographic ranges of many plants and animals is linked to climatic conditions (Root 1988, Shao and Halpin 1995, Visser et al. 1998, Pitelka et al. 1997). Changes in $CO_2$ concentration, temperature, precipitation and sea level in the MAR will interact with other current and future stresses on ecosystems and affect individual species differently. While warmer temperatures, $CO_2$ fertilization, and more precipitation will facilitate the growth of some (particularly plant) species, their expansion could come at the expense of other species (e.g., Drake et al. 1996). The complexity and interconnectedness of ecosystems makes it difficult to predict impacts on particular species and ecosystem functioning.

Climate change might alter natural disturbance patterns, such as the frequency of severe storms or fire. Rapid evolution might help some species with short generation times, such as insects and annual plants, to adapt to environmental changes (Cronin and Schneider 1990). Adaptation will be slower in long-lived species such as trees. Some Mid-Atlantic species might shift their geographic range by invading more hospitable climates, such as the shifts in forest types projected in Chapter 5. Species will shift their geographic ranges at different rates; some will fail because they cannot disperse fast enough to keep pace with change, especially if landscape features such as cities block their movement, or if suitable new habitats simply are not available (Pitelka et al. 1997). The Box 7 case study illustrates potential species shifts for birds in the MAR.

# Chapter 9. Human health

Chapter 8 stresses the cross-cutting importance of ecosystems. Another cross-cutting topic is the relationship between climate change and human health in the MAR. Changes in the frequency and severity of weather events could have direct effects on human physiology or psychology (WHO 1996). Climate change impacts on other biological or geophysical systems that influence human health also could lead to indirect health effects. For example, climate change could influence the range and activity of insects or animals that transmit disease (affecting the incidence of vector-borne disease), the life cycles of pathogens, the levels and biological effects of air pollutants, and the productivity of food systems.

We focused this assessment on how projected climate change would affect health through extreme events, heat related mortality and selected vector/water/food borne diseases. We also initiated assessment of health impacts related to air quality and mental health. As is the case for Chapters 4 through 8, our choices were guided by the input of MARA stakeholder groups, the climate model projections of climate change for the region, and results of prior research.

## Current Health Status and Stresses

The effects of climate change will occur against the backdrop of broader developments in health challenges and the health system. Health is a complex function of many factors including behavioral choices (e.g., cigarette and alcohol consumption, diet, fitness); access to medical care (availability, quality and price of care as well as health insurance status); medical technology; genetic endowment (predisposition to certain diseases); and characteristics of the natural environment and buildings in which people live, work and play (Banta and Jonas 1996).

The health systems of the United States and other developed nations have experienced an incredible evolution over the past 150 years, greatly improving the health status of their citizens and the capacity to manage public health risks (McKeown 1976). For example, the overall mortality rate in 1900 was 1720 deaths per 100,000 people and life expectancy was 47.3 years. By 1990, that rate had dropped to 860 and life expectancy had increased to 75.4 years (Banta and Jonas 1996). These advances and other technological, institutional and economic advances have reduced vulnerability to climate-related health risks (Abler et al. 2000). For instance, the relationship between mortality and extreme temperatures declined through the 20th century (Larsen 1990). A century ago the predominant health problems were epidemics of acute infections (Banta and Jonas 1996). Today's major health risks are chronic diseases such as heart disease and cancer, which are strongly related to personal behaviors. The shift in the sources of health risks explains the changing emphasis in U.S. health policy to issues such as access to health care (organizing the health care system to reach vulnerable populations) and promoting healthy behaviors (U.S. DHHS 1992).

The current health status of the MAR population is similar to that for the U.S. The four leading causes of death in the region and the nation, which account for approximately two thirds of all deaths, are heart disease, cancer, stroke and lung disease (Kocagil et al. 1999). Climate can be an aggravating or contributing factor, but genetic endowment and behavioral choices (e.g., smoking, diet, fitness) are major determinants of these causes of death (CDC 1999a, CDC 1998).

Presently, acute health risks that are largely a function of climate are not major determinants of the health status of the MAR population. The Mid-Atlantic region has very little mortality directly attributable to cold, heat, storms, flooding or lightning. However, the region exhibits more temperature-related mortality, particularly heat-related, than other regions of the U.S. (Kalkstein and Greene, 1997). Examples include deaths from heart disease during heat waves. While this is a matter of concern, heat- and cold-related mortality rates are small compared to the leading causes of death (Chestnut et al. 1995).

# *Planning for the 21st Century*

The Mid-Atlantic Region's economy is robust because it is highly diversified, technologically advanced, and highly integrated with the rest of the United States and the world. Our analysis shows that the MAR economy has relatively little dependence on its climate-sensitive sectors. Even within climate-sensitive sectors such as Agriculture and Forestry, impacts are moderated over time because buyers and sellers within MAR as well as in the rest of the nation and other countries can adapt to changes in availability of Agriculture and Forestry products.

These features make the MAR economy resilient to current climate variability. Along with anticipated technological, institutional and behavioral adaptations, these features also make the MAR ***economy*** reasonably resilient to projected future climate change and its impacts on the region's natural resources.

On the other hand, the MARA suggests that climate change poses diverse and potentially large risks to the region's ***ecosystems,*** which already show signs of stress for diverse reasons. The lingering effects from earlier degradation are compounded by continuing pressures on many of the region's ecological resources. Increased recognition of these pressures has come at a time of growing societal demand for ecological resource protection, both for its own sake and for recreational uses.

Recall that Table 4 shows that the MAR can expect both positive and negative impacts from climate change. Despite efforts to identify as many positive impacts as possible, results show that benefits tend to be fewer and smaller than damages. Underestimating potential damages would be more worrisome than underestimating potential benefits. For benefits that are traded in markets, people and organizations will more-or-less automatically take advantage of opportunities created by climate change, and thus experience the consequent improvement in well-being. Assessment that identifies potential market benefits can spur the market to work more quickly. By identifying potential nonmarket benefits, assessment can provide information for pro-active decisions that enable society to reap those benefits. Even more important, assessment can identify potential damages over which individuals have little control, or that might be managed more effectively at a community or regional level than by individual citizens or firms. Identifying such risks can be a first step in evaluating options for reducing or adapting to them.

The impacts summarized in Table 4 will make some of the region's citizens and organizations better off while others will be worse off. This uneveness in benefits and damages or costs is referred to as ***distributional impacts***. Distributional impacts merit special attention because small average effects can mask impacts that are substantial for especially vulnerable individuals, groups, communities, industries, or subregions. These features—substantial overall resilience in concert with pressure on ecosystems and concern about distributional impacts—summarize the region's basis for taking advantage of new opportunities created by climate change and for coping with negative impacts from climate change.

Table 4 also shows differing levels of certainty about potential impacts. The more we know about the particular climate change and its impacts, and the more such impacts are managed through existing institutions, the more confident we can be that effective adaptation strategies can be implemented now (Downing 1999). As uncertainty increases, it becomes more difficult to determine whether specific adaptive actions are warranted. Box 10 suggests how many of the uncertainties described in earlier chapters combine to signal substantial potential climate threats to the region's urban areas. This complex topic needs additional research and assessment. Fortunately, however, the MAR can reduce much of its vulnerability to climate change by taking actions already justified for other reasons, as summarized in Chapters 10 and 11.

# Chapter 10. What can we do now?

MARA findings suggest win-win actions that have substantial benefits even if climate stays the same, plus a bonus of making the region more resilient to climate change. Many of these win-win strategies will be cost-effective even in the absence of climate change but have not been high on society's agenda. It is desirable to consider such actions sooner rather than later because they make sense even in the face of substantial uncertainties in projecting global climate change and its impacts on the MAR:

- Improve watershed management to reduce flood and drought damages and protect water quality (in streams and rivers, lakes and reservoirs, and ground water). For example, many communities do not have a watershed management plan even when the state requires one; implementation of existing plans tends to be uneven, too.

- Remove incentives for practices (e.g., that promote building or subsidize agriculture in areas vulnerable to erosion and flooding) that place people, investments, and (especially coastal) ecosystems at greater risk to climate variability.

- Establish communication and learning tools and programs that help the region's people identify how they can capitalize on benefits and reduce damages from climate change.

The first two strategies would reduce risks from several causes—including climate change. They imply actions (such as preserving forests and wetlands, minimizing urban and agricultural runoff, protecting stream habitat and reducing the release of toxic chemicals) that also reduce ecosystem stresses; although less certain than the large threats to the coastal zone, Table 4 indicates that threats to ecosystems could be quite large.

We already know about actions that can implement many of these strategies. One example is the weather warning system which has been effective for reducing heat stress in Philadelphia. Such demonstrations of effectiveness can be implemented elsewhere in the MAR.

More specific recommendations are to:

- Identify where coastal protection options such as beach nourishment, dikes or seawalls are cost-effective and where allowing coastal retreat is more cost-effective; prepare strategies for preventing or dealing with losses (in wetlands, infrastructure) from sea-level rise.

- Improve water pricing to increase the efficiency of water use.

- Give higher priority to implementing government programs that indirectly reduce vulnerability to climate variability and change. Examples include the Safe Drinking Water Act (SDWA) regulations, coastal zone management plans, building codes, and land use planning.

- Foster forestry practices to encourage pine and oak-hickory forests, including cutting to minimize wind and ice damage, and monitoring for potential increases in fire, insect pests and diseases that might be more prevalent under climate change conditions.

- Foster continued adaptation in agriculture, especially for precision agriculture and biotechnology (if concerns about unintended effects of biotechnology can be addressed).

- Monitor for the higher-risk climate-related disease vectors identified in the MAR.

The MARA team judges the first three of these specific recommendations to be particularly important.

# Chapter 11. What do we still need to know?

People in the MAR can make better decisions related to climate change if they know more about potential impacts from climate variability and change and the effectiveness of alternative actions. People tend to think of climate change as happening slowly. Of particular concern, however, is the possibility that there could be major surprises because of the many uncertainties about how the region's climate will change and how these changes will affect the region's citizens and ecosystems. Surprises can be defined as rapid, non-linear responses (Watson et al. 1996). An example surprise might be several extreme weather events in a short time span, strong enough to reverse the direction of arrows in Table 4. Efforts to reduce vulnerability are important when such surprises could create serious damages; Downing (1999) reinforces the need to monitor impacts so that people—as individual stakeholders and as members of organizations—will know when they need to accelerate adaptation. Uncertainties about trends, variability, and surprises suggest that the most important information and research needs are to:

- Improve projections for frequency, timing and intensity of average and extreme weather (especially precipitation), at a regional level.

- Improve understanding of how average and extreme weather affect agriculture, forests, fresh water quantity and quality, coastal zones, ecosystems, and human health—including differences in the sensitivities and vulnerabilities of these systems, and whether they have climate-sensitive thresholds—and how adaptation would moderate negative impacts and enhance positive impacts.

- Improve models to evaluate the benefits and costs of alternative adaptation options, so that economic efficiency can be considered in management and policy decisions. For example, such decisions range from insurance coverage versus structural "hardening" against extreme events to land use restrictions versus subsidized changes in land use.

- Improve methods for evaluating how proposed shifts in policy (e.g., health policy, land use policy, agricultural policy) might affect vulnerability to climate variability and change.

More specific information needs include understanding:

- How changes in climate variables affect different ecosystems (with respect to how they function; what fragile components might be affected by invasive species or by changes in nutrient runoff; and how ecosystem changes affect disease vectors).

- How to assign values to climate-related changes in ecosystem components and processes.

- How biophysical impacts from climate change, especially related to ecosystem processes, affect people in different locations (e.g., rural versus urban, coastal versus inland) and with different characteristics (e.g., age, income, education) through impacts on their health, institutions, and other determinants of the quality of life.

- How best to provide information about climate variability and change (i.e., what types of information, what communication modes, what types of interaction strategies) so that diverse stakeholders can make more informed choices about actions that affect future opportunities and vulnerabilities.

- How temperature and precipitation interact, and implications for evapotranspiration, as well as direct $CO_2$ impacts on evapotranspiration.

- How climate change would affect **environmental impacts** from development patterns, agriculture and silviculture, including water quality, landscape amenities, and carbon sequestration.

- How temperature and humidity affect the human immune system; how they interact with air pollution to affect conditions such as asthma.

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# *Appendices*

## Appendix A

### Partners and Participants

An interdisciplinary Pennsylvania State University (Penn State) team is leading the first Mid-Atlantic Regional Assessment (MARA) of Climate Change Impacts. The core team includes 13 faculty members, 6 post-doctoral or associate researchers, 26 graduate assistants, and 11 undergraduates or interns. The core team's expertise is being expanded by substantive collaboration with another 14 researchers at Penn State and other universities plus 3 at private organizations and 5 in government. This entire group interacts frequently with the Advisory Committee, which provides input about what questions are most important to a broad range of stakeholders in the region. The Advisory Committee also provides feedback on draft assessment plans, approaches, and results. Interested stakeholders who cannot participate as fully are Corresponding Advisors. Each of these groups is listed below. Interactions are described in Appendix C.

In addition, sections at the end of this appendix list MARA sponsors as well as primary authors for report chapters.

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# Mid-Atlantic Contribution to the National Assessment on the Potential Consequences of Climate Change for the United States

The overall goal of the National Assessment is to evaluate what is known about the potential consequences of climate variability and change in the context of other pressures on the public, the environment, and the Nation's resources. The National Assessment process has been broadly inclusive, drawing on inputs from academia, government, the public and private sectors, and interested citizens. Starting with broad public concerns about the environment, the Assessment is exploring the degree to which existing and future variations and changes in climate might affect issues that people care about.

The National Assessment has three major components:

1. Regional analyses: Workshops and assessments are characterizing the potential consequences of climate variability and change in regions spanning the US. The reports from these activities address the interests of those in the particular regions by focusing on the regional patterns and texture of changes where people live. Most workshop reports are already available (see http://www.nacc.usgcrp.gov) and regional assessment reports of which this is the first will become available over the next several months.

2. Sectoral analyses: Workshops and assessments are characterizing the potential consequences of climate variability and change for major sectors that cut across environmental, economic, and societal interests. The sectors being focused on in this first phase of the ongoing National Assessment include Agriculture, Forests, Human Health, Water, and Coastal Areas and Marine Resources. Publications and assessment reports started to become available in late 1999.

3. National overview: The National Assessment Synthesis Team is summarizing and integrating the findings of the regional and sectoral studies with the broader literature, and then drawing conclusions about the importance of climate change and variability for the United States. Their report is to be available in 2000.

Each of the regional, sectoral, and synthesis activities is being led by a team comprised of experts from both the public and private sectors, from universities and government, and from the spectrum of stakeholder communities.

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Preparing this report truly has been a team effort. Nevertheless, the enormity of the assessment task dictated that we share writing responsibilities on the basis of expertise. Thus primary authors are indicated below, by report section.

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# Appendix B

## National Assessment of the Consequences of Climate Variability and Change for the United States

Prepared by Michael MacCracken, National Assessment Coordination Office, 10/5/99

The influence of climate permeates life and lifestyles in the US. Year-to-year variations are reflected in such things as the number and intensity of storms, the amount of water flowing in our rivers, the extent and duration of snow cover, and the intensity of waves that strike our coastal regions. Science now suggests that human activities are causing the climate to change. Although the details are still hazy about how much the changes will be in each region of the country, changes are starting to become evident. Temperatures have increased in many areas, snow cover is not lasting as long in the spring, and total precipitation is increasing with more rainfall occurring in intense downpours. These changes appear to be affecting plants and wildlife. There is evidence of a longer growing season in northern areas and changing ranges for butterflies and other species. The international assessments of the Intergovernmental Panel on Climate Change (http://www.ipcc.ch) project that these changes will increase over the next 100 years.

The Global Change Research Act of 1990 [Public Law 101-606] gave voice to early scientific findings that human activities were starting to change the global climate: "(1) Industrial, agricultural, and other human activities, coupled with an expanding world population, are contributing to processes of global change that may significantly alter the Earth habitat within a few generations; (2) Such human-induced changes, in conjunction with natural fluctuations, may lead to significant global warming and thus alter world climate patterns and increase global sea levels. Over the next century, these consequences could adversely affect world agricultural and marine production, coastal habitability, biological diversity, human health, and global economic and social well-being."

To address these issues, Congress established the U.S. Global Change Research Program (USGCRP) and instructed the Federal research agencies to cooperate in developing and coordinating a "comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural process of global change." Further, the Congress mandated that the USGCRP

> *"shall prepare and submit to the President and the Congress an assessment which*
>
> > *1) integrates, evaluates, and interprets the findings of the Program and discusses the scientific uncertainties associated with such findings;*
> > *2) analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity; and*
> > *3) analyzes current trends in global change, both human-induced and natural, and projects major trends for the subsequent 25 to 100 years."*

The USGCRP's National Assessment of the Potential Consequences of Climate Variability and Change, which is focused on answering the question about why we should care about and how we might effectively prepare for climate variability and change, is being conducted under the provisions of this Act.

The overall goal of the National Assessment is to analyze and evaluate what is known about the potential consequences of climate variability and change for the Nation in the context of other pressures on the public, the environment, and the Nation's resources. The National Assessment process has been broadly inclusive, drawing on inputs from academia, government, the public and private sectors, and interested citizens. Starting with public concerns about the environment, the Assessment is exploring the degree to which existing and future variations and changes in climate might affect issues that people care about. A short list of questions has guided the process as the Assessment has focused closely on regional concerns around the US and national concerns for particular sectors:

- What are the current environmental stresses and issues that form the backdrop for potential additional impacts of climate change?
- How might climate variability and change exacerbate or ameliorate existing problems? What new problems and issues might arise?
- What are the priority research and information needs that can better prepare the public and policy makers for reaching informed decisions related to climate variability and change? What research is most important to complete over the short term? Over the long term?
- What coping options exist that can build resilience to current environmental stresses, and also possibly lessen the impacts of climate change?

The National Assessment has three major components:

1. Regional analyses: Regional workshops and assessments are characterizing the potential consequences of climate variability and change in regions spanning the US. A total of 20 workshops were held around the country, with the Native Peoples/ Native Homelands workshop being national in scope rather than regional; to date, 16 of these groups are preparing assessment reports. The reports from these activities address the interests of those in the particular regions by focusing on the regional patterns and texture of changes where people live. Most workshop reports are already available (see http://www.nacc.usgcrp.gov) and assessment reports started to become available in late 1999.

2. Sectoral analyses: Workshops and assessments are being carried out to characterize the potential consequences of climate variability and change for major sectors that cut across environmental, economic and societal interests. The sectoral studies analyze how the consequences in each region affect the Nation, making these reports national in scope and of interest to everyone. The sectors being focused on in this first phase of the ongoing National Assessment include Agriculture, Forests, Human Health, Water, and Coastal Areas and Marine Resources. Assessment reports started to become available in late 1999.

3. National overview: The National Assessment Synthesis Team has responsibility for summarizing and integrating the findings of the regional and sectoral studies and then drawing conclusions about the importance of climate change and variability for the United States. Their report is to be available by Spring 2000.

Each of the regional, sectoral, and synthesis activities is being led by a team comprised of experts from both the public and private sectors, from universities and government, and from the spectrum of stakeholder communities. All their reports have gone through an extensive review process involving experts and other interested stakeholders. The assessment process is supported in a shared manner by the set of USGCRP agencies, including the departments of Agriculture, Commerce (National Oceanic and Atmospheric Administration), Energy, Health and Human Services, and Interior plus the Environmental Protection Agency, National Aeronautics and Space Administration, and the National Science Foundation. Through this involvement, the USGCRP is hopeful that broad understanding of the issue and its importance for the Nation will be gained and that the full range of perspectives about how best to respond will be aired.

Extensive information about the assessment, participants on the various assessment teams and groups, and links to the activities of the various regions and sectors are available over the Web at http://www.nacc.usgcrp.gov or by inquiry to the Global Change Research Information Office, PO Box 1000, 61 Route 9W, Palisades, New York 10964.

# Appendix C

## Stakeholder participation in the MARA process

Penn State's early steps included a September 1997 Workshop focusing on the watersheds for the Chesapeake and Delaware Bays (Fisher et al. 1999a). The workshop's purpose was to develop an initial formulation of "the problem," to identify what types of regional impacts a diverse group of climate experts and regional stakeholders thought might be related to climate variability and change. The 92 participants, representing federal, state and local government, industry, academia, and public interest groups, reported learning 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.

A June 8-9, 1998 researchers' meeting explored questions raised during the September 1997 workshop, particularly related to concerns stakeholders raised about potential effects, and identified available data bases and current research useful for MARA. This open process showed the need to address five topics being emphasized in the national synthesis—forests, agriculture, water, coasts, and human health—as well as cross-cutting issues such as ecosystems.

These researchers are one component of the MARA Advisory Committee. Researchers however, are hardly the only ones with a stake in how climate change might affect the Mid-Atlantic region. In one sense, everyone in the region is a stakeholder in the MARA project because all of the regions' citizens could be affected by climate change. In seeking to identify stakeholders to participate in the assessment process, MARA is paying special attention to groups likely to be particularly affected by climate change and to groups that have expressed an interest in the issue. The non-researcher component of the MARA Advisory Committee represents varied experiences, including representatives from mining companies, non-governmental voluntary organizations, and government.

The process for selecting Advisory Committee members was informal and broad. We identified individuals and groups that had expressed interest in climate change. We also made a strong effort to bring in a diversity of backgrounds and positions. For reasons of manageability of size, we decided not to invite elected officials to join the Advisory Committee, but everyone who sought to participate has been welcomed to the Advisory Committee. Members are listed in Appendix A.

The Advisory Committee met for 2 days each in October 1998 and May 1999. The October meeting focused on identifying climate-related issues important to MAR residents, while the May meeting reviewed the treatment of these and other issues in the *Draft Preliminary Report* (Fisher et al. 1999b).

A number of individuals have wanted to help with the assessment, but were unable to participate in the October 1998 or May 1999 meetings. These individuals provide feedback to assessment designs and documents by e-mail, phone, and mail, often in response to postings on the MARA web site: www.essc.psu.edu/mara. They are Corresponding members of the Advisory Committee.

The Advisory Committee is improving the assessment in four ways:

- Early in the project, members explained what kinds of information they need to help them make decisions in the context of regional climate change.
- During implementation of the project, members reviewed chapter outlines and scenarios used in writing the report.

- At completion of draft assessment reports, the Committee reviews documents and suggests improvements.
- Members are advising the MARA team regarding ways to disseminate the results in the region.

The stakeholders helped refine the research questions. For example, participants at the October 19-20, 1998, Advisory Committee meeting made sure that the assessment would be responsive to climate-related issues most important to the people who live and work in the region, such as the need for reliable seasonal climate projections by water system managers and farm operators. They also expressed concerns about the implications of climate change for insurance coverage and the insurance industry. Stakeholders also are offering advice about developing materials and disseminating the assessment results to a wide audience.

In addition to coming together for working meetings and reviewing draft documents, many stakeholders have maintained informal communications with team members working on particular parts of the report. In our view, successful stakeholder involvement must be ongoing, two-way, and substantive. One part of the two-way communication is making sure stakeholders understand how their participation makes a difference in the assessment process. Ongoing contact between researchers and stakeholders facilitates this understanding.

For example, stakeholders have been invited to suggest agenda items for meetings and to bring case study examples to share with the MARA team as well as the full Advisory Committee. As planning progressed for assessment activities, draft outlines of plans and scenarios were sent for their input. They also have been asked for feedback on draft chapters and journal manuscripts. The *Draft Preliminary Report* (Fisher et al. 1999b) and the earlier draft of this *Overview* were circulated widely for review. Their comments on the *Draft Preliminary Report* are being used to prepare the Foundations Report, which has more detail than could be included in this overview (and expected to be available by July 2000). This *Overview* is much stronger because of the more than 40 sets of comments provided by stakeholders. Documentation of the MARA team's responses to those comments appears on the web site: www.essc.psu.edu/mara/.

One of the goals of the National Assessment process has been to involve stakeholders as actual assessors. This has been difficult to accomplish as fully as hoped in the MARA, partly because of the newness of such an approach (which made it more difficult at the "front end" to set up an effective involvement structure), and partly because of the tight timeframes for the initial assessment. Even so, the MARA team has been delighted by the shift of several Advisory Committee members to the collaborator list. Some of these collaborators are extensively involved in the assessment, as indicated by the Appendix A list of primary authors. The MARA team expects additional substantive stakeholder collaborations during the continuing assessment activities. An example emphasizing ecosystems is described at the end of Chapter 8. Another example is the work on implications of climate variability and change for the insurance industry. Without stakeholder collaboration that provides access to proprietary models and data, the assessment of these implications would be much less complete.

# Appendix D

## Glossary

**algae:** Plants having no true root, stem or leaf, including seaweeds and pond scum.

**anoxia:** Without oxygen.

**aquatic:** Living or growing in fresh water (in contrast with marine organisms found in salt water).

**atmospheric:** In the air surrounding the Earth.

**benthic:** Bottom dwelling aquatic or marine organisms.

**biodiversity:** The range of organisms present in an ecosystem. Biodiversity can be measured by the numbers and types of different species, or the genetic variations within and between species.

**CCC model:** Canadian Climate Centre global climate model.

**Cryptosporidiosis:** Illness with diarrhea as the main symptom, caused by tiny cysts transmitted from animal or human feces through contaminated water.

**downscaling:** Reducing the scale of the model from global to regional level.

**ecosystem:** A unit of ecological analysis in which the physical and biological entities are considered in relation to each other, including energy flows and chemical feedbacks within a defined geographical area.

**estuary:** An estuary is in essence an interface: it is an area where a river meets the sea, where aquatic and marine life meet terrestrial life in marshes and wetlands, and where fresh water can still be influenced by tides. Estuaries can be defined by a salinity gradient that ranges from ocean salinity of 35.0 ppt (parts per thousand) to fresh water with salinity of less than 0.5 ppt.

**eutrophication:** An oversupply of the essential elements necessary for growth of tiny (microscopic) floating organisms, causing them to grow very quickly. This can block sunlight from larger plants growing underwater and deplete dissolved oxygen.

**evapotranspiration:** Loss of water from the soil both by evaporation and by transpiration from trees and other plants.

**fauna**: Animal life, especially the animals found in a particular region.

**flora:** Plant life or vegetation of a region.

**fragmentation:** Occurs when habitat is split by changing land use, leaving isolated pockets of the original habitat.

**GENESIS model:** Global climate model.

**greenhouse gases**: Several gases that allow the earth's atmosphere to trap solar radiation by absorbing heat radiated back from the surface of the earth. These gases include carbon dioxide, methane, water vapor, and nitrous oxide.

**Hadley model:** Global climate model developed by Hadley Centre for Climate Prediction and Research in Great Britain.

**hydrology:** Properties, distribution and circulation of water on the surface of the land, in the soil and underlying rocks, and in the atmosphere.

**invasive species:** Species that grow aggressively in an area and stifle pre-existing species.

**non-point source:** Dispersed emitters of pollutants (such as farms, automobiles, or city streets).

**non-target species:** Species not intended for particular treatment (e.g., by pesticides aimed at other species) that could be affected by the treatment.

**nutrient loading:** The amount of nutrients in a water body.

**passerine:** Birds of the order Passeriformes, including perching birds and warblers such as sparrows, finches, and jays.

**pathogen:** Any microorganism or virus that can cause disease.

**phytoplankton:** Microscopic plants that float in aquatic or marine environments (fresh or salty water).

**point source:** A specific location (such as an effluent pipe or a smokestack) that discharges pollutants into the environment.

**precision agriculture:** Incorporates advanced remote sensing, computer, and information technologies in order to achieve very precise control over agricultural input applications (chemicals, fertilizers, seeds, etc.) so that farmers can compensate for small-scale variations within a farm field in soil nutrients and crop pests.

**primary productivity:** The products of photosynthesis, the primary conversion of the sun's energy into chemical energy that can be stored as sugars or starches in plants. Net primary productivity is the amount of energy available after the plant has met its own energy needs.

**riparian:** Along the bank of a river or stream, or sometimes of a lake or a tidewater.

**rolling easement:** The right of access to waterfront, which "rolls" back as the beach is flooded or eroded so as to maintain the same access distance from the water.

**SIC level:** Standard Industrial Classification of economic activities. A one-digit SIC is the most aggregated; very detailed information is available at the disaggregated 4-digit SIC level.

**silviculture, silvicultural:** Development and care of forests.

**sphagnum bog:** Wet, acid area where mosses grow; their remains become compacted with other plant debris and eventually form peat.

**stakeholder:** Potentially affected or interested person.

**subsidence:** Lowering of land elevation. Such sinking can be caused by groundwater withdrawals or by long-term settling of the Earth's crust.

**sulfate aerosols:** A suspension of fine particles in the air, containing sulfates. These suspensions act like clouds, making the Earth's surface cooler.

**transpiration:** Evaporation from plant foliage.

**turbidity:** In water bodies, the condition of having suspended particles that reduce the ability of light to penetrate beneath the surface. Some rivers and streams are naturally more turbid than others; soil erosion and runoff into streams can increase turbidity.

**vector:** An organism such as a mosquito or tick that transmits disease from infected individuals or animals to humans.

**watershed:** The drainage basin for a particular watercourse or body of water. Watershed scales range from that for a small pond to much larger regions such as the Chesapeake Bay drainage basin.

# Appendix E

## Acronyms and Abbreviations

**CBP:** Chesapeake Bay Program (EPA)

**CCC:** Canadian Climate Centre (global climate model)

**CIRA:** Center for Integrated Regional Assessment (PSU)

**$CO_2$:** carbon dioxide (a greenhouse gas)

**EFS:** Environmentally Friendly and Smaller

**EPA:** U.S. Environmental Protection Agency

**GCM:** General circulation model; also global climate model

**GENESIS:** a global climate model

**GHG:** Greenhouse Gas(es)

**GIS:** Geographic Information System

**HADLEY:** Hadley Centre global climate model

**IPCC:** Intergovernmental Panel on Climate Change

**m:** meter (39.37 inches)

**MAHA:** Mid-Atlantic (Mid-Appalachians) Highlands Assessment

**MAIA:** Mid-Atlantic Integrated Assessment (EPA)

**MAR:** Mid-Atlantic region

**MARA:** Mid-Atlantic Regional Assessment

**NACO:** National Assessment Coordination Office

**NAST:** National Assessment Synthesis Team

**NAWG:** National Assessment Working Group

**NFIP:** National Flood Insurance Program

**NPA:** NPA Data Services, Inc.

**Penn State (PSU):** Pennsylvania State University

**PET:** potential evapotranspiration

**PPR:** Prairie Pothole Region

**ppt:** parts per thousand

**SAV:** submerged aquatic vegetation

**SIC:** Standard Industrial Classification

**SLR:** sea-level rise

**SQ:** status quo

**SRB:** Susquehanna River Basin

**SDWA:** Safe Drinking Water Act

**USDA:** U.S. Department of Agriculture

**USGCRP:** U.S. Global Change Research Program

**USGS:** U.S. Geological Survey

**VEMAP:** Vegetation/Ecosystem Modeling and Analysis Project

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- How climate change might affect weeds, insects, and diseases in crops, livestock, and forests, and how increases in such adverse impacts might be controlled.

- How a warmer, wetter climate will affect the amount, timing, and quality of water available for human and ecosystem use.

- How adaptations in turn will feed back into the production of greenhouse gases.

The information and research needs might seem daunting. Although listed in order of the MARA team's "first cut" at priorities, refining priorities among them can be facilitated by assessing public understanding of, and potential reactions to, climate change and its multiple subtle yet significant impacts. Working with stakeholders can clarify misunderstandings about climate change and their priorities for research on potential impacts from climate change. For example, the MARA shows that ecosystems are especially vulnerable to climate variability and change. The MARA researchers and stakeholders are developing a process for setting priorities for additional ecological assessment. This process will include criteria such as those described in Chapter 2, with an emphasis on how stakeholders' perceptions of and values for potential ecological impacts would affect their priorities about what to assess next.

Our experience shows that stakeholders can be an important contributing resource in the assessment process because of their knowledge of local conditions and their access to valuable information otherwise not available; some of this is being used in the second-year MARA activities (e.g., see page 33). As research and assessment results become available, continuing stakeholder collaboration is crucial for designing and implementing effective strategies to disseminate the findings for citizens' use.

Rather than a straightforward summation of simple measures, overall social well-being is a complex combination of economic, ecological and distributional considerations. The MARA findings provide insights for making better decisions in an uncertain world, with the goal of optimizing social well-being. Chapter 10 summarizes the most important actions for the relatively near term to take advantage of opportunities and enhance the region's resiliency to climate variability and change. Chapter 11 takes a longer view, setting priorities for filling gaps in information and understanding needed to improve the region's future decisions related to climate variability and change.

### Box 10 Climate Change and Mid-Atlantic Cities

*The MAR's 6 largest metropolitan areas (Baltimore, Norfolk, Philadelphia, Pittsburgh, Richmond, and Washington) account for more than half of the region's population. Expected growth makes urban areas among special places where impacts of climate change warrant particular attention. In the context of the U.S. National Assessment, the Metro East Coast assessment examines how climate change might affect the New York City area. Although not a primary focus in the initial MARA, chapters 4-9 indicate the potential for substantial cumulative impacts in urban areas. This box draws attention to several issues for additional analysis: urban climate, urban forests, air quality, and flood risk.*

*Photographic and GIS views of Philadelphia*

**Box 10, continued**

***Urban Climate***

*The climate of cities differs from that of surrounding areas (Oke 1987). Cities are warmer, receive less sunlight because they have higher concentrations of pollutants, and alter wind speed and direction. Although cities (and nearby downwind areas) tend to have higher precipitation than outlying areas, they usually are less humid because of increased runoff and lower evapotranspiration. How climate change will affect urban climates and these urban-rural differences is not known. One reason is that each city has a unique geography. Also, climate models and climate downscaling techniques lack sufficiently detailed spatial resolution.*

*If present differences between urban and rural climate continue under climate change, we might expect that cities would experience more health effects from heat waves, a greater summer heat island effect when air conditioning is increased, even more increases in downwind precipitation, lower costs for snow removal with warmer winters, and greater water use in hotter summers.*

***The Urban Forest***

*Urban trees increase human comfort levels and reduce cooling and heating needs by providing shade and reducing air temperature and wind speed (Grey 1996). Trees are important for their aesthetic appeal, for urban wildlife habitat and for reducing runoff by enhancing water infiltration in soils. In addition to outright removal to make way for development, trees in urban areas often are exposed to stresses such as: damage to boles, roots and branches during construction; increased levels of air pollution; higher urban air temperatures; less soil water; and road salt in runoff water. Only the latter of these would be improved by warmer conditions.*

***Air Quality***

*There are many links among cities, air quality, and climate (McCormick 1991; Yarnal 1991). Both human activities and climate must be studied to understand future pollution trajectories. Future legislation and urban development will both affect emissions of ozone and acid rain precursors. Weather systems develop and deliver ozone and acid rain to the Mid-Atlantic Region (Comrie 1994). Will future climatic conditions increase or decrease the number of these systems or affect their nature, thus influencing regional ozone and acid rain problems? This work is yet to be done.*

***Flood Risk***

*Climate changes that influence the frequency and magnitude of riverine or coastal floods may create substantial threats specific to urban areas. The Federal Emergency Management Agency (FEMA) has encouraged a change in society's response to flood risk. The old approach was largely structural: storing floodwater in dams or preventing it from entering threatened areas (using dikes, levees, or sea walls). The new approach recognizes the importance of limiting development in flood-prone areas through zoning regulations and building codes. However, application of these regulations is largely based on the spatial extent of historical flood frequency, such as a 100-year flood. Changing hydrological conditions upstream in a river basin (such as forest cutting, stream channelization, and increase of impervious surfaces) can increase downstream flood frequency and extent (Dunne and Leopold 1978), as could changing climatic conditions. Flood plain definitions that guide land use management for flood hazard mitigation today are likely to be inadequate in the future. A similar issue will affect coastal cities, where flood risk mapping is based on today's sea level.*

### Extreme Events

The MAR experiences extreme heat and cold, floods, fogs, hurricanes and other weather events that can cause or contribute to injuries and death. These events can have indirect consequences as well. For example, floods can contaminate drinking water supplies.

While climate change will affect the severity and frequency of extreme events, little can be said at this time about resulting impacts on health in the MAR. This is partly because of uncertainty about how climate change will influence the frequency and severity of extreme events in the region. Moreover, while the health consequences of hurricanes and floods are apparent, those of other types of weather are not. For example, fewer motor vehicle accident fatalities occur in snowy or rainy weather (Loeb 1985, Zlatoper 1987), perhaps because people drive less frequently and/or more carefully in such weather.

Mortality risks from extreme events are currently very small in the MAR (Kocagil et al. 1999). This suggests that modest changes in these risks would have little impact on the region's health status (not accounting for how morbidity due to extreme events would affect health status). Furthermore, if weather events that pose threats to health become more frequent or severe, there are structural and nonstructural measures that can be undertaken to reduce vulnerability (see Box 8). These measures include building codes, land-use planning, and severe weather warning systems. Health surveillance during and after extreme events is important in order to choose the most appropriate responses and to evaluate the effectiveness of the responses.

### Heat Related Mortality

Heat and cold currently are not major causes of death in the MAR (Kocagil et al. 1999). Nevertheless, Kalkstein and Swift (1998) estimate that compared with other U.S. cities, MAR cities would experience larger increases in heat-related mortality under climate change. Climate change is projected to increase summer excess mortality in Philadelphia, Baltimore, Pittsburgh, and Greensboro (see Box 9). Infrequent but intense heat waves coupled with vulnerable elderly and poor populations make Philadelphia residents particularly susceptible to heat-related mortality. Winter mortality is not as strongly associated with weather conditions as summer mortality, with winter excess mortality projected to be lower in Philadelphia but higher in Pittsburgh and Washington, DC. Despite potentially large percentage increases in excess mortality, mortality rates due to heat and cold extremes would remain small compared to rates from the region's leading causes of death (Chestnut et al. 1995).

### Vector/Water/Food Borne Diseases

Climate change can affect health risks from vector, water, and food borne diseases. These indirect health effects involve a complex chain of causality from climate change through biophysical systems to human disease risks, making them extremely difficult to quantify (Haines and McMichael 1997). Yet, the emerging view of health impacts at the global level suggests that indirect impacts may be substantially more important than direct impacts (McMichael et al. 1996).

#### *Box 8 Health Risk versus Vulnerability*

*It is useful to distinguish between risk and vulnerability. For instance, research might show that malaria-carrying mosquitos would find more suitable habitat in a region that becomes warmer and wetter, giving the region a higher risk from malaria. However, the region could adapt to reduce its vulnerability through measures such as vector control, disease monitoring and medical treatment, or even development of a vaccine. To be effective, adaptation must be technologically feasible, affordable, and acceptable. There often are trade-offs among these characteristics. Examples include concerns about unintended impacts on non-target species from spraying to control mosquitos and concerns that control measures might not be used by some vulnerable groups (such as susceptible elderly people who feel they cannot afford insect repellent). Thus the availability of adaptation measures does not ensure their adoption, but successful adaptation to the (climate-induced) increase in risk means low vulnerability to that risk.*

## Box 9. Heat- and Cold-Related Mortality for five MAR cities*

*Below are estimates of current excess mortality (i.e., the number of deaths attributable to climate) and projections of the change in excess mortality, adapted from Kalkstein and Greene (1997) and Kalkstein and Swift (1998). Full acclimatization is assumed, and the figures are adjusted for projected population changes. Three general circulation models (GCMs) recommended by the IPCC are used, from the Geophysical Fluid Dynamics Laboratory (GFDL), the United Kingdom Meteorological Office (UKMO), and the Max Planck Institute for Meteorology. These models were used because this research was done prior to the NAST recommendations. Nonetheless, these three GCMs provide a wide range of projections (GFDL low end, UKMO high end) that most likely encompass the Hadley and CCC climate projections. Cities that currently do not have a significant relationship between climate and mortality have no projected excess mortality.*

| | Excess Mortality | Change in Excess Mortality | | | | | |
|---|---|---|---|---|---|---|---|
| | Present Climate | 2020 | | | 2050 | | |
| | | GFDL | UKMO | Max Planck | GFDL | UKMO | Max Planck |
| **Summer** | | | | | | | |
| Baltimore | 93 | -8 | 106 | -3 | 127 | 171 | 134 |
| Greensboro | 29 | 28 | 38 | 28 | 55 | 59 | 49 |
| Philadelphia | 146 | -8 | 361 | 122 | 282 | 682 | 416 |
| Pittsburgh | 46 | -1 | 47 | 44 | 66 | 107 | 129 |
| Washington, DC | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Winter** | | | | | | | |
| Baltimore | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Greensboro | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Philadelphia | 100 | 24 | -79 | 13 | -29 | -82 | 63 |
| Pittsburgh | 23 | 6 | 15 | 7 | 22 | 27 | 16 |
| Washington, DC | 20 | 12 | 19 | 11 | 3 | 21 | 16 |
| **Total (Summer + Winter)** | | | | | | | |
| Baltimore | 93 | -8 | 106 | -3 | 127 | 171 | 134 |
| Greensboro | 29 | 28 | 38 | 28 | 55 | 59 | 49 |
| Philadelphia | 246 | 16 | 283 | 135 | 254 | 600 | 478 |
| Pittsburgh | 69 | 4 | 62 | 51 | 88 | 134 | 145 |
| Washington, DC | 20 | 12 | 19 | 11 | 3 | 21 | 16 |

** Portions of the Greensboro metropolitan statistical area are not located in the MAR.*

Much of the research on climate change and health has focused on the migration of tropical infectious diseases (e.g. malaria, carried by mosquitos) to more temperate zones (Patz et al. 1996; Colwell et al. 1998). The recent outbreak of West Nile virus encephalitis in New York is an example of a migrating disease. As of mid-October, 1999, 7 people had died and 49 had become ill from this mosquito-borne virus which also caused bird deaths in NY, NJ and CT (Fine et al. 1999). This strain of encephalitis had not been observed in the Western Hemisphere prior to this outbreak. Malaria is another disease currently not common in the MAR (Kocagil et al. 1999). However, a warmer and wetter climate could make conditions favorable for the mosquito vector, thus increasing the risk of malaria. Based on experiences in other developed countries (e.g., Australia), vulnerability to malaria can be reduced by vector controls, disease monitoring and medical treatment. Key components to reducing vulnerability include educating physicians to recognize diseases not common to the region and improving surveillance of mosquitos that carry other diseases such as viral encephalitis.

Lyme disease is the most prevalent vector-borne disease in the MAR. Lyme disease rates in the MAR are more than twice the nation's (Kocagil et al. 1999). One way this disease is linked to the climate is by the range and activity of its host vector, the deer tick, which requires certain temperature and humidity conditions (Glass 1995). Links have also been made between acorn production, gypsy moth outbreaks and Lyme disease risk (Jones et al. 1998). The impact of climate change on the risk of contracting Lyme disease is a concern for the MAR (Patz and Yap, 1998). Like malaria, adaptation measures can reduce vulnerability to the disease. Vector controls, prevention, vaccination and early detection are some examples. Research suggests that at this time, it is cost effective to vaccinate only those individuals who spend a lot of time outdoors in areas of high Lyme disease risk rather than everyone (Meltzer et al. 1999, CDC 1999b). In addition, vaccinated people inadvertently may put themselves at higher risk, especially if they presume the vaccine will be more effective than clinical trials have shown. Its cost (currently about $250) may leave lower income individuals at risk even if the region as a whole has low future vulnerability to Lyme disease.

Giardiasis (caused by *Giardia lamblia*) and cryptosporidiosis (caused by *Cryptosporidium parvum*) are two important waterborne diseases in the MAR (Kocagil et al. 1999). Cryptosporidiosis is of particular concern because of the difficulty in removing *Cryptosporidium* from water supplies and the potential deadliness of this disease. Although there are many possible sources of *Cryptosporidium*, an important one is cattle. Increased precipitation over agricultural lands could increase the number of *Cryptosporidium parvum* in water sources (Atherholt et al. 1998). Vulnerability could be reduced by public water treatment, households taking actions to prevent exposure, and source water protection. Current regulatory efforts such as the Enhanced Surface Water Protection Rule are aimed at reducing the amount of *Cryptosporidium parvum* in drinking water.

*Vibrio Cholerae*, the bacterium that causes cholera, is present in the Chesapeake Bay (Colwell et al. 1998) although the disease is not currently a health problem in the MAR. Preliminary research indicates that climate change could facilitate the growth of *Vibrio Cholerae* in the Chesapeake Bay (Gibson 1999). Thus the risk of cholera in the MAR could increase with climate change. However, areas where cholera is currently a major health problem are countries with less developed public health infrastructure than the U.S. Proper food preparation, waste and water treatment can effectively reduce vulnerability to the disease.

The view emerging from our assessment is that the MAR's technological and medical infrastructure should be able to contain endemic and migrating vector/water borne diseases, keeping them from becoming significant regional problems. Thus, while the risks from these diseases could increase, adaptive measures can be taken to reduce the region's vulnerability. However, there are economic costs associated with these measures. Accordingly, while health status may be little affected, the costs of public health would increase. There also may be subgroups with less access to public health measures. In addition, some adaptation measures can have undesirable side effects (e.g., secondary impacts of pesticides used to control disease vectors).

## Air Quality

Without reductions in polluting emissions, heavily populated urban areas could experience more severe air quality problems as a result of climate change effects on the composition, concentration, and duration of chemical pollutants in the atmosphere (Slanina et al. 1999). One important air pollutant is ground-level ozone, which can cause or exacerbate respiratory illness. Ozone precursors include volatile organic compounds (VOC) and nitrogen oxides (NOx). Wind speeds and patterns influence regional transport of ozone and its precursors in the MAR and northeastern U.S. The largest point source of NOx is in the Ohio River Valley while large urban areas, such as the Washington-New York corridor, are sources of both VOC and NOx (Guinnup and Collom, 1997). A key issue for assessing air quality risks is future emissions. Future emissions of air pollutants that are harmful to human health will depend on a variety of factors (e.g., automobile use, technology, regulations) that are not easily forecasted (Davies and Mazurek, 1998). Efforts to reduce greenhouse gas emissions would have the secondary benefits of reducing pollutants harmful to human health.

## Mental Health

Depression and psychological changes can be related to persistent cloudy skies, precipitation, or thunderstorms (Collier and Hardaker 1995). Furthermore, experiencing extreme weather such as hurricanes or floods can inflict psychological stress and trauma (McMichael et al. 1996). This was found to be the case in Pennsylvania from flooding after Hurricane Agnes (Logue et al. 1979). Because such psychological impacts are not fully understood in the current climate regime, it is very difficult to evaluate them under future climate change scenarios.

## Conclusions

Table 13 (drawn from Table 4) summarizes the assessed potential health impacts for the region. The MAR's current and future health infrastructure is expected to be able to respond to the health risks associated with a warmer and wetter climate, although at increased cost from measures to protect the safety of food and water, control disease vectors, and provide health services. Historically the U.S. population has been able to adapt and reduce vulnerability to climate related health risks. With continued investment in public health infrastructure and systems and barring significant unforseen developments, major health policy challenges in the U.S. during coming decades will relate to cost, access, and disparity in care (Kajander 1996, Grayson 1998).

It is evident that further research is needed, particularly to increase our understanding of the indirect effects of climate change on health. Integrated modeling efforts are needed to quantify the complex biophysical and behavioral linkages connecting climate to health. Of equal importance is research on the costs, effectiveness and acceptability of adaptation options. Additional major research gaps are how climate change affects air pollution and motor vehicle accidents. Motor vehicle fatalities currently are an important cause of death in the MAR; the potential for additional motor vehicle fatalities induced by climate change could be larger than other weather-related causes of death. Finally, research on the variation of health risks within the region by location and population characteristics is needed to address the distribution of climate-induced health impacts, especially because different segments of the population (e.g., elderly, poor, less educated) currently tend to face greater health risks in general.

| **Table 13. Summary of MAR Health Impacts** | Negative Impact | Positive Impact |
|---|---|---|
| Most Certain<br>• *Temperature related health status* | heat stress | |
| Moderately Certain<br>• *Temperature related health status* | | less cold stress |
| Uncertain<br>• *Vector and water-borne disease health status* | Cryptosporidiosis, malaria | |

## Box 7 Climate Change and Bird Distributions in the Mid-Atlantic Region

*There are both economic and ecological reasons to care about birds. Watching and feeding birds is big business, generating about $885 million annually in retail sales within the Mid-Atlantic region (MAR) (Bird Conservation 1997).*

*It is difficult to estimate how changes in bird distributions might affect the economics of watching and feeding birds. Spending would shift as some birdwatching sites become less favorable and others become more favorable. Although many bird watchers might adjust to diminished species richness, they will experience the loss of well-being that accompanies a reduction in their preferred activities.*

*Also of concern are potential indirect costs of changes in bird distributions and how these changes will affect ecosystems. Birds provide important ecological services including seed dispersal, plant pollination and pest control. For example:*

- *Blue Jays are a major disperser of oak seeds.*
- *Birds eat up to 98% of the overwintering codling moth larvae in orchards.*
- *Wood warblers are largely responsible for holding down numbers of spruce budworm larvae, eating up to 98% of the non-outbreak larvae.*
- *While the white-footed deer mouse is a more important predator of gypsy moths, birds also hold down numbers of this pest.*

*The table shows results from statistical models that associate bird distributions first with current climatic conditions (1985-1989) and then with temperatures increased by 1.8° F (1° C) from the CCC model (Price, in press; 1995). This temperature change is within the ranges suggested in Figure 8. The gross change represents the overall loss in the number of perching (passerine) species currently found in the area. The net change represents the loss of species currently found there, offset by species moving in from outside the area. Thus a 1.8° F increase in temperature could lead to a loss of 7% of the passerine species currently found in the MAR. These losses would be somewhat offset by birds colonizing from outside the region so the net change would be 3% fewer species than currently found there. This 3% translates into fewer than 5 perching species in the MAR.*

*The colorful wood warblers are a subset of the species from the table, are popular among bird watchers, and are important predators of insects. The same increase in temperature could lead to a gross loss of 14% of MAR warblers. This could be important because it is unknown whether the species colonizing the region would perform the same ecological services of the species currently found there. Even if they did, the net change would still be an 8% reduction in the number of warbler species currently found in the MAR.*

*How quickly these changes might occur is unknown. In the last 20 years, the average latitude for warblers has shifted north by an average of more than 43 miles. This suggests such changes could occur relatively quickly.*

*In summary, climate change will affect bird distribution, perhaps quickly, and the magnitude of ecological and economic effects is unknown.*

Changes in number of perching bird species

| | *With 1.8° F temperature increase* | |
|---|---|---|
| | *Gross Change (%)* | *Net Change (%)* |
| ***Region*** | ***- 7*** | ***- 3*** |
| Delaware | - 3 | 0 |
| Maryland | - 4 | - 1 |
| New Jersey | - 5 | - 1 |
| New York | - 10 | - 4 |
| North Carolina | - 5 | - 2 |
| Pennsylvania | - 9 | - 3 |
| Virginia | - 4 | - 1 |
| West Virginia | - 7 | - 3 |

Because species will be affected differently by climate changes, relationships among species will be altered and this could affect ecosystem functioning. Species that benefit could crowd out others not directly affected by changes in climate variables, as well as those that suffer directly. Although some desired species might become more abundant, the overall result is likely to be a reduction in biodiversity, with uncertain implications for a) the ecosystem functioning—i.e., how ecosystem components interact—that is crucial for ecosystem evolution as well as b) functions that people value, such as pollinating crops, moderating and purifying water flows, and providing diverse wildlife to observe.

Projecting potential ecological impacts of climate change in the MAR is especially difficult because the MAR itself is a complex interconnected system. Although specific impacts still cannot be predicted, ecosystem functioning and biodiversity are likely to experience mostly negative effects from climate change. These impacts on ecosystems in turn could have as yet unpredicted impacts on the sectors described in Chapters 4-9. Monitoring will be important to identify changes in habitat and biodiversity early enough to evaluate whether actions to mitigate those changes are warranted. In sum, the overall ecological impacts could be quite large, even though very uncertain, as shown in Table 12, which is drawn from Table 4.

Because of the potentially significant ecological impacts from climate change in the MAR, a next step is to develop and implement a process of selecting priorities for additional ecological assessment. That process will involve stakeholders and researchers in the MAR. The task now is to devise procedures and methods for ascertaining how stakeholders think about ecological impacts from climate change and other stressors. What do they think should be the priorities for further assessment? Their answers will reflect their mental maps of how they perceive ecosystems, how ecosystem components interact and function, and how ecosystems might change. Their answers also will reflect their values related to these concepts. A key to understanding stakeholder perceptions may be how they see tradeoffs and options.

The process will involve two components: (1) researchers will identify ecological resources that may be at risk, (2) researchers will communicate with stakeholders to determine which ecological resources are most highly valued and which risks are of the most concern. The process will be iterative, with researchers refining the scope of their work in accordance with stakeholder values and with stakeholders refining their statements about their concerns as they learn about how things that they value can be related to ecological risks that can be assessed.

Improving methods for obtaining public and stakeholder views is an important task in the assessment process. There is a common assumption that most people care mostly about big animals (charismatic mega-fauna). The Advisory Committee and our earlier work have convinced us that this view is too simple: how many people think about ecosystems is more complex and quite subtle. A method for the research might involve some sort of "snowball" approach that would look at the literature, speak with some key informants (e.g., regional planners, elected officials, EPA experts), conduct a series of focus groups with different groups (e.g., people who fish commercially, farmers, recreational anglers, developers, foresters), and then use what we have learned to design and implement a general survey in the MAR. The findings would pertain to this region, but the methodological advances would be useful to all assessments. This in-depth work on ecological values and concerns is intended to complement the ongoing activities with our Advisory Committee, filling a gap its members helped identify.

| **Table 12. Summary of MAR Ecological Impacts** | Negative Impact | Positive Impact |
|---|---|---|
| Uncertain | | |
| • *Biodiversity* | migration barriers, invasive species | warmer temperatures |
| • *Ecological functioning* | forest composition, cold water fisheries | warm water fisheries |
| • *Environmental effects from agriculture* | nutrient leaching, runoff | |

that the Hadley and CCC models project increases in precipitation by the year 2100. There is more uncertainty about future storminess, but the benefit of longer coastal recreation seasons could be more than offset by frequent or intense storms.

Higher sea levels will raise storm surge levels, even if the frequency and intensity of storms do not increase. Thus the same strength storm will cause more damage, making it seem like a stronger storm. Najjar et al. (2000) show that what are now considered 100-year floods will occur every 25 to 30 years. Recent experiences such as Hurricane Floyd emphasize that storm damages can be substantial both along the coast and inland. Strong storms can disrupt transportation, settlements, waste treatment, emergency services, and ecosystems. (See Box 5.)

The costs of protecting valued infrastructure or natural areas could be quite high. Parsons and Powell (1998) and Faucett Associates (1998) find that beach replenishment is less costly than the present value of losses from allowing beach retreat. However, an emerging policy of beach replenishment in New Jersey is estimated to cost $60 million per mile and $9 billion over 50 years (Grunwald 1999). Policies for strategic retreat—i.e., deliberately allowing selected low-lying areas to be inundated by sea-level rise—are likely to be controversial and have legal complications, but Titus (1998) argues for rolling easements that would maintain public access to tidal lands as shorelines retreat. Delaware currently allows strategic retreat for state owned coastal lands.

In addition to the aesthetic and economic values discussed above, a changing climate would affect the MAR's ecosystems. The complexity of coastal ecosystems is depicted in Figure 13. The MAR's dominant coastal wetlands are flood-

**Box 5 Hurricane Floyd**

*In September 1999, approximately 2.6 million people evacuated their FL, GA, SC and NC homes in advance of Hurricane Floyd. Even so, there were 77 deaths and more than $6 billion in damages in the Southeast and Mid-Atlantic regions.*

*The environmental, agricultural and human disaster were particularly severe in NC, where rivers were fouled by human and livestock waste (spoiling water supplies and the shrimp harvest), farm losses exceeded $1 billion, millions of dollars in uninsured home and car losses were incurred, and 51 fatalities were attributed to Hurricane Floyd. Observing how NC responds by shifting the types and locations of its socioeconomic activities can be an indicator of how other vulnerable subregions might respond to similar storms in the future.*

*Hurricane Floyd Effects on Franklin, VA*
*(Photo by Liz Roll/FEMA News Photo)*

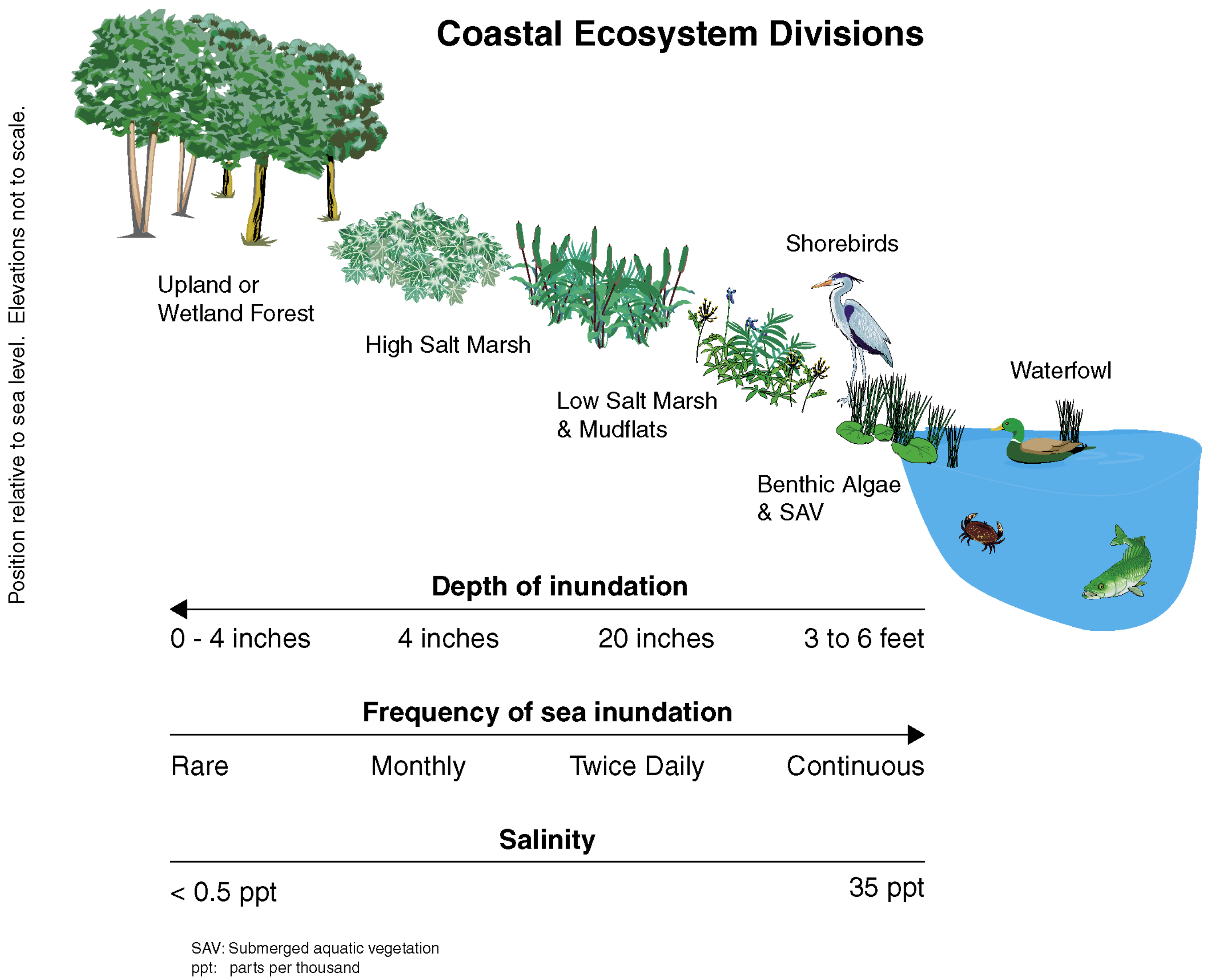



*Figure 13. Coastal ecosystem divisions (adapted from Brinson et al. 1995).*

plain forest, tidal fresh water marsh, and salt marsh, which sort out on the landscape according to gradients in flooding frequency, tidal amplitude and salinity. Wetlands buffer the coast from storms; about half of normal wave energy is dissipated within the first 10 feet of encountering marsh vegetation such as cordgrass (Kesselheim 1995, Moeller et al. 1997). Wetlands also slow erosion (because plant roots hold soils in place) and moderate flooding (because the soils soak up water from heavy rains and increased streamflows). Wetlands slow runoff so that nutrients, sediments and pollutants are trapped before entering coastal waters.

MAR wetlands are important grounds for food, shelter, spawning, nesting, and predation. Fish and invertebrates (such as weakfish, black sea bass, striped bass, herring, spot, summer flounder, blue crab, eastern oyster, and horseshoe crab) need coastal wetlands to survive and reproduce. The Chesapeake and Delaware Bays are homes to two of the largest concentrations of migratory shorebirds in the western hemisphere. Nearly 1.5 million birds, predominantly red knot, dunlin, sanderling, semipalmated sandpiper and ruddy turnstone, stop at the Delaware Bay to feed each spring (Jones et al. 1997). With up to 70 percent of the entire North American population of the red knot in the

**Table 10. Projected change in April-May flow of the Susquehanna River and Chesapeake Bay summertime anoxic volume (Najjar et al. 2000)**

| Change | *2030* | | *2095* | |
|---|---|---|---|---|
| | Hadley | CCC | Hadley | CCC |
| April-May flow *(%)* | *+12* | *-4* | *+4* | *-25* |
| Anoxic volume *(%)* | *+31* | *-10* | *+10* | *-65* |

Delaware Bay at one time, these birds are quite vulnerable to any environmental changes (Sutton et al. 1996). See Box 6 for a case study of potential impacts on waterfowl in the Chesapeake Bay.

Human and ecological forces also interact with respect to sea-level rise. For instance, dams and development that reduce the availability of sand and sediment would lead to greater inland displacements. Land loss and erosion would be reduced if vertical marsh accretion could keep pace with sea-level rise. Salt marshes generally are vulnerable to sea-level rise. For most of the MAR coast, sediments and organic matter are not deposited fast enough to keep up with current sea-level rise and barriers often prevent inland migration (Kearney and Stevenson 1991, Erwin 1999). Losses are very likely in the extensive non-tidal wetlands of the Ablemarle/Pamlico Peninsula, which receive little riverine sediment (Moorehead and Brinson 1995). Some of this loss may be offset by an increase in organic matter accumulation stimulated by the higher levels of $CO_2$ (Drake et al. 1996) and warmer temperatures (Callaway et al. 1996, Bricker-Urso et al 1989).

Much of the response (for salinity, dissolved oxygen, submerged aquatic vegetation (SAV), phytoplankton, fish and shellfish) of the Mid-Atlantic estuaries to climate change cannot be predicted reliably because of uncertainties in future streamflow. What is clear is that relatively modest changes in stream flow can have a dramatic impact on water quality. For example, Table 10 shows how anoxia (lack of oxygen) would increase in the Chesapeake Bay, given the stream flow changes projected in Chapter 6. Fish and shellfish will migrate away from increased anoxia, while decreased anoxia will be beneficial. This calculation does not include the direct impact of warming, which is likely to exacerbate the already low summer oxygen levels in Mid-Atlantic estuaries because of increased oxygen demand and decreased oxygen solubility. Some mobile estuarine species also will be displaced northward by warming.

Sea-level rise is likely to have the largest climate-related impact on coastal wetlands. However, continuing current development practices will cause much larger impacts. This suggests that strategies to minimize adverse ecological impacts of human activities on coastal ecosystems in the MAR could help mitigate some of the risks from future climate variability and change. Table 11 (drawn from Table 4) summarizes the impacts from climate variability and change on the MAR's coastal zones.

| **Table 11. Summary of MAR Impacts on Coastal Zones** | Negative Impact | Positive Impact |
|---|---|---|
| Most Certain | | |
| • *Coastal zones* | erosion, saltwater intrusion | |
| Uncertain | | |
| • *Biodiversity* | migration barriers, invasive species | warmer temperatures |

## Box 6 Impacts of Climate Change on Waterfowl in the Chesapeake Bay

*About a million ducks, geese and swans use the Chesapeake Bay estuary to feed and rest during the winter and thousands more use it as a migration stopover point. Average population sizes for most duck species have declined markedly since the 1950s while populations of Canada Geese, Snow Geese and Brant have increased (Perry and Deller 1995). See table below. Most of these changes are attributed to changes in food resources in and around the Bay, particularly the widespread decline of submerged aquatic vegetation (SAV), a prime waterfowl food (Perry and Deller 1996). Excessive nutrients and sedimentation result in blooms of algae and high turbidity that shade SAV and limit its growth (Hurley 1991). A few species have adapted by changing their diet. For example, swans and geese now feed largely in upland agricultural areas on waste corn and winter cover crops (Perry 1987). Canvasbacks switched from a diet of wild celery and sago pondweed to Baltic clams, an invertebrate that has become more plentiful (Perry and Uhler 1988, Haramis 1991a). Species apparently unable to adapt to the loss of SAV have shown drastic declines; the Northern Pintail, Redhead, and American Wigeon have largely abandoned the Bay as a wintering site (Haramis 1991b, Perry and Deller 1995).*

*Global climate change is likely to affect both waterfowl breeding and wintering habitats. Warmer and drier conditions are projected for the Prairie Pothole Region of the north-central U.S. and south-central Canada, an area known as the continent's "duck factory" (Sorenson et al. 1998; Sorenson et al. in prep). By reducing the pothole wetlands, these changes could reduce the number of ducks in the region and their reproductive success. Sorenson et al. (in prep) project 20-40% declines in the number of ducks breeding in Praire Canada for the 2030s. In turn, this could decrease waterfowl abundance in the Bay, because many of the ducks that winter in the Bay breed in the Prairie Pothole Region. These include the Mallard, Northern Pintail, American Wigeon, Canvasback, Redhead, Lesser Scaup, Common goldeneye, Ruddy Duck, and Bufflehead.*

*Projections of warmer water temperatures, possible streamflow increases and larger human populations in the MAR suggest that water quality in the Bay and thus SAV will continue to decline. Sea-level rise might reduce the amount of shallow water habitat suitable for wintering waterfowl. Thus climate change will add to the habitat pressures already being experienced because of human activity.*

*Many questions remain, such as how alternate breeding grounds further north will be affected by climate change. Even so, projections of declining breeding populations producing fewer young due to drier conditions on the prairies, coupled with likely impacts of climate change on winter habitat quality bode poorly for future duck populations in MAR waters.*

Average waterfowl populations wintering in Chesapeake Bay

| Species | 1950-1959 | 1985-1999 | % Change |
|---|---|---|---|
| *Redhead ** | 76,000 | 2,000 | -97% |
| *American Wigeon ** | 77,000 | 5,000 | -94% |
| *Northern Pintail ** | 40,000 | 3,000 | -93% |
| *Common Goldeneye *** | 22,000 | 6,000 | -73% |
| *American Black Duck *** | 143,000 | 45,000 | -69% |
| *Canvasback *** | 179,000 | 57,000 | -68% |
| *Ruddy Duck *** | 66,000 | 33,000 | -50% |
| *Scaup *** | 102,000 | 52,000 | -49% |
| *Mallard *** | 71,000 | 60,000 | -15% |
| *Bufflehead *** | 9,000 | 20,000 | +55% |
| *Canada Goose **** | 178,000 | 386,000 | +54% |
| *Snow Goose **** | 5,000 | 90,000 | +94% |
| *Brant **** | 13,000 | 22,000 | +41% |

*Major food: * SAV, ** invertebrates, *** agricultural fields*

## Box 3 Water Managers Report Systems Are Vulnerable to Weather Variability

*In 1998, 504 Pennsylvania water system managers responded to a mail survey. The table shows that many systems suffer difficulties from weather events. Power outages from storms, affecting the ability to pump water, are the most frequent weather-related problems. Managers having problems now also expect disruptions in their daily operations in the next 5 years.*

*Perhaps surprisingly, larger systems report more weather-related problems than do smaller systems. Larger systems often draw on more than one source of water; this complexity may increase their vulnerability to extreme weather. These data call into question assumptions that the current consolidation trend is reducing the vulnerability of water systems to weather variability.*

*Water system managers are ambivalent about climate change. When provided options, only 9 percent checked that they are not concerned because climate change is unlikely to happen. A much larger share (21 percent) checked that "global warming is real" and that they are concerned. Still, the highest share (50 percent) checked that they simply do not know what to believe about climate change. Another 18 percent checked that climate change may happen, but is so long-term that adaptations are beyond their planning horizon. Seventy-eight percent of managers indicate their planning horizon is 5 or fewer years.*

*In summary, most Pennsylvania water system managers face disruptions from weather events and expect these problems to continue. They are concentrating their energies on addressing current concerns amid a changing regulatory climate. While only a small number reject climate change as unlikely, most are unsure about climate change; in any event, few plan beyond 5 years. This ambivalence may give way to concern for adaptation if water system managers learn that climate change impacts include more frequent and intense weather events.*

***Question:*** *"How many times in a typical year has your current system experienced some form of difficulty due to the types of events listed below?"*

| ***Answers:*** (percent who responded...) | *"never"* | *"1 or 2 per year"* | *"more often"* |
|---|---|---|---|
| Drought conditions lowered the supply of water in the system | 60 | 35 | 5 |
| Drought conditions forced us to seek out another source | 88 | 9 | 2 |
| Drought conditions led to significant increased demand on our system | 58 | 34 | 9 |
| Flash floods have overloaded our recharge area's ability to filter surface water naturally | 94 | 6 | 1 |
| Flash floods have increased the turbidity in our surface water system | 75 | 14 | 12 |
| Storm water runoff has threatened our recharge area | 89 | 9 | 2 |
| Extremely high air temperatures have overloaded electrical circuits and knocked out pumping stations | 90 | 9 | 1 |
| Extremely high air temperatures have increased demand and thus strained our water supply | 72 | 23 | 5 |
| Extremely low air temperatures have frozen water pipes that expanded and broke water lines | 67 | 27 | 5 |
| Electrical storms have led to power outages that affected our ability to pump water | 32 | 58 | 11 |
| Heavy, wet snows have led to power outages that affected our ability to pump water | 55 | 42 | 2 |
| Heavy winds have led to power outages that affected our ability to pump water | 56 | 42 | 3 |

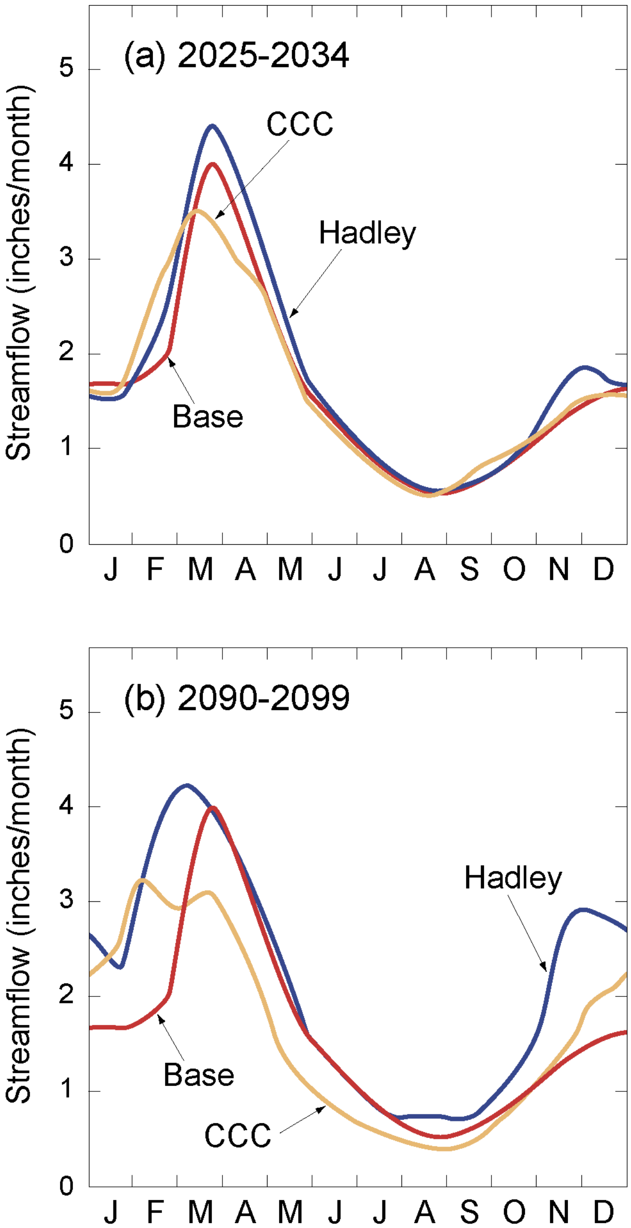



*Figure 11. Predicted streamflow changes*

storms. Although smaller water systems and individual well owners cannot spread these costs over large numbers of users, improved use of water markets could increase the efficiency of water use for both large and small systems.

The effects of changed climate on the MAR hydrology are likely to stress ecosystems. Because warmer water holds less oxygen, dissolved oxygen levels—an indicator of the general ecological health of water bodies—will decrease as the higher average air temperatures cause the region's streams and lakes to warm. Runoff from increased thunderstorm activity and more rapid snow melt will carry more contaminants and sediment to streams. Changes in the amount, timing, and quality of water might affect ecosystems from the headwaters throughout the drainage basins to the region's estuaries and bays. For instance, under the Hadley scenario, the increased spring runoff and stream flow following fertilizer application will increase nutrient loads in and from agricultural watersheds. Coastal areas downstream of such areas will have greater risk of eutrophication. Under the CCC scenario of decreased spring and summer stream flow, however, nutrient loads will decrease at this time of year. Such changes will affect recreation opportunities as well as the general quality of life. (As an example, see Box 4 for a case study on recreational fishing.) Because land use decisions have long-lasting effects on the quantity and quality of runoff, future water resource vulnerabilities will be influenced by the interaction between land use decisions and climate change impacts. The nature of these interactions and their outcomes require further research.

Table 9 (drawn from Table 4) summarizes the impacts on the region's fresh water quantity and quality.

| **Table 9. Summary of MAR Fresh Water Impacts** | Negative Impact | Positive Impact |
|---|---|---|
| Uncertain | | |
| • *Fresh water quantity* | more variability | more average streamflow |
| • *Fresh water quality* | runoff | |
| • *Ecological functioning* | forest composition, cold water fisheries | warm water fisheries |

**Box 4** **Recreational Fishing and Climate Change in the MAR**

*The Mid-Atlantic Region (MAR) is home to many recreational freshwater fish species including brook trout, rainbow trout, brown trout, largemouth bass, smallmouth bass, catfish, carp, and panfish. Bass and trout are the most popular for recreational fishing.*

*Different types of fish thrive in different temperatures. Bass can be found throughout warm waters in the MAR, but trout are cold-water species. The current southern distribution limit of trout is in the Appalachian Mountains of North Carolina and Virginia where higher elevations have cooler summer water. Brook trout typically are found in the highest elevations, with rainbow and brown trout in lower elevations. Brown and rainbow trout compete with brook trout for food and habitat; they also prey on brook trout.*

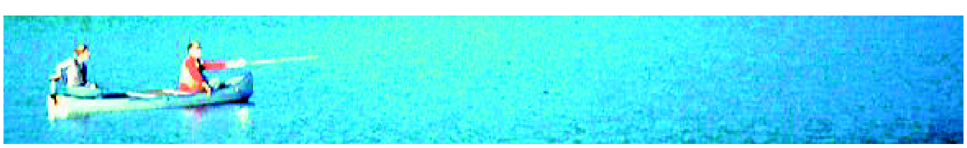
*Water temperatures are affected by both groundwater temperature and local average annual air temperature. If the climate warms, trout habitat will shrink in low elevations and low latitudes, and bass habitat will increase. Higher stream temperatures could increase the mortality rate for brook trout, the least tolerant to temperature fluctuations. It could also increase the competitive advantage of both brown and rainbow trout over brook trout. Brook trout might be lost from many MAR streams.*

*Fish populations also follow changes in stream flow (one measure of fish habitat space). Even though the MAR may have more summer precipitation, warmer temperatures may mean less snowpack and thus lower summer stream flows and lake levels; in turn, this would reduce trout habitat. However, not all fish species will be hurt by decreases in stream flow. In the Susquehanna River, low flows actually benefit smallmouth bass populations while above-normal stream flows have produced the smallest populations of smallmouth bass (McCosh 1993).*

*Riparian and instream habitat restoration in upper reaches of some watersheds could help maintain brook trout habitat, but two factors could offset the effectiveness of this management option. First, increased temperatures will likely continue to favor brown trout, which are likely to migrate into these improved habitats and continue to compete with the brook trout population. Second, recent evidence indicates that past land use, particularly poorly managed agriculture and forestry, continues to influence stream invertebrates and fish. Related instream sedimentation and loss of gravel spawning areas are difficult to restore, even if the watershed is restored to forested land cover.*

*Protection and restoration require resources that otherwise could be put to alternative use. In a related study, anglers were asked their willingness to pay to avoid decreases in cold-water fishing opportunities accompanied by increases in warm-water fishing opportunities (Heberling et al. 1998). On average they were willing to pay around $4.00 per angler per year to avoid the changes. Aggregating such estimates can help answer questions about whether protection and restoration are worthwhile.*

*Overall recreational fishing prospects are complex in a climate change scenario. Gains in warm-water habitat could moderate losses in cold-water habitat in terms of total fish populations, but there still will be economic damages. Some economic damage could be offset by anglers switching to other fish (i.e., cold-water anglers become warm-water anglers). However, some cold-water habitat will not be suitable for warm-water fish, so some fishing opportunities will be lost.*



More than 20 percent of the respondents reported major impacts from heavy rains, high winds or ice storms. About 15 percent reported major impacts from low rainfall or heavy snowfall. Fewer than 5 percent reported major impacts from very high or low temperatures. Compared with government operators, private foresters find high rainfall to be a bigger problem, reflecting their interest in access to harvest sawtimber and pulpwood. Not surprisingly, foresters in the upland hardwood subregion are more concerned about heavy snowfall than those in the southern pine subregion. Analysis of the full set of responses will serve as a baseline for predicting how forest managers would respond to changes in extreme events—but we need better ways of projecting how the magnitude and frequency of extreme events might be affected by overall climate change.

If projections of future patterns of extreme events are uncertain, there is greater certainty that higher temperatures and changes in precipitation will directly affect tree growth and survival. In addition, increased concentrations of atmospheric $CO_2$ may enhance growth and allow plants to use water more efficiently (Bazzaz 1990, Eamus 1996). And, changes in the distribution and abundance of pests, frequency of fires, erosion and decomposition could cause indirect impacts on forests (Watson et al. 1996). Recent work forest sector analysis for the National Assessment has suggested that temporary or long-term conversion of forest to grassland/savanna may occur in parts of the east/ southeast U.S.

We used a statistical procedure (Iverson and Prasad 1998) to relate current environmental conditions to current abundance of 75 tree species; we then projected potential future abundance based on future climatic conditions. The model uses county-level data for 33 environmental variables. Climate data include monthly averages for precipitation, temperature, and potential evapotranspiration (PET) for current conditions and for climate models. Unlike other chapters in this report, the forest projections are based on equilibrium climate scenarios for a doubling of $CO_2$. However, the temperature and precipitation changes for these equilibrium scenarios are similar to those for the 2090-2099 period of the transient climate scenarios. Thus we consider the two to be comparable. (Detailed transient model data were not available in time for our forestry assessment, and use of the $CO_2$ doubling allows comparison with prior studies.) Species are assumed to be able to colonize all suitable sites. Time lags in species' migration are not accounted for (so this assumes trees are able to migrate in pace with climate), nor are competitive interactions among species.

Climate change is likely to reduce the dominance of maple-beech-birch forests in the MAR, with an increase in oak-hickory forests, and, to a lesser extent, southern pine and mixed oak-pine forests. The lower part of Figure 10 shows how the dominant forest types would be distributed under the CCC and Hadley models, for comparison with the current distribution in the upper part. The shifts in forest types and their locations could diminish the competitiveness of the many small hardwood processors (e.g., for furniture and cabinetry). Although overall primary forest productivity might increase, the relatively rapid shift in dominant forest types might foster invasive species and decrease biodiversity in the region's forests. Rapid shifts in forest types also might affect hydrology so that forests provide less filtering and moderation of stream flow. Relatively little is known about how the changes in forest types might affect recreation opportunities in forests. Thus forest impacts are shown in the "moderately certain" and "uncertain" categories in Table 8 (which is part of Table 4).

| **Table 8. Summary of MAR Impacts on Forestry** | Negative Impact | Positive Impact |
|---|---|---|
| Moderately Certain | | |
| • *Forestry production* | extreme events | more growth, different mix |
| Uncertain | | |
| • *Ecological functioning* | forest composition, cold water fisheries | warm water fisheries |