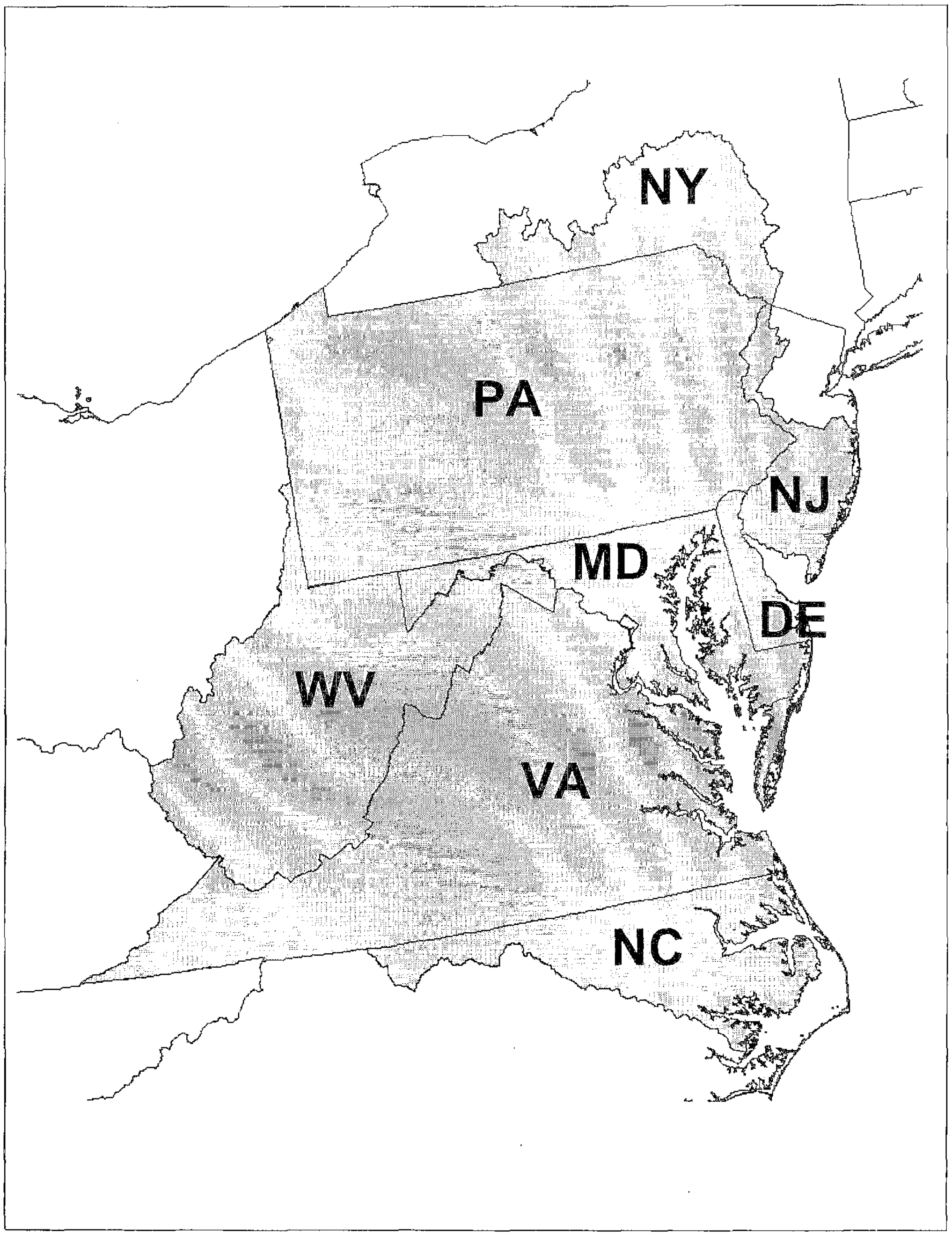
Mid-Atlantic Regional Assessment (MARA) Draft Preliminary Report on Impacts from Climate Change



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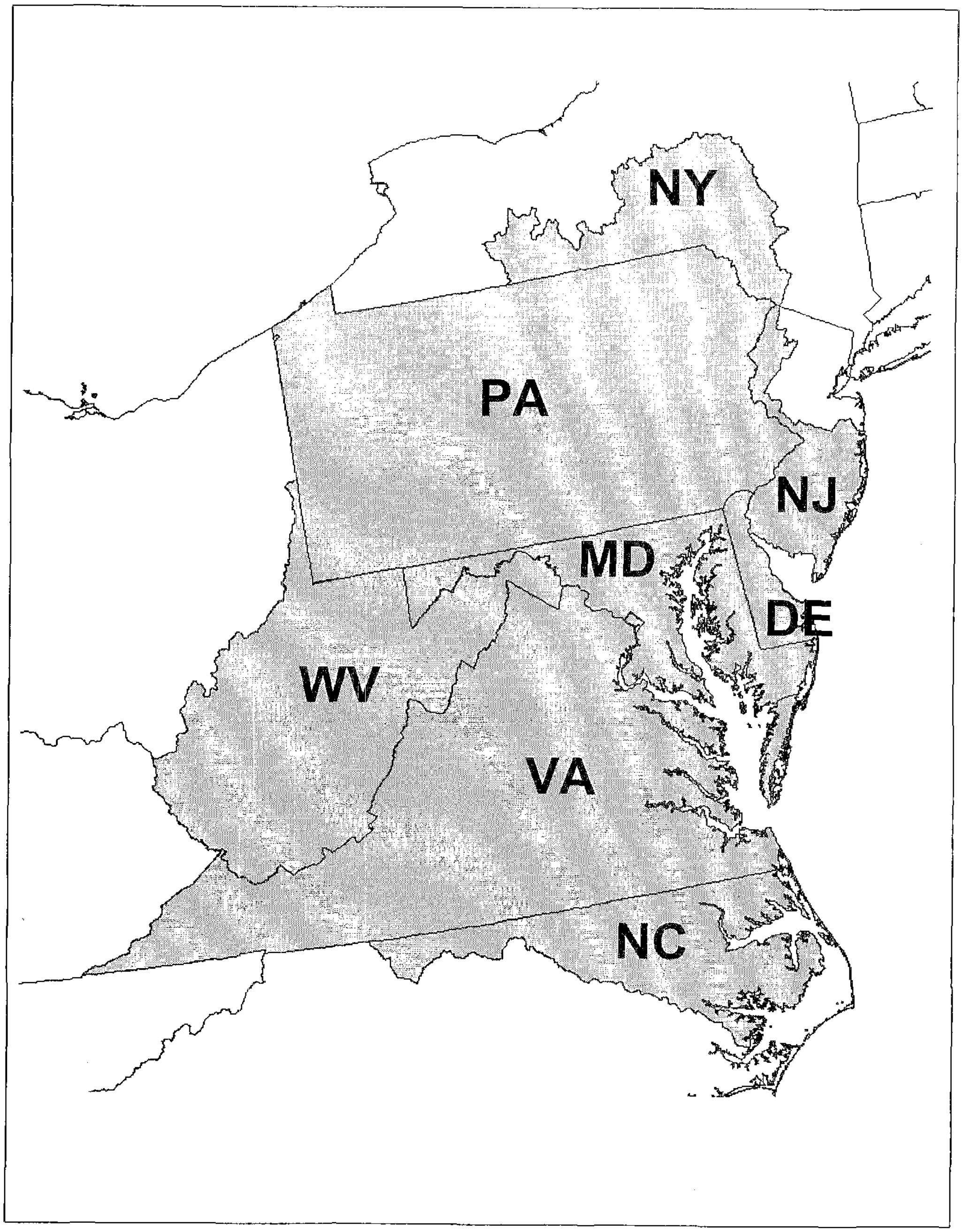

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(Short Title: MARA Draft Preliminary Report)

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[To be written.]

Preface

The Global Change Research Act of 1990 requires the US Global Change Research Program (USGCRP) to submit a report to Congress (by January, 2000) on the potential national impacts of global climate change. Input for that report is being provided by simultaneous assessments for regions within the United States and for national cross-cutting issues such as water resources and human health. These assessments are unique because of their reliance on multi-disciplinary integrated approaches and substantial stakeholder participation. These challenges are compounded by the uncertainties in projecting both climate change and how our society will evolve – with or without climate change.

Aided by financial support from the US Environmental Protection Agency (EPA), Penn State here provides a draft preliminary report on the progress made toward these challenges for the Mid-Atlantic region (MAR). The full Mid-Atlantic Regional Assessment (MARA) team (i.e., the core faculty, research associates and assistants, and external collaborators, as listed in Appendix A) has accomplished an immense amount of work through their initial analysis of the region's current stresses, how those stresses might be affected by climate change, what actions could be taken soon to capitalize on opportunities or reduce vulnerabilities from climate change, and what information is most needed to improve the region's decisions related to climate change. Yet much work remains to be done before the MARA team will be satisfied to produce the **Report on the First Mid-Atlantic Regional Assessment of Impacts from Climate Change**. This draft is being circulated now to get feedback on the work done so far and to provide preliminary input for the national synthesis.

This draft is truly the product of a team effort – again, see Appendix A. Meetings among the researchers and with stakeholders often have seemed to sparkle when people from different disciplines and perspectives suddenly realize how diverse components fit together into a whole that is greater than the sum of its parts. My thanks to each team member for his or her contributions to this draft. On behalf of the core faculty, thanks to the research associates and assistants, and to the external collaborators for expanding our expertise with their input. On behalf of the full MARA team, thanks to the Advisory Committee members for their insights and thoughtful responses to our requests for information. On behalf of all of these groups, I extend sincere appreciation to Ron Smart for compiling the diverse components into a readable draft preliminary report.

All of us look forward to your feedback, which can be directed to any team member or to me (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
April 6, 1999

Part 1: Introduction
(Fisher)

1.1 National needs

The impacts of climate 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 US Global Change Research Program (USGCRP) has been collaborating with federal agencies (represented in the National Assessment Working Group, NAWG) to sponsor 18 regional assessments. These organizations also are sponsoring 6 nation-wide assessments of the following "sectors": coastlines, fresh water, agriculture, forests, health, and Native Peoples. 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 change. These assessments will allow the interdisciplinary National Assessment Synthesis Team (NAST) (whose members represent academia, government, and business) to convey important differences across regions and sectors in its synthesis report. The NAST report is due to Congress by January 2000. Appendix D has additional information about the national assessment process.

1.2 Regional assessment approach

An interdisciplinary Pennsylvania State University (Penn State) team is leading the first Mid-Atlantic Regional Assessment (MARA) of Climate Change Impacts. Appendix A lists MARA's many partners and participants. As the report cover shows, 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. Four questions guide MARA:

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

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

3. What actions would 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?

Penn State's approach is based on a framework developed by its Center for Integrated Regional Assessment (CIRA) (Knight et al., 1999), and models such as the one they developed for the Susquehanna River Basin assessment. NAST and NAWG have recommended specific global climate models (GCMs) and socioeconomic projections, to enable aggregation across the assessments. In addition, Penn State is using its own empirical downscaling and nested GCM/mesoscale models, which provide finer resolution as appropriate for regional assessment. The CIRA framework accommodates an iterative approach, with increasingly complex quantitative analysis for important components. Appendix B includes more information on the assessment approaches used for MARA.

1.3 Regional assessment process

Penn State's early steps included a September 9-11, 1997 Mid-Atlantic Workshop focusing on the watersheds for the Chesapeake and Delaware Bays. The 92 participants, representing federal, state and local government, industry, academia, and public interest groups, reported learning more 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. For more about this workshop, see http://www.essc.psu.edu/ccimar/ or Fisher et al. 1999.

A June 8-9, 1998 researchers' meeting explored questions raised during the September 1997 workshop 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. MARA's working groups for these topics include about 20 collaborators from other research organizations.

To maximize the assessment's usefulness, the MARA team has been relying on frequent input from the MARA Advisory Committee. This diverse group represents potentially interested or affected parties, i.e., stakeholders. Its 85 members, listed in Appendix A, include 9 researchers, 20 public interest group representatives, 24 from industry and 32 from local, state, and federal government. At meetings, by mail, phone, fax, and e-mail, they are providing feedback to:

1) indicate what information stakeholders need to make more informed decisions related to regional impacts of climate change,

2) ensure the assessment is responsive to climate-related concerns most important to the people who live and work in the region,

3) identify relevant data not otherwise available to the assessment team, and

4) help prioritize options for building resilience and flexibility within the region, based on their knowledge of regional and local social, cultural, and political institutions.

1.4 Reporting on MARA

Reporting on MARA can provide an overview of baseline conditions and how human and natural systems might be affected by climate change, using an integrated assessment framework and in-depth case studies to illustrate important impacts. The report brings together information about diverse beneficial and detrimental impacts into a picture of the effects on the region as a whole.

Because MARA is an interactive, iterative process, this Draft Preliminary Report is being circulated in April 1999 even though much assessment work is not yet complete. One reason for the timing of this draft is to help NAST with its strict schedule. The other reason is to get early stakeholder feedback on preliminary findings. At a May 2-3, 1999 meeting, the Advisory Committee will review the draft assessment results and recommend strategies to display and disseminate the findings. Based on additional assessment and Advisory Committee feedback, this draft and its supporting documents will be revised and circulated for additional review (Summer, 1999). A revised Final Preliminary Report is planned for distribution by the end of 1999. Concise versions of the report's main sections will be submitted for a special issue of the journal, Climate Research.

Assessment work will continue during the coming year. (Periodic updates will be posted at http://lumen.deasy.psu.edu/mara/.) Additional assessment results will be combined with the results here into a Report on the First Mid-Atlantic Regional Assessment of Impacts from Climate Change. Throughout the assessment, Team members will present results at professional meetings for peer review. The final products will serve as a baseline for future assessments, expected to be conducted on a 4-5 year cycle.

During the coming year strategies for communication and outreach will be emphasized, especially strategies that establish new and enhance existing linkages for decision making within and among communities and organizations across the region. MARA and its interactive, substantive stakeholder participation process can be a key to helping communities move toward sustainability. Appendix C describes this important component of MARA.

1.5 Guide to this report

Part 2 describes the Mid-Atlantic region's physical and economic features, and the region's historical climate. This serves as a baseline for "what-if" scenarios of the region's future, in terms of both socio-demographics and climate. Note that time and budget constraints precluded printing in color for this draft. Color versions of several maps and figures are available on the MARA web site; throughout the draft, the specific address is given with the version printed here.

Part 3 summarizes the consequences, challenges, and opportunities facing the region. To make it manageable, Part 3 is segmented into discussions for agriculture, forestry, water, coasts, ecosystems, and human health. Then the economic impacts are summarized across these topics.

Part 4 summarizes the key findings from Part 3, and available strategies for adapting to both opportunities and challenges posed by climate change. Part 4 also discusses how to make sure the assessment results get used now and updated for future use. The continuing process requires maintaining and enhancing mechanisms for public involvement as well as setting priorities for research and information needs.

The Appendices contain additional information about the regional and national assessment process and its participants. They also explain more about the assessment data, methods and analysis, and how uncertainty is factored into the results. Appendix E includes a glossary of terms and identifies acronyms, so that the reader does not have to search for a definition. Perhaps most important, Appendix C summarizes the broader stakeholder engagement process, including initial plans for the coming year.

Part 2. The Mid-Atlantic Region: Past, Present and Future

2.1 Past and Present (Polsky)

2.1.1 Introduction

An assessment of likely regional impacts from climate change begins with the baseline setting, including the region's climate and natural and human environments. For the Mid-Atlantic Region (hereafter MAR; Figure 2.1.1), historical climate is outlined by Yarnal in section 2.3. The region's natural and human environments and their evolutions over the past three decades are summarized here, providing context for the sector-specific analyses that follow.

The MAR as defined for this assessment includes all of five states (Delaware, Maryland, Pennsylvania, Virginia, West Virginia) parts of three states (south-central New York, western and southern New Jersey, northeastern North Carolina), and the District of Columbia. The region contains 358 counties intersecting four principal physiographic regions (Figure 2.1.1 and Appendix E), or areas of similar landforms (Tarbuck and Lutgens, 1996; Miller, 1995). Table 2.1.1 shows the size of these regions relative to the greater MAR. In all, the MAR covers about 5 percent of the land area in the 48 contiguous United States (US Bureau of Census, 1997).

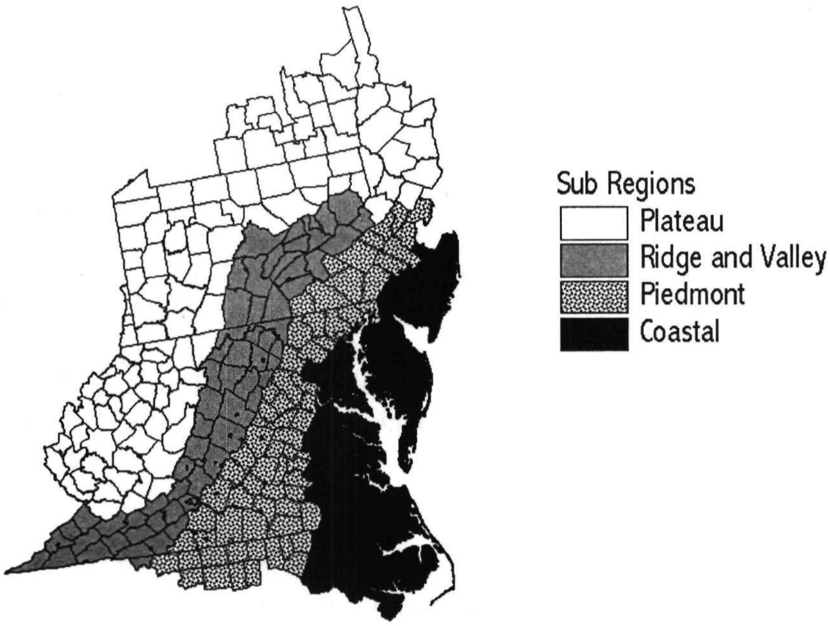


Figure 2.1.1. Mid-Atlantic Region Counties and Physiographic Regions

Table 2.1.1. The Mid-Atlantic Region at a Glance

	Counties	**Surface Area (square miles)**
Coastal Plain	98	31,005
Piedmont	76	32,851
Ridge & Valley	75	29,857
Appalachian Plateau	109	69,237
Mid-Atlantic Region	**358**	**162,950**

(NPA, 1998; US BOC, 1998a)

2.1.2 The Natural Environment

The Physiographic Regions

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

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

Land Cover

The MAR is largely covered by forest and agriculture (US EPA, 1997). As shown in Table 2.1.2, these two categories account for about 90 percent of land cover in the MAR (65 percent forest, 25 percent agricultural). The highest concentrations of forest area are in and around West Virginia and north-central Pennsylvania; agriculture is the predominant land use in the lowlands to the east.

Table 2.1.2. Land Use in the Mid-Atlantic Region, 1992

Land Use Category	Percentage of Total Land Area
Forest	64.5
Agriculture	25.0
Wetlands	4.1
Commercial, Industrial, and Residential	3.6
Open Water	1.6
All Other Land Uses	1.2

All MAR watersheds have at least half of their total stream length in forest cover, providing some buffering against agricultural runoff and other pollution to water sources (US EPA, 1997). However, all MAR watersheds also have some agriculture operations and many have roads located near the streams, indicating a potential for considerable, if diffuse, risk of water pollution (US EPA, 1997). For instance, two-thirds of the Chesapeake Bay's nutrient loading comes from upstream sources, and the same proportion of its sediment loading comes from non-point sources. Pollution in this water body is long-lived: the Chesapeake Bay flushing rate, at about 350 days, is one of the slowest rates for a water body in the United States (NOAA, 1998b). The Chesapeake Bay and Albermarle/Pamlico Sound are the nation's two largest estuaries – or zones of mixing between fresh and ocean waters – and are thus of particular ecological and economic importance both to the MAR and the US (NOAA, 1998b). The chapter on ecosystem impacts contains more information about the plants and animals in the MAR's natural environment.

2.1.3 The Human Environment

The People

The natural environment must be viewed alongside the MAR's human population to define the relative sensitivities of the region to climate change. From a demographic perspective, the Mid-Atlantic Region has a growing and aging population. In economic terms, the region has grown wealthier over the past few decades, both on regional aggregate and per capita bases. The MAR economy is diversified and well connected to the rest of the country and the international marketplace. Of all the sectors and geographic locations, the Coastal Region may in the medium- and long-run prove to be the area most sensitive to the impacts of climate change and most vulnerable to these changes. In contrast, for a relatively small economic sector such as agriculture, whatever threat climate change poses to agricultural employment and production, these impacts should not profoundly affect the region as a whole.

Tables 2.1.3 and 2.1.4 and the subsequent sections in this document expand upon the general trends noted above. Approximately 35.2 million people live in the MAR (1995 estimate; Table 2.1.3), representing close to 15 percent of the entire US population (NPA, 1998; US Bureau of the Census, 1998c). Nearly ninety percent of the MAR population is under the age of 65. The western half of the region houses about one-third of the MAR working-age population, and one-half of the farm employment. At least 60 percent of all MAR population, income and jobs are concentrated in the coastal plain and piedmont, where the urban agglomerations are found. These concentrations translate into a markedly higher per capita income for these two sub-regions compared to the Ridge & Valley and Appalachian Plateau.

While large cities do not cover much of the MAR surface area, collectively they constitute one of the more important population concentrations in the country. Of the MAR urban areas, Philadelphia, Pittsburgh, Baltimore, Washington, D.C., Richmond and Norfolk are among the largest cities in the US (US Bureau of the Census, 1998a). These cities have accounted for about one-half of the total MAR population since 1980 (data for earlier years unavailable) (NPA, 1998).

Table 2.1.3. Geographic Distribution of Key Socio-Economic Variables for the Mid-Atlantic Region: 1995 Percent and Value

	Coastal Plain		Piedmont		Ridge & Valley		Appalachian Plateau		*Totals*	
Population (million people)	36%	12.7	29%	10.1	10%	3.5	25%	8.9	*100%*	*35.2*
Age 0-19	37%	3.5	28%	2.7	9%	0.9	25%	2.4	*100%*	*9.5*
Age 20-64	37%	7.6	29%	6.1	10%	2.0	25%	5.1	*100%*	*20.8*
Age 65+	33%	1.6	27%	1.3	10%	0.5	29%	1.4	*100%*	*4.8*
Income (billion 1992$)	38%	$301	22%	$255	8%	$64	22%	$171	*100%*	*$791*
Income per Capita (1992$)	$23,747		$25,272		$18,277		$19,160		*$22,479*	
Total Employment (million jobs)	38%	7.5	30%	5.9	10%	1.9	23%	4.5	*100%*	*19.7*
Total Farm Employment (thousand jobs)	19%	48	30%	77	21%	53	30%	76	*100%*	*254*

(NPA, 1998)

The MAR population increased by approximately 20 percent during the past three decades, about 0.7 percent per year on average (Table 2.1.4). This trend resembles that for the nation as a whole, which grew by 33 percent at a rate of 1 percent per year (US Bureau of the Census, 1998c). The MAR has experienced a steady increase (1.2 percent per year) of working-age residents since the late-1960s, and a steady decrease (about 0.6 percent per year) of people under the age of twenty; in recent years this latter trend has reversed. In contrast, the elderly population in the MAR grew by about 70 percent during the same period.

Total regional personal income more than doubled over this period, and per capita income grew by 82 percent (Table 2.1.4). Income in the services sector recorded the largest growth over the period, over 300 percent. The sectors of services, government and manufacturing presently account for nearly one-half of all regional income (NPA, 1998). Total employment has increased by more than half since 1967, fueled largely by non-farm industries such as services, which more than doubled over the period. By contrast, farm-related employment declined by almost one-half. As such, agriculture in the MAR is becoming progressively less important over time from an economic perspective, reflecting the broader national trend (Shane, Roe and Gopinath, 1998).

Table 2.1.4. Changes in Key Socio-Economic Variables for the Mid-Atlantic Region: 1967-1995

	Total Change	Average Annual Change
Total Population	22.5%	0.7%
Age 0-19	-13.4%	-0.5%
Age 20-64	39.1%	1.1%
Age 65+	79.1%	2.0%
Income	129.9%	2.9%
Income per Capita	92.3%	2.3%
Total Employment	65.0%	1.8%
Total Farm Employment	-43.5%	-1.9%

(NPA, 1998)

The Coming Decades

There are many ways to project future values of these economic and demographic variables using the historical trends noted above. The resulting projections can differ substantially depending on the projection methodology employed. One set of projections for three key variables (population, income, employment) to the year 2025 is presented in Figure 2.1.2. This figure reflects a 'baseline' scenario (i.e., where current trends are assumed to persist), and 'low' and 'high' scenarios (i.e., where current trends diminish and increase, respectively, in the coming decades). These projections are driven primarily by assumptions regarding the net effect of birth, death, immigration and internal (US) migration rates, per capita income, and overall economic activity. For more details on the underlying assumptions, see Section 2.2.2 and NPA (1998).

The MAR Economy in Detail (Rose)

MAR's employment of nearly 20 million in 1995 represented 13% of the US total, and its income of $915 billion in that year represented 15% of the US total. Another measure of economic activity is gross output (sales revenue), which includes both intermediate goods (goods used to produce other goods and services) and final (consumer) goods, amounting to nearly $1.7 trillion. Of this, $547 billion, or 32.7% of gross output, was exported (see Table 4). Imports of $597 billion comprised 35.7% of inputs to the regional economy as well. Thus the MAR is not self sufficient, but it has a reasonable trade balance. Still, the sizeable export and import flows do have broader ramifications. They mean that major impacts of climate change in MAR will affect other parts of the US economy; even if the MAR region has only minimal direct effects, its economy could be affected significantly by economic changes elsewhere in the US and the world. These conditions would affect the cost of imports to the MAR, as well as the demand and price for its exports.

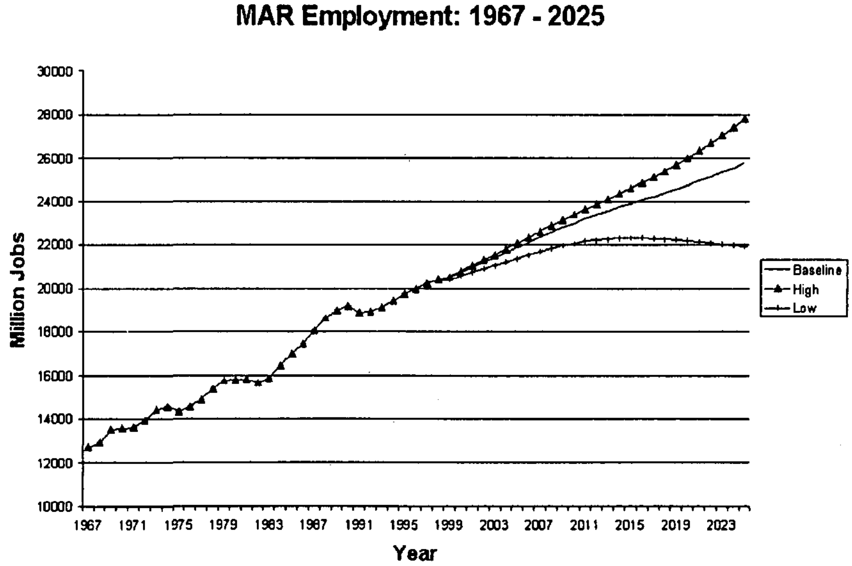


Figure 2.1.2a. Employment projection.

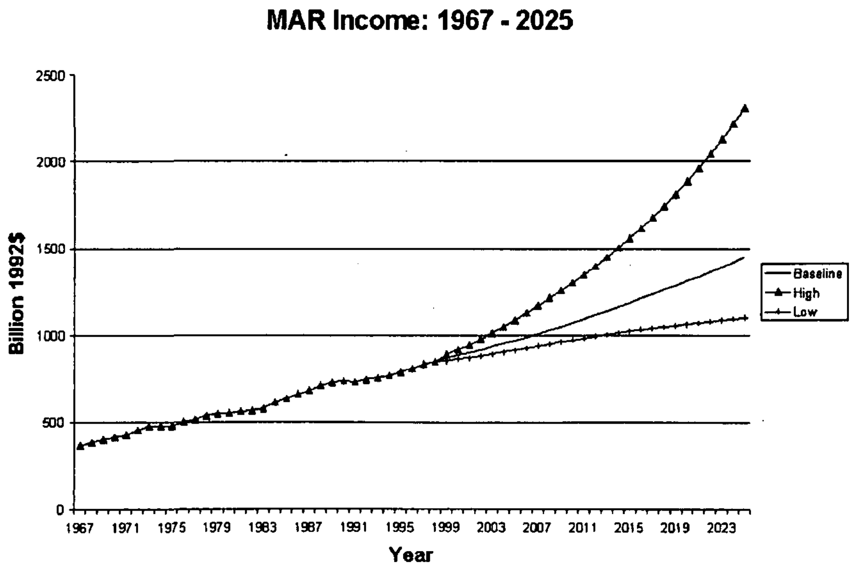


Figure 2.1.2b. Income projection.

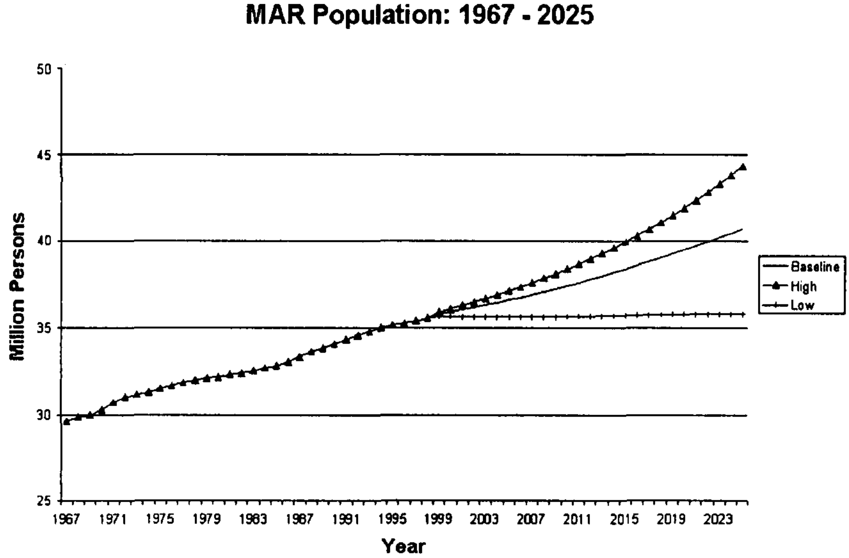


Figure 2.1.2c. Population projection.

Table 2.1.5. Structure of the Mid-Atlantic Region Economy, 1995 (billions of dollars)

Agriculture	13
Forestry	5
Mining	14
Construction	105
Manufacturing	444
Food/Textiles	97
Wood/Paper	64
Chemical/Materials	114
Primary/Fabricated Metals	55
Equipment	105
Other Manufacturing	9
Transport & Communication	86
Utilities	46
Trade	201
Services	440
Health & Education	142
Government Enterprises	174
Total	**1671**

(Data from IMPLAN, 1998)

Table 2.1.6. Sectoral Production in the Mid-Atlantic Region, 1995 (billions of dollars)

	Coastal Plain	Piedmont	Ridge & Valley	Plateau	Total
Total Employment	6.8	5.8	2.8	4.5	19.8
Income	359.1	274.6	97.1	184.4	915.2
Total Gross Output	610.5	511.1	189.5	360.0	1671.1
Structure of Output					
Agriculture	4.3	3.8	2.4	2.9	13.4
Forestry	1.7	1.5	0.6	0.8	4.7
Mining	1.2	0.9	2.0	10.2	14.3
Construction	32.5	34.5	15.0	22.8	104.8
Manufacturing	134.3	157.7	48.5	104.0	444.4
Food/Textiles	31.5	43.6	12.3	9.5	96.9
Wood/Paper	20.9	21.0	9.7	12.5	64.1
Chemical/Materials	44.7	34.7	7.9	27.1	114.4
Primary/Fabricated Metals	8.0	17.7	5.0	24.3	55.1
Equipment	26.9	39.1	12.8	26.3	105.2
Other Manufacturing	2.2	1.6	0.8	4.2	8.8
Transport & Communication	31.8	23.8	12.3	18.4	86.3
Utilities	13.4	12.3	4.7	15.7	46.1
Trade	71.0	61.1	23.1	45.7	200.9
Services	171.5	139.7	50.9	78.1	440.3
Health & Education	49.8	39.1	18.0	35.4	142.3
Government Enterprises	98.8	37.0	12.1	25.8	173.6
Trade Balance					
Commodity Exports	172.3	174.5	79.8	120.6	547.3
Commodity Imports	210.2	184.9	64.6	137.0	596.8

(IMPLAN, 1998)

Table 2.1.5 presents a structural disaggregation of the MAR economy. On a direct output basis, the primary sectors of Agriculture, Forestry, and Mining together comprise only $32 billion, or about 2% of the Region's economy. On the other hand, Manufacturing output of $444 billion and Service sector output of $440 billion, comprise 26.6% and 26.3%, respectively, of the economy. On the surface it would appear that the MAR economy is not very vulnerable to climate change, but this can be misleading. All sectors of an economy are linked directly and indirectly, and a shock to any one of them will ripple through the economy so that the total effect of climate change would be some multiple of the original stimulus. These "multiplier" effects would typically be on the order of 2.0 to 3.0 for a region of the size and structure of the MAR. An example of this interdependence can be illustrated by referring again to Table 2.1.5. Damage to trees in the MAR affects not only the Forestry sector of $5 billion, but also the Wood/Paper industry of $64 billion. Furthermore, any decrease in output in the latter sector would touch off a decrease in orders for goods and services to direct and indirect suppliers. Also, decreased profits and worker layoffs would result in reduced income, which sets off its own multiplier effects.

The overall impact from a change to one (or several) of these small sectors is likely to have a modest impact on the overall regional economy. Of course, there still could be substantial direct impacts on these small sectors themselves, and substantial indirect impacts in sub-regions where these account for a large share of economic activity. So distribution impacts may be more pronounced than the impact on the MAR economy as a whole.

The MAR Physiographic Regional Economies in Detail

The structure of the economies of the four physiographic sub-regions is summarized in Table 2.1.6. The Ridge and Valley sub-region stands out in terms of its relatively small size (see rows 1 and 2), but is the only sub-region with a positive trade balance (see the last 2 rows). A structural comparison of sectors can best be depicted by Figure 2.1.3, in which each bar represents the proportion of a sub-region's gross output devoted to an individual sector. Interestingly, there is little variation for most sectors across the sub-regions. Exceptions on the high side include Food/Textiles in the Piedmont and Metal Manufacturing in the Ridge and Valley and Plateau sub-regions. These same sub-regions have relatively less Food/Textiles. Services stand out as dominant. These sub-regions are highly interconnected, even more so than the MAR is with the rest of the US.

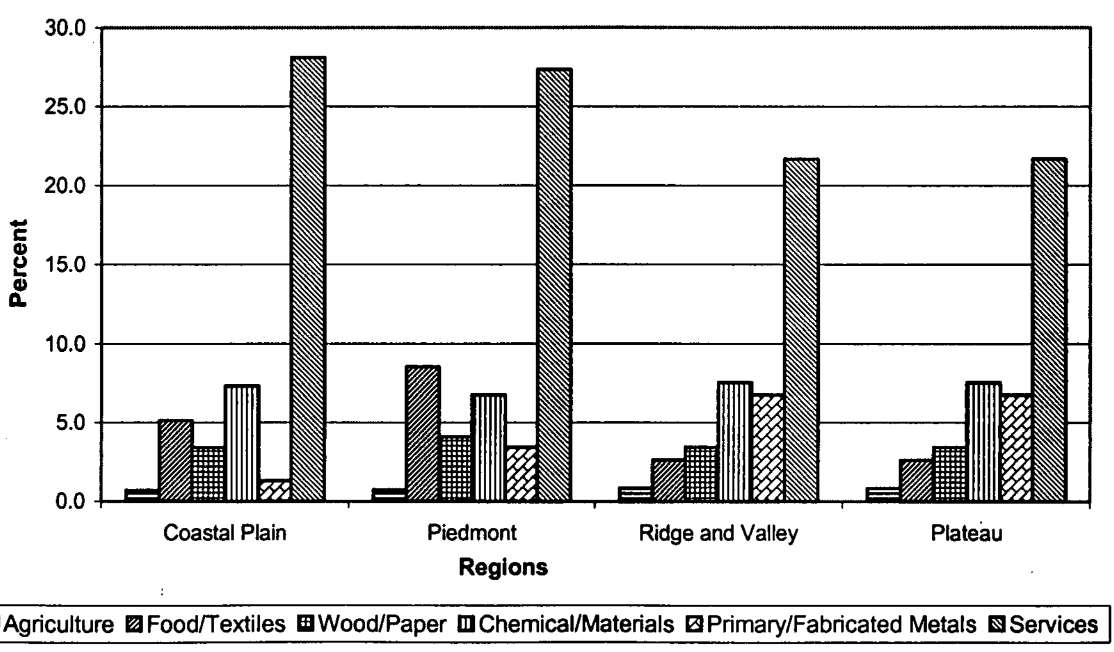


Figure 2.1.3. The Economic Structure of the Mid-Atlantic Region

2.2 Future Baseline Socioeconomic Scenarios

2.2.1 General Considerations in Constructing Scenarios (Abler and Shortle)

By definition, socioeconomic impact analysis involves comparing "with" and "without" states of the socioeconomic systems under study. At least three kinds of scenarios are required for socioeconomic impact assessment of climate change. These are 1) climate scenarios that describe future climates, 2) baseline scenarios that describe what the economy and society would be like without climate change, and 3) climate response scenarios that describe how society might respond to climate change.

Climate Change Scenarios

In climate impact research, the typical approach is to generate climate scenarios based on assumptions about growth in emissions of greenhouse gases and other driving forces behind climate change. The climate scenarios then are the basis for analyzing socioeconomic impacts. This approach is flawed if the economy is important to greenhouse gas emissions and other drivers behind climate change. Climate and economic scenarios are necessarily inseparable and dynamic at the global or large-scale regional level. However, economic activity in a region such as the MAR is likely to have minimal effects on the global climate, making it more plausible to use separable climate and socioeconomic scenarios.

Baseline Socioeconomic Scenarios

Because climate change is a long-term phenomenon, potential societal conditions far into the future must be considered to generate baseline socioeconomic scenarios. Global, national, and regional economies and societies have changed radically over the last century, and there is no reason to expect the rapid pace of socioeconomic change to slow down. Economic growth from the beginning of civilization, and especially since the industrial revolution, has involved substitution of human capital and physical capital for natural capital, greatly reducing the degree to which human conditions are affected by and dependent on the natural environment (Solow, 1992; Ruttan, 1992). Most people live and work in structures that protect them from the elements, often with sophisticated climate control systems. Unlike preindustrial times, even in many developing countries only a small proportion of the population is directly engaged in producing food and fuel. Substitution of human and physical capital for natural capital (through, e.g., mechanization, specialization of production, irrigation systems, pest management systems, transportation systems to move food and inputs) has tremendously increased the productivity of agricultural systems in developed countries and many developing countries (Hayami and Ruttan, 1985). The prevention and treatment of disease has been revolutionized since the 1850s (Patz et al.). Mining, forestry, agriculture, and manufacturing were the largest components of the economy at the turn of the century, but today they are much diminished in importance. Similarly, the economy and society of the MAR will undoubtedly be substantially different in the future than they are today in terms of structure, producer and consumer technologies, the range of available goods and services, and public and private institutions. This in turn means that the MAR may be significantly different in terms of its sensitivity to climate change and its potential for response and adaptation.

Climate Change Response Scenarios

Climate change, as well as expectations of climate change, will stimulate socioeconomic responses to reduce risks and exploit opportunities. These responses differ from, but have the potential to shape, final impacts. Studies of the economic impacts of climate change differ substantially in the assumptions they make about the ability of economic actors to respond and adapt to a changing climate (Tol and Fankhauser, 1998). Tol et al. (1998) distinguish among four approaches to characterizing adaptation in the economic literature: no adaptation; arbitrarily imposed types or levels of adaptation (arbitrary adaptation); adaptation based on observed responses by economic actors to different climatic conditions in other regions or at previous points in time (observed adaptation); and adaptation based on simulation models of the behavior of economic actors (modeled adaptation). Simulation models typically presume that economic actors make choices so as to maximize their own objective functions, subject to limits on the physical and financial resources at their disposal and to constraints imposed by the economic, political, and natural environment.

The extreme characterization of no adaptation is sometimes referred to as "business as usual." No adaptation is not a plausible assumption for market goods and services. Insofar as changes in climate lead to changes in prices of market goods and services, or prices of inputs into production, producers and consumers will have direct and obvious incentives to respond. Simulations in Yohe and Schlesinger (1998) suggest that adaptation can significantly reduce the economic costs of sea level rise along the US coastline. Studies of agricultural impacts also indicate that adaptation by farmers can significantly reduce economic costs or increase economic gains (see Tol et al., 1998). On the other hand, the situation could be much different for nonmarket goods and services, because there are no direct price signals to guide producers and consumers.

Of the three remaining approaches to characterizing adaptation, modeled adaptation may be most appropriate for assessing responses to climate change. Modeled adaptation can be impeded by computational considerations, which often require the aggregation of goods, services, production inputs, and economic actors into a relatively small number of categories, and which often necessitate strong simplifying assumptions about the behavior of economic actors. Nonetheless, unlike arbitrary adaptation, which is typically confined to a few alternative adaptation possibilities, modeled adaptation can permit a wide range of types and levels of responses. These can include responses that a modeler attempting to construct a list of "plausible" alternatives for an arbitrary adaptation exercise would have never foreseen. Unlike observed adaptation, modeled adaptation in principle can examine responses under scenarios with future climates, technologies, and economic and political institutions that have no contemporary or historic analogues.

Within the category of modeled adaptation, two modeling frameworks may be distinguished: static and dynamic. By "static," we mean that production technologies for market and nonmarket goods used within the region, the region's stock of human capital, its stock of physical capital, its stock of natural capital, and its economic and political institutions are all assumed to be exogenous. Stocks of physical, human, and natural capital may change as a direct consequence of climate change (e.g., losses in physical capital due to hurricanes), but they do not change in response to decisions made by economic actors within or outside of the region. Technologies, capital stocks, and/or institutions are endogenous within a dynamic framework, and as such can change in response to decisions by economic actors.

Socioeconomic Scenario Design

The goal in constructing socioeconomic scenarios should not be to assemble an exhaustive list of all possible futures, or even "probable" futures. Even if future scenarios are defined with respect to a small number of variables, and only a few values for these variables are considered, the number of possible combinations quickly becomes unmanageable. For example, suppose that socioeconomic futures are defined with respect to k variables and that a alternative values are considered for each variable. For instance, when $a = 3$, one could think in terms of a "high," a "medium," and a "low" value for each variable. The number of possible combinations of values in this case is a^k, which is large even for moderate values of a and k. For example, if $a = 3$ and $k = 5$, the number of possible combinations is $3^5 = 243$. If $k = 10$, the number of possible combinations is $3^{10} = 59{,}049$.

At the same time, the goal in constructing socioeconomic scenarios should not be limited to making point forecasts of future socioeconomic conditions. Economic and technological forecasting accuracy diminishes rapidly with forecast length. Point forecasts of socioeconomic conditions for the year 2030, to say nothing of the year 2100, would be far more likely to be wrong and misleading than to be useful. In this respect, economic modeling is well behind climate modeling – though the challenges involved in long-term economic modeling are arguably much greater than those involved in long-term climate modeling.

This inability to forecast is more acute at a regional level than at a national level. Many socioeconomic processes and interrelationships are less stable over time and thus less predictable at a regional level. This is because large shifts in the production of many goods and services can occur from one region to another within a country based on regional differentials in labor costs, government fiscal and regulatory policies, or other factors. These shifts can lead to significant changes in income, employment, and socioeconomic structure at the regional level even while these variables are relatively stable for the country as a whole. For example, population cannot be predicted accurately at a regional level, because at this level the key determinants of population growth are not birth and death rates (which can be predicted with some confidence) but rather migration inflows and outflows (which are essentially impossible to predict on a long-term basis).

It is more fruitful to construct socioeconomic scenarios with the objectives of identifying and bounding major potential threats and opportunities, and identifying critical research and adaptation policy issues. Increased vulnerability clearly emerges in scenarios that combine greater future baseline socioeconomic or ecosystem sensitivity with increased climate stresses on socioeconomic or ecological systems and little ecological and/or socioeconomic adaptation (see Table 2.2.1). Upper bounds would be in this category. Similarly, reduced risks clearly emerge in scenarios that combine reduced baseline socioeconomic or ecosystem vulnerability with reduced climate stresses. Lower bounds would fall in this category. Combinations of climate and socioeconomic scenarios that combine offsetting effects may have greater or smaller risks. The intervals between the upper and lower bounds could be viewed as confidence intervals. This is much different from placing upper and lower bounds on each of the variables hypothesized to affect future baseline socioeconomic conditions. Out of the large number of possible combinations of alternative values for the baseline variables, a much smaller number of combinations of these values may suffice to establish upper and lower bounds on climate change impacts.

Table 2.2.1. Future Baseline Socioeconomic/Ecological Sensitivity

Future Climate Stress	Future Baseline Socioeconomic/Ecological Sensitivity			
	Greater Sensitivity		Smaller Sensitivity	
	Societal/Ecological Adaptation Responses		Societal/Ecological Adaptation Responses	
	Low	High	Low	High
Greater	Increased Vulnerability	?	?	? Moderate Vulnerability
Smaller	?	Reduced Vulnerability ?	Reduced Vulnerability	Reduced Vulnerability

In selecting scenarios to identify and bound risks, attention should be given to errors analogous to the Type I and Type II errors in statistical hypothesis testing. A Type I error would be to accept a false positive on either a threat or opportunity from climate change. A Type II error would be to accept a false negative about either a threat or opportunity from climate change. In the former case, the error is to falsely conclude that climate change has a significant impact (positive or negative), while in the latter, the error is to falsely conclude that climate change is benign. There is generally a tradeoff between these errors. In classical statistical hypothesis testing with a random sample of observations of the system, the chance of a Type I error decreases while that of a Type II error increases with the stringency of the test for accepting the hypothesis of a significant impact. In climate impact analysis, researchers do not typically have random samples of observations for use in testing. The choice of scenarios and their analysis are key determinants of the errors.

In constructing and analyzing scenarios, it should be borne in mind that the ultimate goal is to inform present-day public and private decision-making. Rather than an abstract exercise in futurism, the assessment should have concrete implications for choices and decisions facing us today. It should indicate when climate change impacts are likely to be large enough to justify action today and what types of actions may be desirable in order to exploit opportunities and reduce threats.

Key Socioeconomic Variables for the Mid-Atlantic Region

Key socioeconomic variables for assessing impacts include major indicators of the status of the economy and human welfare, and indicators of socioeconomic drivers that affect climate, ecosystems, socioeconomic systems. Figure 2.2.1 illustrates linkages between the global climate, the MAR economy, and the economy of the rest of the world (ROW) (which encompasses other regions of the US and other countries). (This discussion is based on Abler et al, 1999.) Climate potentially can have strong impacts on both the MAR economy and the ROW economy. Activities in the ROW economy also can have strong feedback effects on climate. But activities in the regional economy are less likely to have significant feedback effects on climate, at least when regions are defined at a scale that is small in economic terms. However, it might still be possible for a region to be small in economic terms but important as a source or sink of greenhouse gases or other climate-altering activities. Thus, even though the ROW economy can exert a strong influence on the regional economy, the MAR economy is unlikely to affect the ROW economy because MAR is small in economic terms. Of course, the sum total of regions comprises the global economy, and regional analysis is valuable as a bottom-up determination of aggregates.

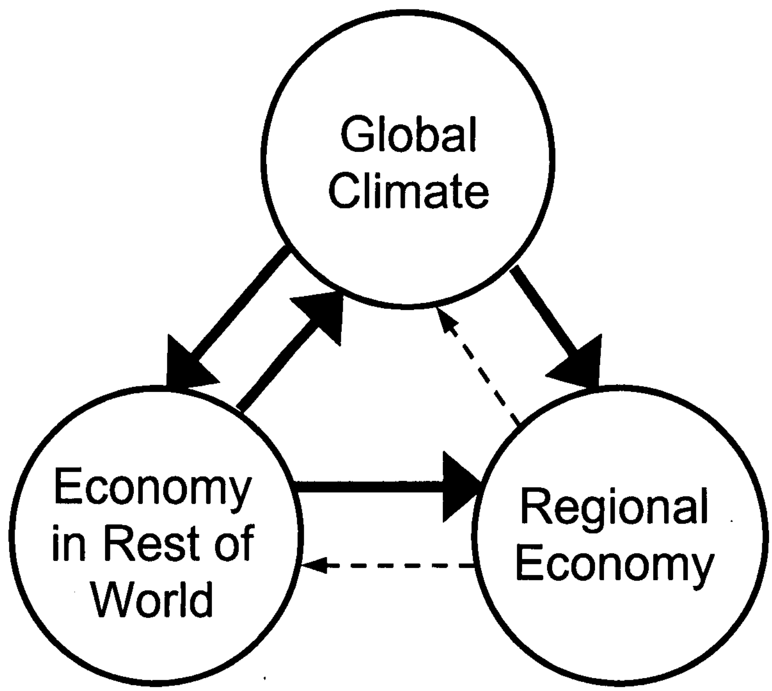


Figure 2.2.1. Climate-Regional Economic Interactions

Broadly speaking, climate change can have four types of economic impacts at a regional level. First, it can affect production of market goods and services within the region.

Market goods and services are those sold by an economic actor (a company, institution, household, or individual) to another economic actor, with payment being in cash, in kind (barter transactions), or both. Second, climate change can affect the supply of nonmarket goods and services within the region. Nonmarket goods are those that are not traded, and in which property rights are not well defined. Unlike a market good, the value of a nonmarket good (what people would be willing to pay for it if it were bought and sold) is unaccounted for by the market. Third, climate change can have indirect effects on economic sectors within the region that are not directly affected by climate change. Fourth, climate change can have indirect effects on the region through effects on other regions of the same country or other countries.

Table 2.2.2, from the 1995 IPCC report (IPCC, 1996b), provides an overview of several potential market and nonmarket impacts of climate change, as well as the state of the literature on estimating these impacts at the time the report was written. The table is helpful in providing some examples of market and nonmarket goods. For instance, agricultural products, forest products, water, and energy are all market goods, since they are all bought and sold, at least in most countries. On the other hand, ecosystems, species, human health, and human life are all nonmarket goods because there are no markets where these goods are bought and sold. Even though there are no markets to assign prices to them, these goods have value to society. Excluded from the nonmarket category in Table 2.2.2 are more traditional public goods such as education, national defense, police protection, and information services. Although these goods also are very important and potentially could be affected by climate change, we confine the discussion here to human health and environmental services.

The distinction between market and nonmarket goods is critical in analyzing the impacts of climate change. Those who have property rights in market goods stand to reap the rewards or suffer the consequences of direct and indirect effects that climate change may have on the value of their assets. This gives them incentives to anticipate climate change and respond to its impacts. In contrast, while nonmarket goods are essential to human welfare and of great economic importance (Costanza et al., 1997), markets do not provide meaningful incentives or mechanisms to reduce risks or exploit opportunities.

Referring to Figure 2.2.1, effects on market and nonmarket goods and services within the region are represented by the arrow running directly from global climate to the regional economy. Effects operating indirectly through other regions are represented by the two arrows running first from global climate to the rest-of-world economy and then from the rest-of-world economy to the regional economy.

This framework suggests the following types of socioeconomic variables:

1. Standard socioeconomic indicators, such as population, age distribution, per capita income, employment, and health status.
2. Key variables describing conditions in regional and international markets for goods and services produced in the MAR and exported to ROW, especially in those sectors that are highly climate dependent such as agriculture, forests, and water.

3. Key variables describing conditions in markets for goods and services purchased from ROW by consumers and producers in the MAR region.
4. Technologies available to producers and consumers in the MAR region.
5. Indicators of the use and status of nonmarket goods.
6. Characterizations of public policies and institutions

Note three caveats for the following discussion: 1) We emphasize the period between now and 2030, because projections become so much more speculative as the time horizon is extended. 2) We exclude consideration of major surprises in the rest of the world, such as multi-country uprisings or widespread epidemics. 3) At this stage, the interest is in general trends that will occur even without climate change. Part 3 will add climate change to the assessment.

Summary charts based on NPA point projections are described earlier for most variables in item 1). We present this data as one look at the future. The caveats we noted in our earlier discussion of point forecasts apply to these data. At the national level, NPA assumes rising labor force participation rates (particularly for older people), rising birth rates, and more immigration. NPA expects aging of the population to reduce the ratio of employment to population after 2015. Yet earnings per job and per capita income will continue to grow (although more slowly than recently) because of new capital investment and improvements in productivity.

NPA uses a "regional growth accounting model" and disaggregates the national forecast to counties by using relative growth rate differentials (e.g., for employment by industry) and multiplier analyses. The regional growth rate differentials for each industry are assumed to decay over time. Similarly, the differences in regional earnings-per-job multipliers are assumed to decay over time. Aside from near-term adjustments for closings and relocations of military bases, the NPA projections to not account for future changes in institutional structure, the types of commodities people might want to buy (including entirely new goods), or technologies for producing them. Nor does NPA account for changes in institutions that might affect the demand for or profitability of different goods.

Migration was estimated from the difference between the open population projected by NPA's REPS economic model and their closed population projections based on births and deaths in each area. NPA adjusted domestic migration rates to reflect college, correctional, and active duty military populations.

Table 2.2.2. A Taxonomy of Market and Nonmarket Impacts of Climate Change

State of Literature	**Market Impacts**				**Nonmarket Impacts**		
	Primary Economic Sectors	*Other Economic Sectors*	*Property Loss*	*Damage from Extreme Events*	*Ecosystem Damage*	*Human Impacts*	*Damage from Extreme Events*
Fully Estimated, Based on Willingness to Pay	Agriculture		Dryland loss Coastal Protection		Wetland loss		
Fully Estimated, Using Approximations	Forestry	Water Supply		Hurricane Damage	Forest Loss		Hurricane Damage
Partially Estimated	Fisheries	Energy Demand Leisure Activity	Urban Infrastructure	Damage from Droughts	Species Loss	Human Life Air Pollution Water Pollution Migration	
Not Yet Estimated		Insurance Construction Transport Energy Supply		Nontropical Storms River Floods Hot/Cold Spells Other Catastrophes	Other Ecosystem Loss	Morbidity Physical Comfort Political Stability Human Hardship	Nontropical Storms River Floods Hot/Cold Spells Other Catastrophes

(IPCC, 1996b, Chapter 6)

Because of uncertainties about any baseline projection, NPA also prepared high and low growth projections by using substantially higher or lower assumed values of these variables: birth rates, survival/death rates, international immigration, labor force participation rates of population groups age 55 and older, and the growth rates of national productivity (output per person employed). The values are intended to represent plausible bounds on the wide range of uncertain growth outcomes.

Thus the NPA projections presume a continuation of recent trends. Factors for which the MAR counties currently differ from national trends are assumed to be moderated so they become more like the national pattern. The NPA projections do not account for surprises, such as major changes in tastes and preferences, technology, or institutions.

2.2.3 A View of the Mid-Atlantic Region in 2030 (Fisher)

Because of the many uncertainties in forecasting, this view is intended not as a point estimate but as an informed yet impressionistic view of the future. It provides context for deciding whether the NPA projections (summarized above) provide appropriate bounds, and can serve as a rough baseline for constructing the upper and lower bound scenarios for each sectoral analysis in Part 3.

The Mid-Atlantic region is likely to continue having a diverse economic base, although with changes in relative importance among sectors. Population is likely to grow in the VA, DE, MD and NC portions of the MAR, but less so in the PA, NY, NJ, WV and DC portions. Much of this growth is expected to occur in the eastern portions, particularly in coastal counties. The age distribution in the MAR is likely to become older, partly reflecting the national trend and partly because more people decide to retire in a region with changing seasons, diverse geography, and cultural amenities in a range of community sizes. The aging is likely to increase demand for health services. Despite expected growth in managed health care, improvements in medical technology, and increased self-care and use of alternative therapies, medical care is likely to become more costly.

Agriculture is expected to continue the trend toward a smaller economic role in the MAR, because of factors such as trade liberalization and higher values for land in alternative uses. Pressure for development of farmland will continue, especially in those sub-regions that we expect to have continued population growth. Concerns about 1) preserving our agricultural heritage, 2) cultural groups that rely heavily on agriculture, and 3) the amenity aspects of agricultural landscapes may increase the amount of farmland in land conservation programs within MAR. Growing urban/suburban areas are likely to continue converting nearby agricultural and forest lands for residential and commercial development. Such conversion is likely to exacerbate concerns about fragmentation and the implications for wildlife habitat. At the same time, marginal agricultural lands in more rural areas are likely to revert to forest cover. The harvest of hardwoods is expected to increase, but probably will not exceed forest growth in the MAR.

If trends of the recent past hold, rising per capita incomes are expected to increase the demand for outdoor recreation as well as other forms. Rising per capita incomes also increase the demand for environmental quality. These non-market components range from landscape and other aesthetics to wildlife habitat to air and water quality. For example, the increase in impervious surfaces accompanying residential and commercial development can increase impacts from storm water runoff, such as localized flooding, erosion, and eutrophication of downstream areas because of nutrient enrichment. Rising per capita incomes may increase the demand for infrastructure to moderate these impacts and recharge groundwater. Although the MAR is water-rich overall, areas with growing populations can expect corresponding pressure on water supplies, infrastructure, and land use planning at a time when many government responsibilities are being shifted from the national level to state and local levels. Some areas could experience substantial competition for water supplies. For example, although the ski industry is small in the MAR, snow making accounts for the second largest withdrawals (behind power generation) from the Susquehanna River Basin.

The MAR will have more interconnectedness with the rest of the nation and the rest of the world as communication technology continues to improve and transportation costs continue to decline. The resulting increase in external competition makes it more important to identify and capitalize on those activities for which the region has a comparative advantage, as a way to strengthen its economic base. At the same time, the interconnectedness will reduce prices faced by MAR residents for externally produced inputs and outputs.

After writing baseline descriptions of current conditions for their sector, each working group developed an initial set of key socioeconomic variables and boundary scenarios. The intent was to identify broad trends likely to be affected by climate change, and account for uncertainties such as potential thresholds that might substantially affect one or more trends. The sets of scenarios were reviewed by the MARA team and the Advisory Committee, and revised for use in assessing the Mid-Atlantic region's potential impacts from climate change. The variables that are key for one sector are not always the ones that are key for another sector. Thus each sectoral assessment in Part 3 describes its key variables and boundary scenarios. Yet all of these are consistent with the general scenario described above. After the challenging task of projecting how these key variables might change in the future, Part 3 identifies (for each sector) those likely to be affected by changes in the MAR's climate so that the climate impacts can be assessed.

2.3 Mid-Atlantic Region's Climate (Yarnal)

2.3.1 Introduction

One way to estimate the regional impacts of future global climate change is to study how the region has responded to past climate variations. First, however, it is important to clarify some basic definitions and facts about climate, climate change, and climate variation.

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

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

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

Climate change arises from human activity, but climate variation results from natural forces operating at different time scales. The two most fundamental variations in climate are daily cycle and the seasonal cycle, which result from relationships between the sun and Earth on time scales of days and years, respectively. The third most important variation in the climate system is El Niño-Southern Oscillation (ENSO) events, which perturb the global oceanic and atmospheric circulations and can produce droughts and floods in certain regions. For example, during warm phases of ENSO (known as El Niño), the southern United States tends to be very wet and may suffer floods; during ENSO cold phases (known as La Niña), this region is prone to drought. ENSO extremes usually occur roughly every three to five years and last for about a year and a half. Scientists are developing the ability to predict these events and their regional patterns of flood and drought many months in advance. Besides ENSO, other large-scale perturbations of the ocean-atmosphere system influence regional climates. One example is the North Atlantic Oscillation, which affects the climate of the North Atlantic basin and which may be particularly important to the Mid-Atlantic Region. Many other seasonal to interannual causes of variation, such as volcanic eruptions, are difficult to predict.

Climate also varies on time scales ranging from decades to millions of years. Decade-long variations result from interactions among the different components of the Earth system: atmosphere, ocean, land, biosphere, and ice. Because each of these components is characterized by different response times, their interactions produce climate variations on many time scales. Decade-long variations can also result from variations in solar output tied to sunspot cycles. On century time scales, planetary warming and cooling can be caused by long-term oscillations in solar output. In the last two to three million years and on time scales of ten thousand years or more, variations in Earth's orbit around the

Sun are related to more than 20 glacial-interglacial cycles. Even longer-term changes in the configuration of the continents and associated mountain-building episodes result in climate variations over ten million years or more. Examples include the ice-age conditions of the last 35 million years and the generally warm Earth inhabited by the dinosaurs.

Climate varies over space as well as time. In any given year or decade, the climate in one region may be unusually warm or cool, or wet or dry, while temperature and precipitation in an adjacent region may be close to average.

In the United States, storms, floods, heat waves, droughts, and cold outbreaks are regional phenomena, although their impacts may be serious enough to spread throughout the nation and the world. For example, the 1988 drought so devastated the Midwest that it had a measurable influence on the national and world economies.

Although there is considerable uncertainty about how climate change will influence specific regions, scientists expect changes in the frequency and intensity of storms, floods, droughts, heat waves, and cold outbreaks. Some regions may suffer more frequent and intense droughts, while others may have fewer and weaker droughts. In any case, because regional variations in climate are normal, it may be difficult to distinguish anthropogenic climate change from natural climate variation.

Thus, an important first step in determining the potential impacts of climate change is to understand how climate variation affects regional climate today. The next subsection summarizes climate variations observed in the Mid-Atlantic region during the past century and then during the last 1000 years. The section concludes by summarizing what we know about climate variation in the Mid-Atlantic Region and what we need to learn.

2.3.2 Recent Climate Variation in the Mid-Atlantic Region

There is a wealth of observed climate data – that is, data recorded by weather instruments – for the Mid-Atlantic Region. The relatively short period of these data, however, only provides insight on recent climate variations of years and decades. Longer time-scale variations can be reconstructed by interpreting natural phenomena and human artifacts containing climate information, as described in the next subsection.

Data for precipitation and temperature extend back to 1895 and are shown in Figure 2.3.1 for a Mid-Atlantic region defined by the watershed boundaries of the Chesapeake and Delaware Bays. The figure shows that the precipitation and temperature of the Mid-Atlantic Region have varied substantially on annual and decadal time scales over the last century.

Relationship to atmospheric circulation variations

The global models used to project climate change rely heavily on atmospheric circulation inputs. Thus linking surface climate variations to variations in the region's atmospheric circulation is an important step in assessing changes in the region's climate (as discussed further in Section 2.4).

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

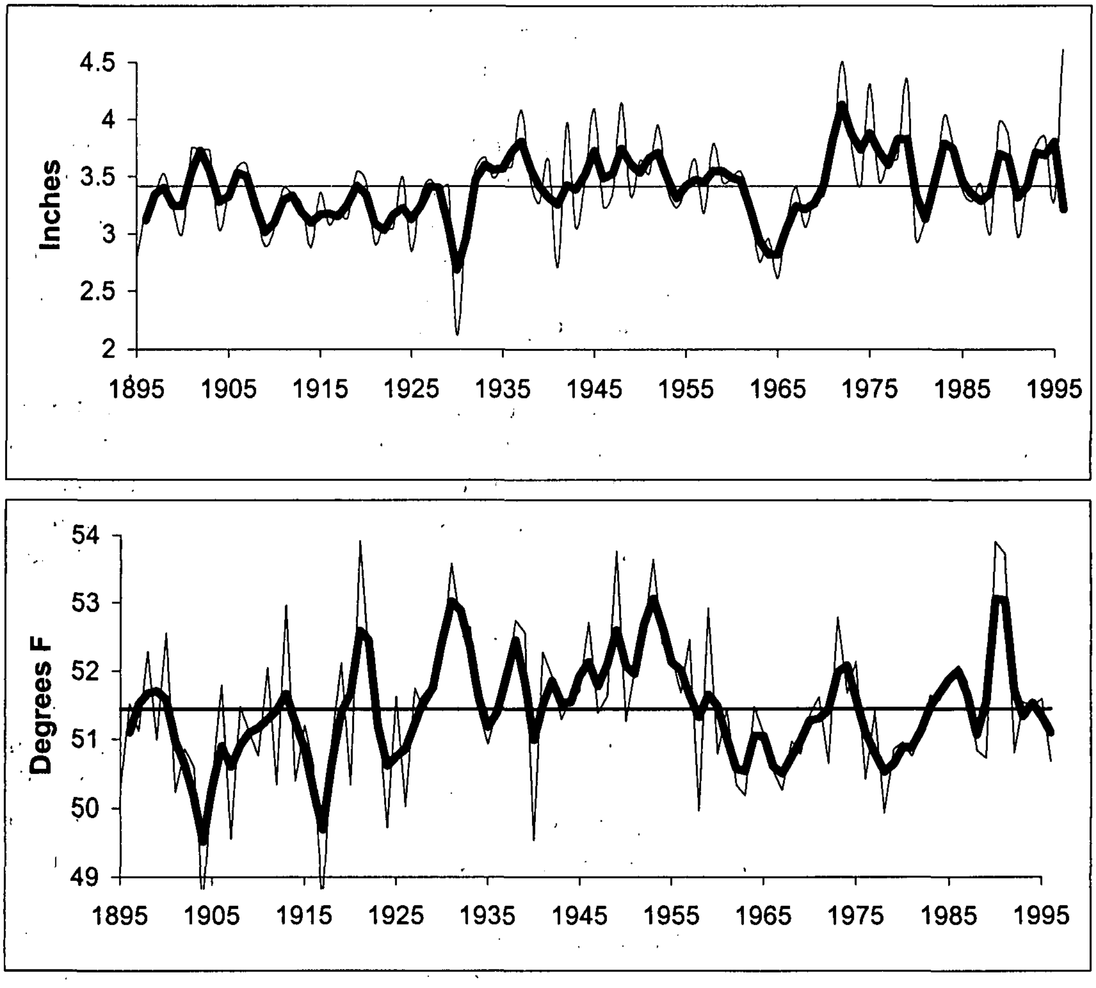


Figure 2.3.1. Departures from long-term (1895-1996) average monthly precipitation (inches, in top figure) and annual temperature (° Fahrenheit, in bottom figure) in the Mid-Atlantic Region. The dashed line denotes average annual values, while the bold, solid line is a five-year running average.

These variations in regional climate since World War II can be explained by changes in the atmospheric circulation. (Jet stream-level data needed to make the following generalizations are not available for earlier periods.) A zonal regime dominated the atmospheric flow over North America through the late 1940s and early 1950s. (A *zonal* *flow* regime means that the jet stream over the United States tends to flow from west to east, with few of the north-south excursions that produce ridges of warm air and troughs of cool air. In contrast, during periods of *meridional flow*, the jet stream has a much greater north-south amplitude, often producing a big ridge of warm sub-tropical air over the western United States and a deep trough of polar air over the eastern half of the nation.) The zonal regime produced normal to slightly above-normal temperatures and variable precipitation over the Mid-Atlantic Region. Then in the mid- to late 1950s, the circulation changed from zonal to meridional flow. During the 1960s, the Mid-Atlantic Region tended to be influenced by a deep trough of continental polar air, that pushed the storm track southeast of its long-term average position so that precipitation often fell off the Atlantic coast. This regime promoted a relatively cool, dry climate. The early 1970s saw the continuation of this meridional regime, but the trough migrated westward, putting the average position of the storm track over the Mid-Atlantic Region. This change increased precipitation in the region. Finally, the mid-to-late 1970s brought a large change in the atmospheric circulation. Since then, there have been unusually large variations in the shape and positioning of the month-to-month and year-to-year jet stream flow over North America. Such major variations in circulation have produced a highly variable surface climate.

2.3.3 Short-term extreme events

Because of the potential harm from extreme events such as severe storms, heat waves, droughts, and cold winters, a regional climate impact analysis needs to determine whether extreme events are increasing or decreasing. Finding trends in the historical climate records, however, is difficult because data on extreme events still are sparse. Still, a few trends are emerging.

Current trends suggest a change toward fewer extreme temperatures in the Mid-Atlantic Region. The last frost of spring tends to come progressively earlier, and there are fewer very cold winter days. Although the region's winters are warming, the number of very hot summer days appears to be decreasing (although there is some question about the reliability of these data).

Extreme precipitation, expressed as those rainfall events exceeding two inches in 24 hours, has increased dramatically in the Mid-Atlantic Region during the 20th Century (and is reflected in the region's observed overall increase in precipitation). One implication is that severe thunderstorms are on the increase over the Mid-Atlantic Region. In addition, winter coastal storms affecting the region appear to be increasing in their power, with seven of the eight most destructive storms of the past half-century occurring in the last 25 years (Davis and Dolan, 1993).

The region also appears to be experiencing significant interannual and intra-annual swings in the climate. For example, the three coldest winters in the record happened in succession in 1976-77, 1977-78, and 1978-79, while some of the warmest winters ever occurred in 1982-83, 1994-95, and 1997-98. The region has experienced several severe droughts in the last two decades, but the wettest year in more than a century was 1996 and the second wettest year was 1972 (Figure 2.3.1). In most of the Mid-Atlantic Region, the four snowiest winters were 1977-78, 1992-93, 1993-94, and 1995-1996, while 1994-1995 and 1997-98 were two of the least snowy winters on record.

Within individual seasons and years, climate has oscillated, too. For instance, December 1989, the coldest December on record, was followed by the warmest January-February in the books. Interestingly, the extreme opposite signs of these months canceled each other so that winter 1989-1990 was an average winter statistically. Precipitation has behaved similarly. The first half of 1998 was the wettest on record in many areas in the Mid-Atlantic Region and it appeared that calendar year 1998 was going to beat 1996 easily for the all-time wettest year. In spite of that, drought gripped the region during the second half of 1998, making it an average year statistically.

2.3.4 The climate of the last 1000 years

Long records of climate variations would allow scientists to compare the natural variation of the period before the Industrial Revolution with the mixed natural and anthropogenic climate signal observed since then. Unfortunately, comprehensive climate observations are restricted to the last century and a half, and to even shorter periods in many regions. As a result, pre-instrument (paleoclimate) climate variations must be deduced from proxy data for climate-sensitive phenomena, such as tree rings, corals, glacier ice cores, and chronologies of alpine glacier advance and retreat. Quantitative data can also be culled from historical records, such as journals and tax and mercantile records. Data from the last 1000 years have the advantage of being relatively abundant and fresh. In addition, the variations they portray are most relevant to the current climate.

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

Despite these data problems, paleoclimate reconstructions show that *globally* the 20th century has been warmer than any century since 1400 AD, and is probably the warmest century in the last 1000 years. Some evidence suggests that this century is as warm as any comparable period in the last 10,000 years – that is, since the retreat of the continental glaciers from North America and Eurasia. The estimated variation of global average temperature over the last millennium is less than ± 0.9°F, but century-scale climate data suggest that natural variation can be abrupt and large.

Reconstructions of Mid-Atlantic Region climate using tree rings and historical data from diaries, newspapers, and periodicals suggest that between the mid-17th century and the late 19th century, the region was cool and somewhat wet, but was affected by individual years of intense drought and occasional decades of prolonged drought. Overall, the year-to-year and decade-to-decade climate was highly variable and not unlike that observed in the latter 20th century. After about 1880, the area warmed gradually. Climate variation decreased until the latter 20th century. For the entire record, the longest drought extended from about 1850-1873, although the most severe prolonged drought occurred in the 1960s. Throughout the entire period of reconstruction, the (admittedly limited) evidence suggests that ENSO events have a significant effect on the hydrology of the Mid-Atlantic Region.

2.3.5 Conclusions

Knowing how the climate of a region has varied in the past provides a baseline for assessing future regional climate change.

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

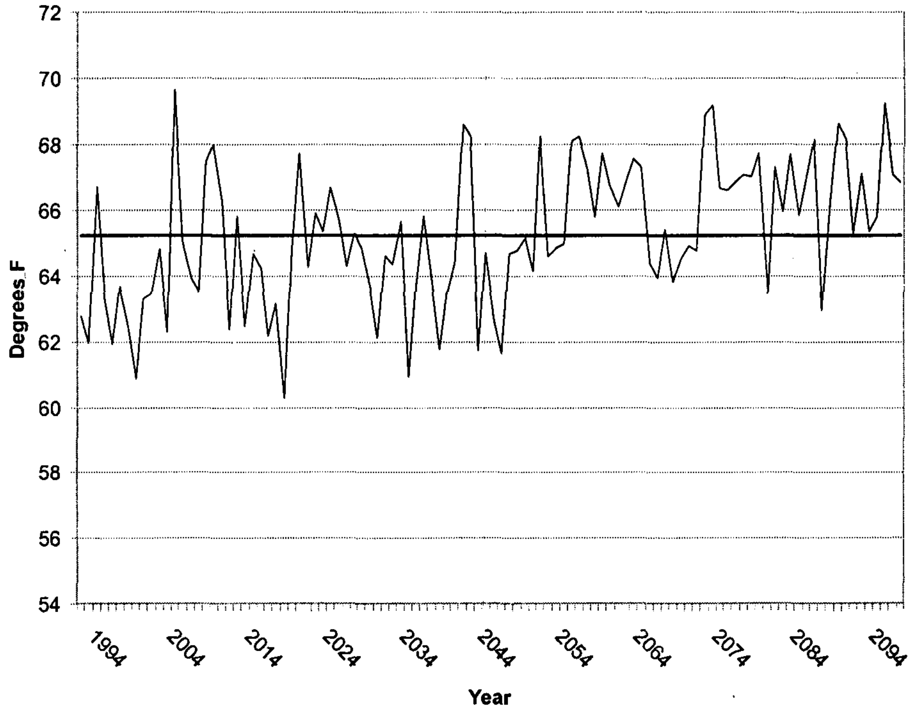
2.4 MARA Region Climate Change Scenarios (Crane)

The Mid-Atlantic Region (MAR) climate change scenarios are derived from a numerical model of the global climate system developed by the Hadley Center for Climate Prediction and Research. The model projects climate change as an experiment including the effects of both sulfate aerosols (which tend to reduce temperatures) and atmospheric greenhouse gases, which increase global temperatures. Starting with 1990 values, this experiment increases the greenhouse gas (carbon dioxide [CO_2]) content of the atmosphere by 1% per year, to the year 2099. (Additional information about climate modeling appears in Appendix B.)

The net effect of the projected global changes in sulfate aerosols and greenhouse gases is to produce an increase in maximum and minimum temperatures for the MAR of approximately 4° F and 5° F respectively over the 100 year period (Figure 2.4.1). The annual average temperature change is on the order of 4.5° F – slightly less than the global average of approximately 5.5° F. By the decade 2025-2034, minimum and maximum temperatures both increase by approximately 2° F. Note, however, that there is considerable year-to-year and decade-to-decade variability. The decade 2035-2044 actually cools slightly before increasing again from 2050 onward. Average monthly precipitation increases by approximately 0.25 inches per month between the present and 2025-2034, and by about one inch per month by 2090-2099 (Figure 2.4.2).

Figure 2.4.3 shows the distribution of modeled January and July average maximum temperatures over the MARA region for the present (1984-93) and for 2025-2034. It suggests that much of the temperature change will occur in the summer, with the greatest changes being in the southeast. Minimum temperatures show a somewhat different pattern (Figure 2.4.4). Higher summer temperatures again occur in the southeast, but there are lower winter temperatures in the central and northern parts of the region.

Much of the increase in precipitation also takes place in the summer. Figure 2.4.5 shows the modeled distribution of precipitation for 1984-1993 and for 2025-2034. A comparison of the modeled and observed data for 1984-1993 indicates that in January the model produces slightly more precipitation than observed over much of the region except for the Carolina coastline, which receives slightly less. The net effect is to slightly reduce the east-west precipitation gradients. In July, the model is too dry over most of the region. In both seasons, however, the model does produce very realistic patterns of the geographic distribution of precipitation. Comparing the model results for 1984-1993 with 2025-2034 we see a slight and fairly uniform increase in January. Precipitation also increases across the whole region in July, but with the greatest increases being in the southeast.



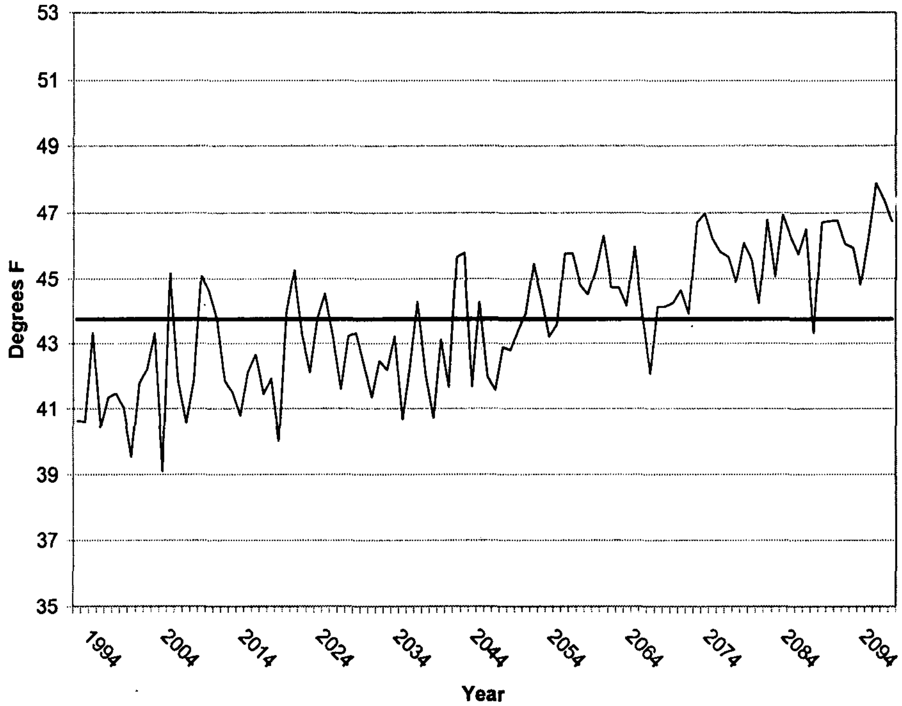


Figure 2.4.1. Average annual maximum (top) and minimum (bottom) temperatures for the MARA region from the Hadley Center global climate model.

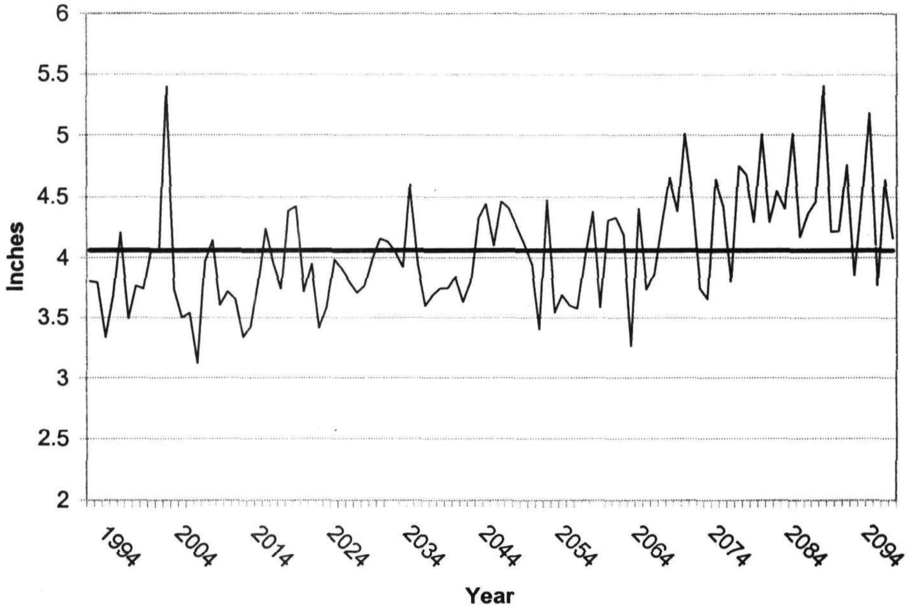


Figure 2.4.2. Monthly precipitation for the MARA region from the Hadley Center global climate model.

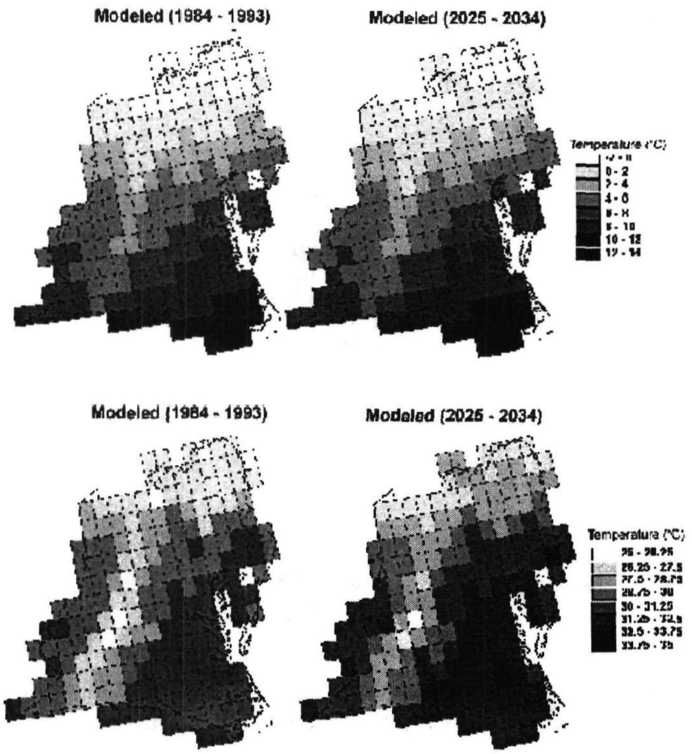


Figure 2.4.3. Average January (top) and July (bottom) maximum temperatures from the Hadley Center model for 1984-1993 (left) and 2025-2034 (right).

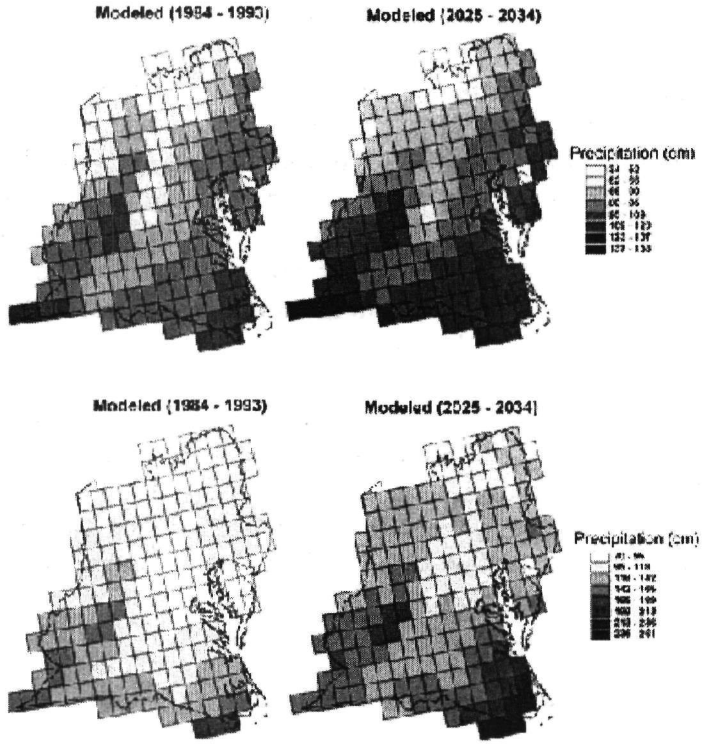


Figure 2.4.4. Average January (top) and July (bottom) minimum temperatures from the Hadley Center model for 1984-1993 (left) and 2025-2034 (right).

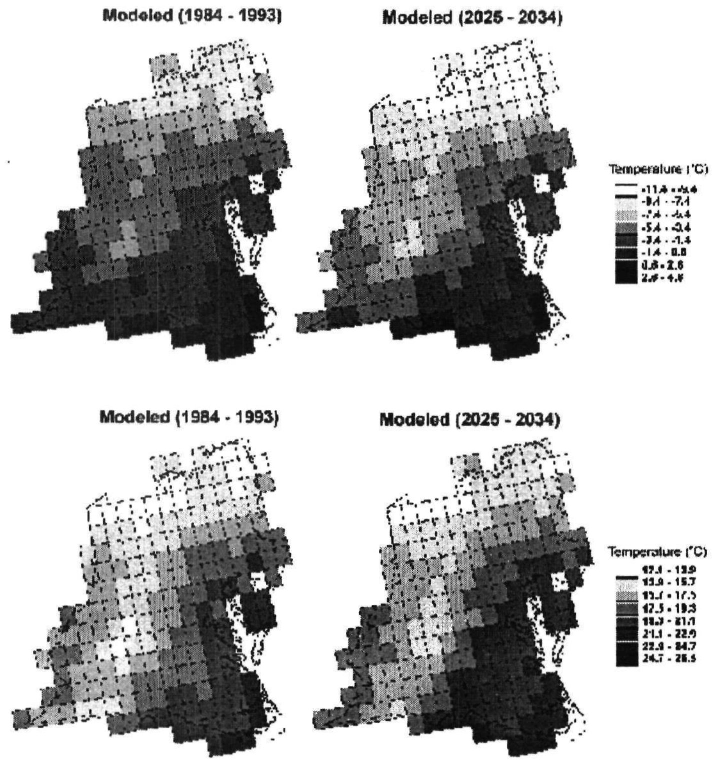


Figure 2.4.5. Average January (top) and July (bottom) precipitation from the Hadley Center model for 1984-1993 (left) and 2025-2034 (right).

These results are broadly consistent with earlier studies of the MARA region using a different global climate model (GENESIS). The GENESIS climate change experiment was for a doubling of atmospheric CO_2 above late 20th century values, and did not include the effects of sulfates. A study that used a regional climate model in conjunction with GENESIS global model produced a similar increase in annual precipitation, although with a greater increase in winter rather than summer. A second study, employing a later version of GENESIS and using observed relationships between the regional climate and local precipitation, also found a large increase in precipitation. In this case the increase was concentrated in the summer months, with the largest changes occurring to the south, but over the mountains.

In sum, these models suggest a) modest warming (2°F) by 2030, and substantial warming (4.5°F) by 2100, with more of the warming during the summer and in the southeast portion of the MAR, and b) modest increases in precipitation (0.25 inches/month) by 2030 and substantial increases (1 inch/month) by 2100. The precipitation increase is likely to be mostly in the summer, but there is substantial uncertainty about its typical distribution within the year and within the region.

Part 3: Impacts, Challenges and Opportunities

The background summaries in Part 2 provide context about the Mid-Atlantic region's physical and socio-demographic environment within which its people live, its historical climate, and likely changes in its future climate. The next step is to assess a) the impacts on the MAR from climate change, b) how the region's citizens can take advantage of opportunities and increase resilience to vulnerabilities from climate change, and c) additional information needed to improve individual and organizational decisions related to impacts from climate change.

The MARA team is committed to an integrated assessment approach. But few studies have taken an integrated approach at the scale of a region such as the Mid-Atlantic. Thus it initially appeared desirable to demonstrate the MARA approach on a small number of sectors especially likely to be affected by climate change. However, available research suggested a broad range of potential impacts, with none of those overwhelming the others for this region. Meetings with the Advisory Committee demonstrated substantial interest in many types of potential impacts. This convergence of scientific implications and stakeholder interests resulted in a decision to assess impacts for each of the following: agriculture, forestry, water resources, coastal zones, ecosystems and human health. These include the sectors to be covered in the national assessment. Their order of coverage here reflects the fact that linkages among the first four tend to flow downstream; the ecological and human health impacts are more cross-cutting. The assessment focuses on the year 2030, discussion of impacts for 2100 is necessarily more speculative.

3.1 Agriculture (Abler, Shortle, Nizeyimana, and Corradini)

Mid-Atlantic agriculture, like agriculture worldwide, has an intrinsic relationship with climate. Climate variability has strong impacts on Mid-Atlantic agriculture. Climate change potentially also could have significant impacts. This section reviews the current status and stresses on Mid-Atlantic agriculture and how climate variability affects agriculture in the region. It goes on to consider how climate change might affect future Mid-Atlantic agriculture, bearing in mind that Mid-Atlantic agriculture is likely to change dramatically independent of climate change. This section then considers some management and adaptation options for farmers, agribusinesses, and governments. It concludes with priorities for research and information that should be addressed in future assessments.

3.1.1 Current Status and Stresses

Compared to many other parts of the US, Mid-Atlantic agriculture is characterized by smaller farms and a wider range of crops and livestock products. Average farm size in the Mid-Atlantic is about 180 acres, compared with over 500 acres for the rest of the US (USDA National Agricultural Statistics Service, 1999a). However, poultry and hog operations within the Mid-Atlantic tend to be quite large as measured by the number of livestock per farm and quite intensive as measured by the number of livestock per acre.

The single largest source of cash receipts in most of Pennsylvania, upstate New York, and much of Maryland is dairy production. Mushrooms and other vegetables and nursery products are important in New Jersey, parts of Maryland, and parts of eastern Pennsylvania. Chicken and eggs tend to dominate in the Delmarva Peninsula and in parts of Virginia and southern Pennsylvania. Significant production of apples, peaches, and other tree fruits occurs in certain areas of Maryland, New Jersey, Pennsylvania, and West Virginia. In western Virginia and West Virginia, cattle farming is the most important agricultural activity. Tobacco production tends to predominate in southern Virginia and northern North Carolina.

Due to historically adequate supplies of rainfall in most years, crop production in the Mid-Atlantic region is overwhelmingly rainfed. Less than 3% of crop acreage in the Mid-Atlantic is irrigated, compared with about 13% in the rest of the US. (USDA National Agricultural Statistics Service, 1999a).

Present-day Mid-Atlantic agriculture can be illustrated using data for major land resource areas (MLRAs) within the region. MLRAs are areas characterized by common patterns of soil, climate, water resources, and land uses. MLRAs for the Mid-Atlantic region were obtained using geographic information systems (GIS) boundaries assembled by the US Geological Survey (1999). Figure 3.1.1 shows MLRAs for the Mid-Atlantic region. Table 3.1.1 presents statistics for Mid-Atlantic agriculture at the MLRA level.

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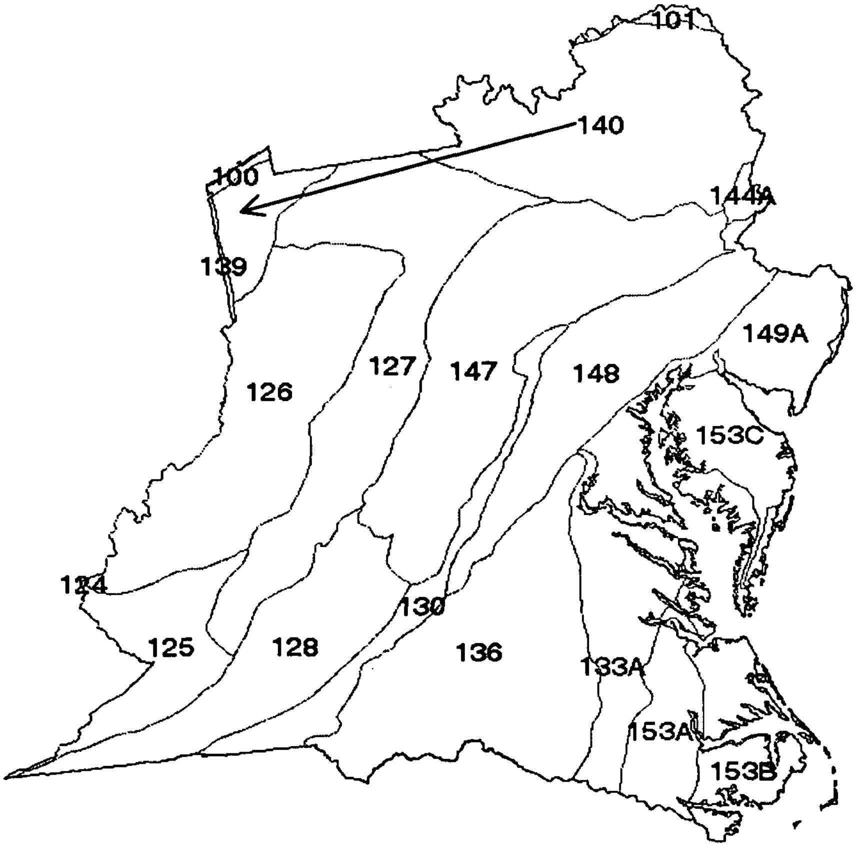


Figure 3.1.1. MLRA Map of the Mid-Atlantic Region

Agricultural land use and sales data in Table 3.1.1 are from county-level data in the *1992 Census of Agriculture* (Government Information Sharing Project, 1999). Employment data, which include full-time as well as part-time farmers, use 1996 county-level data from the US Bureau of Labor Statistics (1999). In cases where a county spans two or more MLRAs, county data are apportioned among MLRAs according to the proportion of total county area in each MLRA.

Table 3.1.1 indicates that agriculture accounts for about one-fourth of total land area in the Mid-Atlantic region. Among MLRAs, this proportion varies from over one-half in the Mid-Atlantic Coastal Plain (153C) to less than 4% in the Cumberland Plateau and Mountains (125). Hay and pastureland are the predominant uses of agricultural land, accounting for nearly three-fourths of total agricultural land in the Mid-Atlantic region. The remainder, about one-fourth, is accounted for by cropland. Hay and pastureland are also the predominant uses of agricultural land in most MLRAs. Exceptions include the Atlantic Coastal Flatwoods (153A) and the Tidewater Area (153B) along the southern Virginia and northern North Carolina coasts, where producers grow a mixture of crops.

Table 3.1.1. Mid-Atlantic Agriculture at the MLRA Level

MLRA	MLRA Name	MLRA Area Lying in Mid-Atlantic Region (1000 Acres)	Percentage of Total Land in MLRA, 1992: Hay and Pastureland	Percentage of Total Land in MLRA, 1992: Cropland	Percentage of Total Land in MLRA, 1992: All Agricultural Land	Farm Labor Force as Percentage of Total Labor Force, 1996	Percentage of Total Farm Sales, 1992: Livestock and Livestock Products	Percentage of Total Farm Sales, 1992: Crops
100	Erie Fruit and Truck Area	426	25.0	9.3	34.3	1.1	45	55
101	Ontario Plain and Finger Lakes Region	835	29.6	6.9	36.6	3.7	89	11
124	Western Allegheny Plateau	7	13.5	2.5	16.0	1.3	31	69
125	Cumberland Plateau and Mountains	9,196	2.4	1.5	3.9	2.8	27	73
126	Central Allegheny Plateau	25,855	18.6	3.2	21.8	4.1	56	44
127	Eastern Allegheny Plateau and Mountains	25,935	8.3	1.7	10.0	3.2	78	22
128	Southern Appalachian Ridges and Valleys	16,105	18.2	2.9	21.1	10.9	79	21
130	Blue Ridge	7,106	20.9	2.2	23.1	10.1	78	22
133A	Southern Coastal Plain	10,888	12.7	12.8	25.5	4.9	14	86
136	Southern Piedmont	27,707	15.8	5.8	21.5	7.6	34	66
139	Eastern Ohio Till Plain	311	26.5	9.9	36.4	2.4	74	26
140	Glaciated Allegheny Plateau and Catskill Mountains	30,017	19.6	3.7	23.3	3.6	67	33
144A	New England and Eastern New York Upland, Southern Part	874	16.8	2.6	19.5	1.7	45	55
147	Northern Appalachian Ridges and Valleys	29,605	26.6	7.6	34.2	4.6	68	32
148	Northern Piedmont	16,586	37.9	10.8	48.7	2.6	43	57
149A	Northern Coastal Plain	11,557	13.4	6.7	20.0	1.1	5	95
153A	Atlantic Coastal Flatwoods	5,994	10.4	18.9	29.3	6.3	32	68
153B	Tidewater Area	9,082	12.0	19.5	31.5	6.7	8	92
153C	Mid-Atlantic Coastal Plain	6,458	30.0	21.8	51.8	3.4	35	65
Entire Mid-Atlantic Region		234,545	18.4	6.6	25.0	4.0	26	74

About three-fourths of total farm sales in the Mid-Atlantic region are accounted for by crops rather than livestock or livestock products. Among MLRAs, crop sales as a proportion of total farm sales vary from about one-tenth in the Ontario Plain and Finger Lakes Region (101) to over 90% in the Northern Coastal Plain (149A) and the Tidewater Area (153B).

Agriculture accounts for about 4% of the total labor force in the Mid-Atlantic region (including both full-time and part-time farmers). This proportion ranges from over 10% in the Southern Appalachian Ridges and Valleys (128) and Blue Ridge (130) to less than 1% in the heavily urbanized Erie Fruit and Truck Area (100) and Northern Coastal Plain (149A).

Agriculture's importance in the Mid-Atlantic region extends well beyond its role as a source of income and employment. Rural and urban populations within and outside the region value the region's agricultural and rural land as open space and as a source of countryside amenities. Fishing, boating, hunting, sightseeing, and other recreational activities are important in rural areas throughout the Mid-Atlantic. Agricultural land is an important habitat for some wildlife species within the region. These values are reflected in public programs to protect farmland from development and preserve agricultural landscapes in all eight states within the region (American Farmland Trust, 1997). Programs in place within the region include agricultural protection zoning, differential property assessment, and conservation easements.

Agriculture in the Mid-Atlantic is also a source of negative environmental impacts, particularly water pollution from nutrients, eroded soils, and pesticides. Of 2,105 watersheds (defined at the 8-digit hydrologic unit code level) in the 48 contiguous states, watersheds in southern New York, northern Pennsylvania, southeastern Pennsylvania, western Maryland, and western Virginia rank in the top 10% in terms of manure nitrogen runoff, manure nitrogen leaching, manure nitrogen loadings from confined livestock operations, and soil loss due to water erosion (Kellogg et al., 1997). Watersheds in southeastern Pennsylvania and along the southern Virginia/northern North Carolina coasts also rank in the top 10% in terms of nitrogen loadings from commercial fertilizer applications (Kellogg et al., 1997). Watersheds in the tobacco-growing areas of southern Virginia and northern North Carolina rank near the top as measured by potential threats to human drinking water supplies, fish, and other aquatic life from pesticide leaching and runoff (Kellogg et al., 1999).

Environmental side effects of agricultural production in the Mid-Atlantic are of concern for many reasons, but perhaps the most important is because of their impact on the Chesapeake Bay. Human activity within the Chesapeake Bay watershed during the last three centuries has had serious impacts on this ecologically rich area, including significant declines in highly valued fish and shellfish populations. Soil erosion and nutrient runoff from crop and livestock production have played major roles in the decline of the Chesapeake Bay.

3.1.2 Climate Variability and Mid-Atlantic Agriculture

Crop production in the Mid-Atlantic region has historically been sensitive to climatic variations. Extreme events such as heat waves, droughts, freezes, floods, hailstorms, and hurricanes have had strong impacts on crop yields over the years. For example, a drought and heat wave in the summer of 1980, as well as in the summer of 1991, significantly reduced crop yields in Maryland, Pennsylvania, Virginia, and other parts of the Mid-Atlantic.

Among major crops within the Mid-Atlantic, yields of corn are perhaps the most climate-sensitive because virtually all corn is rainfed and water is a limiting input into corn production in many years. This is confirmed by statistical analysis of crop yield data for 1980-1998 from the USDA National Agricultural Statistics Service (1999b) for states in the Mid-Atlantic. This analysis indicates that corn yields tend to deviate significantly around their trend rates of growth – often more than 30% above or below trend. On the other hand, yields of crops such as hay and tobacco show much smaller deviations – generally on the order of 5-10% – around their trend rates of growth.

In general, livestock production tends to be less sensitive to climate variability than crop production. This is particularly true for poultry production in the Mid-Atlantic, the vast majority of which occurs indoors under controlled climatic conditions. For outdoor livestock production, heat waves can lead to increased livestock mortality, lower livestock yields, and lower reproductive capacity (Klinedinst et al., 1993). Especially cold weather during the winter can also increase livestock mortality.

3.1.3 Future Agricultural Baseline Scenarios

Mid-Atlantic agriculture, like US agriculture as a whole, has changed radically during the last century. With the notable exception of some Amish, tractors and other farm machinery have virtually eliminated the use of draft animals and have made it possible for a single farmer to cultivate tracts of land orders of magnitude larger than a century ago. The introduction of synthetic organic pesticides in the 1940s revolutionized the control of weeds and insects. Similarly, there has been tremendous growth in the use of manufactured fertilizers and hybrid seeds. Farmers have become highly specialized in the livestock products and crops they produce, and they have become much more dependent on purchased inputs. Crops that were virtually unheard of 100 years ago, such as soybeans, are of major importance today. As agricultural productivity has risen, and as real (inflation-adjusted) prices of farm commodities have fallen, substantial acreage in the Mid-Atlantic has been taken out of agriculture and either returned to forest or converted to urban uses.

For reasons discussed in more detail in Appendix B, there are few reasons to expect this rapid pace of change to slow down during the coming century. Biotechnology is already having significant impacts on agricultural production, and could lead to revolutionary changes in the types of crops and livestock produced and in the way that they are produced. Precision agriculture and improved climate forecasts may give farmers much greater understanding of, and control over, growing conditions. Biotechnology and precision agriculture could also lead to substantial reductions in the negative environmental side effects of agricultural production. At the same time, economic conditions facing Mid-Atlantic agriculture can be expected to continue changing for many other reasons. Real prices for agricultural commodities are likely to continue their long-term downward trend, the opportunity cost of labor facing Mid-Atlantic agriculture (what farmers and farm workers could earn in other occupations) is likely to continue its long-term upward trend, and pressures to convert agricultural land to urban uses are likely to continue, but perhaps at a slower pace due to farmland protection efforts. These trends, when taken as a whole, suggest that Mid-Atlantic agriculture will be smaller but more productive on a per farm basis.

With an eye toward establishing plausible upper and lower bounds on potential climate change impacts on Mid-Atlantic agriculture, along the lines discussed in Part 2 of this report, two baseline scenarios are considered here for the year 2030. These two scenarios, continuation of the status quo (SQ) and a smaller, more "environmentally friendly" agriculture (SEF), are detailed in Table 3.1.2. The SEF scenario is much more probable than any scenario approximating a continuation of the status quo, but both scenarios are needed to establish bounds on climate change impacts. As discussed in Appendix B, the SEF scenario helps establish lower bounds on any negative impacts on agricultural production due to climate change, and upper bounds on any positive impacts on production. It also helps establish lower bounds on positive or negative impacts of how climate change might affect the environmental side effects of agricultural production. The SQ scenario is the opposite of the SEF scenario, in that it helps establish upper bounds on negative production impacts, lower bounds on positive production impacts, and upper bounds on positive or negative environmental impacts.

Table 3.1.2. Baseline Agricultural Scenarios for the Year 2030

Scenario	Scenario Details
Smaller, More "Environmentally Friendly" Agriculture (SEF)	• Major decline in field crop production in region • Smaller but still significant decline in livestock production • Significant decrease in number of farms in region • Substantial increase in agricultural productivity due to biotechnology and precision agriculture • Major increase in agricultural production per farm on the remaining farms • Significant decrease in agriculture's sensitivity to climate variability due to biotechnology, precision agriculture, and improved climate forecasts • Some conversion of agricultural land to urban uses, with conversion slowed by farmland protection programs • Some reforestation of existing, economically marginal agricultural lands • Significant decrease in commercial fertilizer and pesticide usage due to biotechnology • Less runoff and leaching of agricultural nutrients and pesticides due to precision agriculture • Stricter environmental regulations facing agriculture, especially intensive livestock operations
Status Quo (SQ)	• Agriculture as it exists today in the Mid-Atlantic region

For the year 2100, the uncertainties are so overwhelming that it is very difficult to think about baseline agricultural scenarios. To illustrate this point, it would have been exceedingly difficult if not impossible for someone in 1900 to foresee the dramatic changes that would occur in Mid-Atlantic agriculture during the 20th century. It is probable that Mid-Atlantic agriculture in 2100 will bear only a faint resemblance to the region's agriculture today, but it is not possible to say with any confidence what the major changes between now and then might be.

3.1.4 Potential Climate Change Impacts on Mid-Atlantic Agriculture

This section assesses potential climate change impacts on four types of crops (corn, soybeans, tobacco, and tree fruits) and two types of livestock (dairy and poultry) that are currently important to Mid-Atlantic agriculture. The region's major tree fruits are apples, cherries, peaches, and pears. This section also assesses potential climate change impacts on environmental side effects of agricultural production within the region. Our assessment draws in part on previous assessments for US and world agriculture (Adams et al., 1999; Adams et al., 1998; Darwin et al., 1995; IPCC, 1996; Lewandrowski and Schimmelpfennig, 1999; Rosenzweig and Hillel, 1998; Schimmelpfennig et al., 1996).

Carbon dioxide (CO_2) accumulation and climate change are expected to have direct effects on the region's agriculture (Adams et al., 1999; Rosenzweig and Hillel, 1998).

Elevated levels of CO_2 may lead to an increase in photosynthesis and thus crop yields, a phenomenon known as the CO_2 fertilization effect. They may also lead to a decrease in transpiration (evaporation from plant foliage), which would reduce water stress during periods with little or no rainfall. Projected increases in summer temperatures and summer precipitation within the region (see Part 2 of this report) could also have significant effects, particularly on climate-sensitive crops such as corn.

Beyond these direct effects, climate change may have indirect effects on Mid-Atlantic agriculture (Adams et al., 1999; Schimmelpfennig et al., 1996). Climate change in other regions and countries may affect agricultural production in those areas. As national and global agricultural commodity markets adjust to these changes in production, commodity prices facing Mid-Atlantic farmers could change. Climate change may also have impacts on nonagricultural sectors of the Mid-Atlantic economy or economies of other regions and countries. These changes, which we refer to as economywide effects, might manifest themselves as changes in prices of purchased inputs used by Mid-Atlantic farmers, competing demands for land within the region, or alternative employment opportunities available to Mid-Atlantic farmers.

Potential climate change impacts on Mid-Atlantic agricultural production in the year 2030 are shown in Table 3.1.3. Impacts are reported under our two alternative baseline scenarios – a smaller, more environmentally friendly agriculture (SEF), or a continuation of the status quo (SQ). Each impact in Table 3.1.3 is classified as either a significant increase (+), significant decrease (–), no significant impact in either direction (0), or unknown (?) based on currently available knowledge. Table 3.1.3 also reports our assessment of overall effects for each of the four crops and two livestock products.

Overall, the impacts of climate change on crop production within the Mid-Atlantic may be beneficial. Soybean and tree fruit production within the region may increase under both baseline scenarios due to CO_2 fertilization effects, increased summer precipitation, and reduced transpiration (for soybeans). Corn production will probably either not change significantly (SQ scenario) or may even increase (SEF scenario). Of the four crops, tobacco appears to have the highest probability of suffering production losses because of climate change. Even here, the direct effects of climate change on production within the region may on the whole be beneficial. However, similar direct effects are also expected to be operating in other regions and countries, leading to increases in global tobacco production and that would depress world tobacco prices and act as a disincentive to tobacco production within the Mid-Atlantic.

Table 3.1.3. Potential Climate Change Impacts on Agricultural Production in 2030

	Impact Accounting for Adaptation by Producers* (Significant Positive +, Significant Negative –, No Significant Impact 0, or Unknown ?)					
	Corn	**Soybeans**	**Tobacco**	**Tree Fruits**	**Dairy**	**Poultry**
Direct Effects**						
Increased Photosynthesis	0	+	?	+	0	0
Reduced Transpiration	+	+	+	0	0	0
Higher Summer Temperatures	0 SEF – SQ	0	0 SEF – SQ	0 SEF – SQ	0	0
Increased Summer Precipitation	+	+	+	+	0	0
Changes in Extreme Weather Events	?	?	?	?	0	0
Changes in Weeds, Insects, and Diseases	0 SEF ? SQ	0 SEF ? SQ	0 SEF ? SQ	0 SEF ? SQ	0 SEF ? SQ	0 SEF ? SQ
Indirect Effects**						
Changes in Farm Commodity Prices	0	0	–	?	0	0
Economywide Effects	0	0	0	0	0	0
OVERALL EFFECTS:						
SEF Scenario	+	+	0	+	0	0
SQ Scenario	0	+	–	+	0	0

* Accounting for actions taken by producers to minimize negative climate change impacts on production and exploit positive impacts on production.
** Unless otherwise noted, the effect (+, –, 0 or ?) is the same in the SEF and SQ scenarios.

We do not anticipate the effects of climate change on livestock production within the Mid-Atlantic to be significant in either a positive or negative direction. For example, increases in summer temperatures projected for the region will probably not be large enough to be a major detriment to livestock production. This is particularly true for confined livestock operations, where producers have a number of low-cost ways to adapt to higher temperatures, including fans and improved ventilation. Confined livestock operations already account for a significant proportion of total livestock production within the region, and we anticipate that this proportion will increase. In principle, climate change can also affect livestock production through changes in the quality and availability of forage, or through changes in prices of purchased feeds. Here too, however, available evidence suggests that there may be no significant impacts one way or another.

The impacts in Table 3.1.3 take into account adaptation by farmers to climate change. Farmers have a wide array of options at their disposal for minimizing negative impacts on production and exploiting positive impacts. For crops these options including changes in crop acreages, the types or varieties of crops grown, planting and harvesting dates, crop rotations, tillage practices, fertilization practices, and pest management practices. For livestock these options include changes in herd sizes, livestock types or breeds, feeding rations, and heating and cooling systems.

Potential climate change impacts for the year 2030 on the environmental side effects of agricultural production are shown in Table 3.1.4. Impacts are reported in Table 3.1.4 under the two alternative baseline scenarios and are classified as either a significant increase (+), significant decrease (–), no significant impact in either direction (0), or unknown (?) based on currently available knowledge. An increase implies a worsening of an environmental problem, while a decrease implies an environmental improvement.

Table 3.1.4 first reports impacts assuming that farmers do not adapt in any way to climate change, and then brings potential environmental side effects of farmer adaptation into the picture. Impacts assuming no farmer adaptation are based on existing studies (e.g., Favis-Mortlock and Savabi, 1996; Follett, 1995; Phillips et al., 1993; and Rosenzweig and Hillel, 1998). Environmental side effects of farmer adaptation are based on changes in crop acreages, crop management practices, and other factors that we anticipate might occur as a result of the production impacts reported in Table 3.1.3.

Many of the impacts of climate change on environmental side effects of agricultural production are very difficult to assess given current evidence. In particular, changes in extreme weather events such as floods or heavy downpours could easily overwhelm the other effects in Table 3.1.4, but we lack good evidence on how these extreme events might change. Leaving aside extreme events, nutrient leaching and runoff from livestock may increase in the SQ scenario, primarily due to an increase in summer precipitation. In the SEF scenario, no such increase occurs because in this scenario livestock producers are subject to stricter environmental regulations that limit nutrient losses. In the SEF scenario, livestock production is also much smaller than in the SQ scenario and has fewer

Table 3.1.4. Potential Climate Change Impacts on Environmental Side Effects from Agriculture in 2030

	Impact (Significant Positive +, Significant Negative –, No Significant Impact 0, or Unknown ?)			
	Nutrient Leaching and Runoff from Crops	**Nutrient Leaching and Runoff from Livestock**	**Pesticide Leaching and Runoff**	**Water Erosion**
Effects Assuming Farmers Do Not Adapt to Climate Change*				
Increased Photosynthesis	–	0	0 SEF ? SQ	?
Reduced Transpiration	–	0	0 SEF ? SQ	?
Higher Summer Temperatures	0	0	0	0
Increased Summer Precipitation	+	0 SEF + SQ	0 SEF + SQ	+
Changes in Extreme Weather Events	?	?	?	?
Changes in Weeds, Insects, and Diseases	0	0	0	0
Effects of Farmer Adaptations to Climate Change*	0 SEF ? SQ	0	0 SEF – SQ	0 SEF ? SQ
OVERALL EFFECTS:**				
SEF Scenario	0	0	0	0
SQ Scenario	0	+	0	0

* Farmer adaptation is discussed in the text. Unless otherwise noted, the effect (+, –, 0 or ?) is the same in the SEF and SQ scenarios.
** Effects assuming no significant changes in extreme weather events.

environmental side effects because of biotechnology that reduces the nutrient content of animal wastes. Beyond this, based on the existing evidence we do not anticipate major changes in either direction in environmental side effects.

For the year 2100, the same overwhelming uncertainties that make it impossible to construct baseline scenarios also make it impossible for us to assess potential climate change impacts on agricultural production or its environmental side effects.

3.1.5 Management and Adaptation Options

In their review of the literature on climate change and US agriculture, Lewandrowski and Schimmelpfennig (1999) conclude that costly adaptation strategies are not warranted on the basis of available evidence. Our assessment for the Mid-Atlantic leads to the same conclusion. The impacts of climate change on Mid-Atlantic crop production may on the whole be beneficial, while impacts on Mid-Atlantic livestock production will probably not be large one way or the other.

Many adaptations to exploit opportunities created by climate change and minimize climate-related risks will occur more or less autonomously as farmers and agribusinesses react to experiences with climate change and evolving climate expectations. Agriculture is an industry already very familiar with continual, rapid, and often tumultuous change.

Nevertheless, there are actions that can be taken to facilitate adaptation. Our assessment of agriculture's adaptive abilities hinges in large part on the development and adoption of new technologies, particularly biotechnology, precision agriculture, and improved climate forecasting. Farmers will need to have the education and skills to understand and exploit these technologies. Public- and private-sector agricultural and meteorological research organizations will need employees with the scientific skills to build on today's technologies. This poses a challenge for educational institutions within the region, particularly the region's land-grant institutions.

One potential threat to adaptation identified in previous assessments for other regions of the US is access to additional irrigation water, particularly in the face of growing demands for water from other sectors (Lewandrowski and Schimmelpfennig, 1999). Based on available evidence, this would not appear to be a major concern for the Mid-Atlantic because less than 3% of its crop acreage is irrigated. Irrigation is currently uneconomic for most crops in most parts of the Mid-Atlantic, and projections suggest that regional precipitation may increase under climate change.

3.1.6 Priorities for Research and Information

Several types of additional research and information would be useful. However, three stand out as priorities for Mid-Atlantic agriculture and perhaps other regions of the US as well:

Climate Change and Weeds, Insects, and Diseases

Climate change is likely to affect pest-crop and pest-livestock relationships, but we have very little evidence on how these relationships are likely to change (Rosenzweig and Hillel, 1998). Consequently, we were forced to largely ignore them for purposes of this assessment, even though they could be more important than many of the impacts we did consider. Additional research on these relationships is needed at all levels – from the level of individual weed, insect, crop, and livestock species to the aggregate ecosystem level.

Extreme Weather Events and Agriculture

Additional research is needed on the effects of climate change on extreme weather events and in turn on agricultural production and environmental side effects from agricultural production. We currently lack good evidence on how the timing, frequency, and intensity of extreme events might change, particularly at a regional level. We also lack good evidence on how changes in extreme events might affect agricultural production and its environmental side effects.

Climate Change and Environmental Side Effects from Agriculture

The vast majority of research to date on climate change and agriculture has focused on agricultural production impacts. Very little work has been done on how climate change might lead to changes in the environmental side effects of agricultural production. To our knowledge, no research has been done at all that considers how responses by farmers to climate change might mitigate or exacerbate environmental side effects. Given the magnitudes of environmental side effects in many areas, including the Chesapeake Bay, this should be a high priority for research.

3.2 Forestry (DeWalle, Easterling, Iverson, Prasad, Rose, Buda, Cao)

3.2.1 Current Status and Stresses

3.2.1.1 Forests of the Mid-Atlantic Region

Forests are the dominant land cover in the Mid-Atlantic Region with a rich mix of species diversity from the pine and coastal wetlands regions in the south to the northern upland hardwoods (Figure 3.2.1). In terms of current volumes of growing stock, dominant hardwood species are red oaks, white oak, yellow-poplar, red maple, sugar maple, black cherry, beech and sweetgum. Softwood forests are dominated by loblolly, shortleaf, and white pines and hemlock. Many other species are abundant only in localized parts of the region. The dominant forest types in the region are oak-hickory (46% of area) and maple-beech-birch (37% of area), with pine and mixed pine-hardwood forests representing about 8% of the forest area.

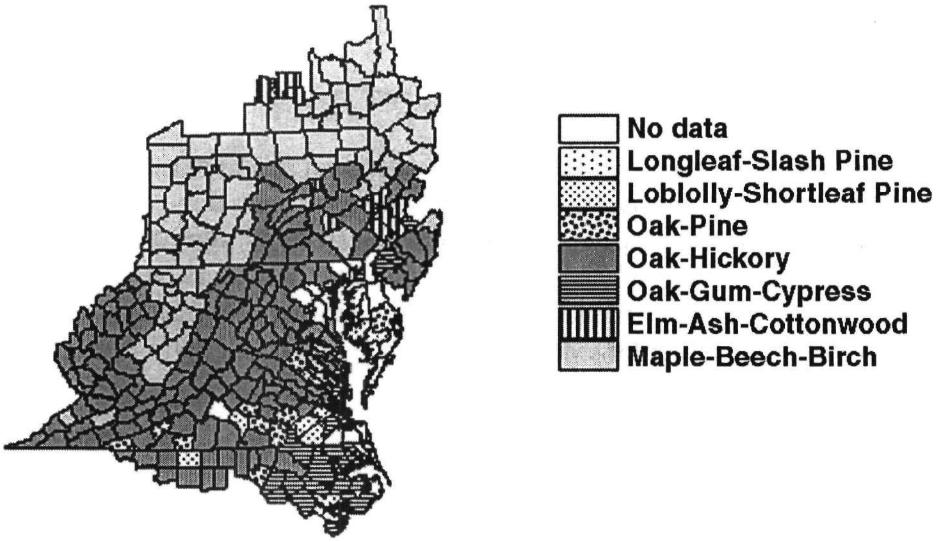


Figure 3.2.1. Distribution of Major Forest Types in the Mid-Atlantic Region. (Based upon Forest Inventory and Analysis data collected by USDA, Forest Service and compiled by Iverson (1996).)

Forests in the region were extensively cut for wood products in the early 1900's. Active management and protection from fire since then has resulted in second-growth forests that are rapidly approaching maturity. Forests in the region as a whole are primarily in 10-12 inch (25-30 cm) diameter classes, however substantial volumes of sawtimber exist in the larger diameter classes (Powell et al. 1994).

Forested area in the Mid-Atlantic states is relatively stable, decreasing very slowly by about 1% per decade (Powell et al. 1994). Most of the forests (88%) in the region are privately owned and management decisions rest largely with non-industrial private landowners.

Net volume of forest growing stock in the Mid-Atlantic Region states for hardwoods is steadily increasing, but growth rates are slowing as the forests approach maturity (Figure 3.2.2). Softwood growing stock volumes have leveled off somewhat and are expanding only very slowly. Net growth of wood (growth minus mortality) currently exceeds removals for wood products by about two to one for the region; softwood=1.25 and hardwood=2.18. Mortality is only about 0.6 to 0.8% of growing stock annually.

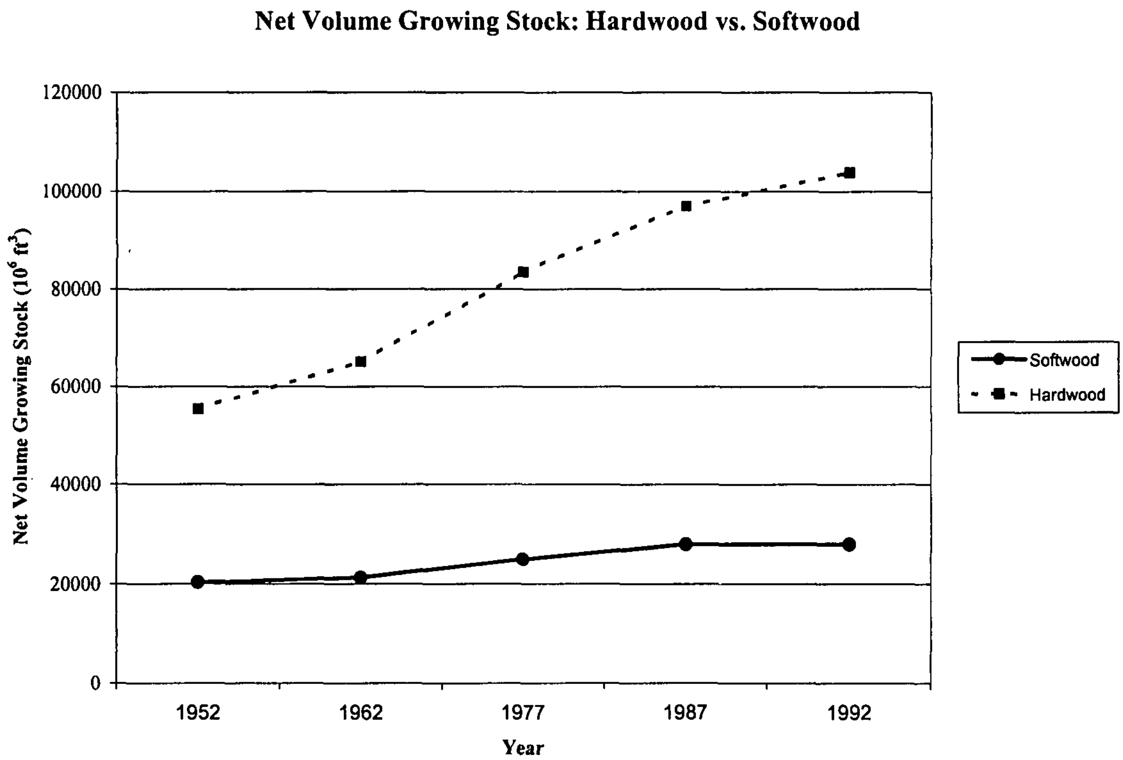


Figure 3.2.2. Trends in the Net Volume of Forest Growing Stock for States in the Mid-Atlantic Region (Powell et al., 1996)

Forest products produced in this region are primarily sawlogs, pulpwood, fuelwood, and veneer logs, and other products such as maple syrup, nuts and edible plants. Forests in this region are also highly valued for the recreational, watershed and riparian buffer, wildlife, biodiversity and other ecosystem benefits they provide.

3.2.1.2 Role of Mid-Atlantic Forests in the Regional Economy

This analysis examined 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. The combined total gross output (sales revenue) of these sectors in 1995 was $41.9 billion, or 2.5% of the $1,671.2 billion total gross output in the Mid-Atlantic Region. This small percentage, however, understates the economic role of forest-related sectors. First, these sectors stimulate additional production and employment in supplier and customer sectors through backward and forward linkages, respectively. Second, forests provide a base for hunting, camping, hiking, birdwatching and fishing, which contribute to the service and other sectors of the economy. In addition, forests provide a range of non-market services such as carbon sequestration and wildlife habitat.

An input-output economic analysis for the forest-related sectors in the Mid-Atlantic Region yields insight into the interconnections among the individual forest-related sectors and their role in the regional economy (Table 3.2.1). The rows labeled R1 to R9 depict the sales of each of these products by businesses within the Region for intermediate demand, for consumer demand, and for export. Analogously, the rows labeled M1 to M9 depict imports of each of these products by each of the demand categories. Despite the Region's extensive forest resources, more than half of each of the nine forest-related sector products is imported. At the same time, the Region exports $27.0 billion of its $41.8 billion production of forest-related products, or well over 50%.

Economic interdependency with the rest of the US stems from the fact that the Mid-Atlantic region borders regions with extensive forest resources as well, and hence many Mid-Atlantic businesses may be closer to suppliers and customers in other regions than to suppliers and customers within the region itself. It also stems from the uniqueness of some resources (e.g., hardwoods) that have a broad export market both domestically and internationally. Finally, the relatively high level of aggregation in Table 3.2.1 obscures the production of specialty products (e.g., wood furniture and printing) that are typically not self-contained within any one region. The implications are that climate change effects on forests in the Mid-Atlantic region will have an economic ripple effect on other regions and vice versa.

Despite economic linkages to other regions, forest sectors within the Mid-Atlantic Region are also highly interdependent, as is evidenced by the large numbers in the sub-matrix of rows R1 to R9 and columns 1 to 9 in Table 3.2.1. For example, the inputs of Millwork & Plywood, Other Woodproducts, Wood Furniture & Fixtures, and Paper & Paper Products are mainly from Sawmills as indicated by the transaction from Sawmills to those four sectors of $260.4 million, $322.5 million, $137.9 million, and $233.3 million, respectively. Also, Regional Logging Camps & Contractors supplied the majority of inputs to Sawmills and Pulpmills in the region.

3.2.1.3 Current Stresses on the Mid-Atlantic Forests

Forests in the Mid-Atlantic Region are currently stressed by factors that are natural or linked to human activities: loss of forest land to urban/suburban development, insects and diseases (especially gypsy moths), atmospheric pollution and wildfire. Although overall forested area currently is declining only slightly, increased urban/suburban development could contribute to decreased forest land areas in localized areas. Fragmentation of forests into smaller areas due to development, which may limit the ability of plant and animal species to survive and migrate, is a related stress.

draft

Table 3.2.1. Forest-related Sector Flows in the Mid-Atlantic Region Input-Output Table, 1995: Intra-Regional and Import Flows (in millions of 1995 dollars)

	Intermediate Sector Demand									Total F-R Intermed Sales	Personal Consump-tion	Exports	Other Final Demand	Total Gross Output
	1	2	3	4	5	6	7	8	9					
Forest-Related Subtotal Regional Inputs:	6.2	107.8	1.5	77.8	768.0	516.6	607.5	359.5	637.4	3082.3	1972.0	29942.1	1202.9	41826.1
R1. Forest Products	0	0	0	0	0	0	0	0	0	0	1.1	291.2	0	292.2
R2. Forestry Products	0	1.9	0	10.8	8.0	2.3	0	0	0	23.0	6.5	866.7	0.2	906.3
R3. Agricultural, Forestry, Fishing Services	5.6	105.9	1.4	0	0.2	0.2	0.3	0.4	1.8	115.8	31.3	2478.6	96.7	3453.8
R4. Logging Camps & Contractors	0	0	0	65.7	563.1	88.6	64.5	0	317.8	1099.7	0	85.4	15.0	1217.9
R5. Sawmills	0	0	0	1.3	193.3	260.4	322.5	137.9	233.3	1148.7	2.3	1726.6	10.7	3720.0
R6. Millwork & Plywood	0	0	0	0	0	121.6	53.9	47.7	0	223.2	10.6	183.2	34.4	3206.0
R7. Other Woodproducts	0.6	0	0	0	3.4	43.2	147.7	48.6	8.2	251.7	168.1	2384.7	217.7	3846.1
R8. Wood Furniture & Fixtures	0	0	0	0	0	0	18.4	123.7	0	142.1	1709.5	1271	809.5	4212.5
R9. Paper & Paper Products	0	0	0.1	0	0	0.3	0.2	1.2	76.3	78.1	42.6	20654.7	18.7	20971.3
Total Regional Intermediate Inputs	148.2	316.7	211.1	246.0	1465.5	1074.7	1438.6	1397.3	6641.0	12939.1	483426.4	686481.3	430147.2	1131387.7
Total Imported Inputs	81.5	450.6	26.9	556.8	1087.5	743.7	1018.5	1205.0	7107.2	12277.7	177705.2	0	56389.1	502838.8
Forest-Related Subtotal Imports:	15.3	347.9	10.6	464.2	958.3	543.5	635.5	371.0	5024.2	8370.5	4127.3		2170.2	32822.4
M1. Forest Products	0	0	0	0	0	0	0	0	0	0	75.5		3.0	78.6
M2. Forestry Products	0	73.1	1.8	409.6	301.5	85.2	0	0.9	0	872.1	245.7		6.3	1385.8
M3. Agricultural, Forestry, Fishing Services	14.5	274.6	3.7	0.1	0.6	0.5	0.7	1.1	4.6	300.4	81.2		250.7	2512.4
M4. Logging Camps & Contractors	0	0	0	52.8	452.6	71.2	51.8	0	255.4	883.8	0		12.1	905.1
M5. Sawmills	0	0	0	1.3	196.2	264.3	327.3	140.0	236.8	1165.9	2.4		10.9	2115.3
M6. Millwork & Plywood	0	0	0	0	0	43.3	19.2	17.0	0	79.5	3.8		12.2	1083.2
M7. Other Woodproducts	0.8	0	0	0	5	62.4	213.3	70.1	11.9	363.5	242.7		314.3	2092.3
M8. Wood Furniture & Fixtures	0	0	0	0	0	0	10.3	69.1	0	79.4	954.2		451.9	1702.2
M9. Paper & Paper Products	0	0.2	5.1	0.4	2.4	16.6	12.9	72.8	4515.5	4625.9	2521.8		1108.8	20947.5
Total Value Added	62.4	138.9	3130.6	415.5	1167.1	1387.6	1389.0	1610.2	7223.0	16524.3	20904.7	13556.8	2468.4	36929.9
Total Gross Outlay	292.2	906.3	3453.8	1217.9	3720.0	3206.0	3846.1	4212.5	20971.3	41826.1	682036.3	349204.5	489004.7	1671156.4

Each entry in the main body of the table represents a sale from the sector (in the MARA Region) indicated by the corresponding row label to the MARA Region sector indicated by the corresponding column label.

(Computed from IMPLAN, 1997)

Forests in the Mid-Atlantic Region periodically experience problems due to insects and diseases. In particular, gypsy moth larvae have caused extensive and locally heavy defoliation of hardwood (especially oak) forests over the past 1-2 decades in all Mid-Atlantic Region states except North Carolina. Successive years of defoliation have led to tree mortality in localized areas. Fortunately, forests generally survive isolated defoliation events even though trees are undoubtedly weakened.

Atmospheric pollution leading to high levels of deposition of acidic compounds and high ground levels of ozone also are stressing forests in the region. Acidic atmospheric deposition of nitrate and sulfate can accelerate leaching losses of base cations from forest soils. Base cations such as calcium and magnesium are needed to maintain forest health and growth.

Wildfires are not a serious problem currently within the Mid-Atlantic Region. However, occasionally in dry years wildfires damage large acreages of forest land, especially in the south of the region.

3.2.2 Effects of Current Climate Variability

Because little specific information was available on how climate currently affects forestry activities in the Mid-Atlantic Region, we developed a questionnaire to investigate how extreme weather affects day-to-day forestry operations. The questionnaire was targeted to government agencies (federal and state), private firms (consulting foresters, loggers, and industrial foresters), and urban and municipal foresters within the Mid-Atlantic region. The questions were designed to obtain responses about effects of extreme weather on specific aspects of forestry operations, coping mechanisms currently being employed or contemplated, and effects on costs of operation and income. Respondents were identified via a random sample. A total of 592 surveys were mailed in late November 1998 followed by a second mailing to non-respondents in January 1999. A total of 322 surveys were returned, yielding an overall response rate of 57% after correction for erroneous addresses.

Respondents primarily represented private forestry firms (159 consulting foresters, logging companies, and industrial foresters) and public forestry agencies (114 state and federal agencies/offices). Of the total respondents, 66 percent operated in the upland hardwood forest type, while 22 percent operated only within the pine types. Watershed protection (60%), harvesting sawtimber (59%) and maintenance of forest aesthetics (38%) were the three management objectives most commonly cited by respondents.

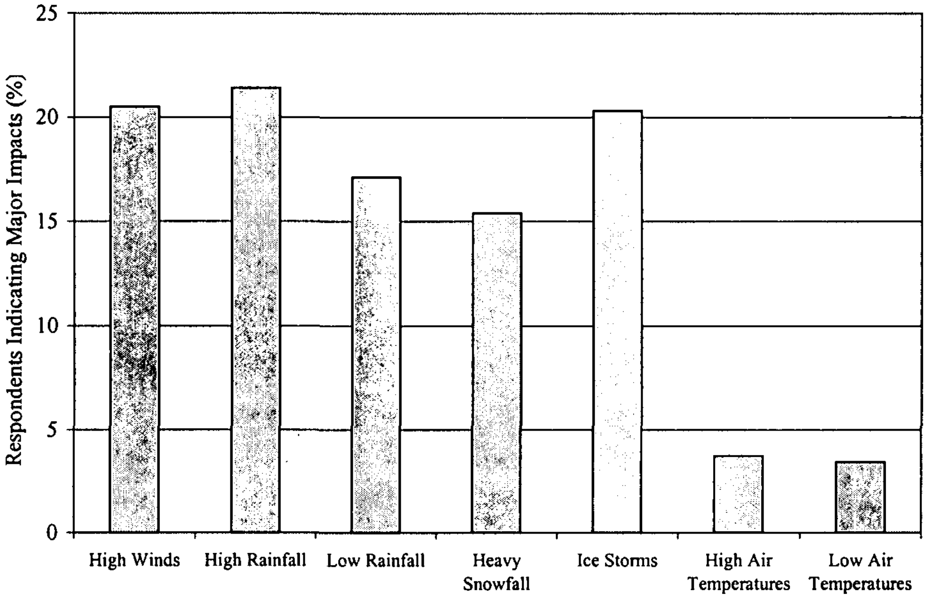


Figure 3.2.3. Effects of Extreme Weather Events on Forestry Activities in the Mid-Atlantic Region. Percentage of 322 Respondents Indicating Major Impacts Due to Each Type of Extreme Weather Event.

Several types of extreme weather events currently have major impacts on forestry activities in the Mid-Atlantic Region (Figure 3.2.3). Over 15% of respondents report major impacts (5 point scale from 1=no impact to 5=major impact)from high winds, high rainfall, low rainfall, heavy snowfall and ice storms on their forestry operations. Fewer than 5% of respondents perceived major problems from extremely high or low air temperatures. Extreme rainfall, snow and ice events cause problems by reducing access to forest lands and increasing the cost of road maintenance. Dry periods had the opposite effect, improving access to normally wet areas. Respondents associated wind and ice events with direct damage to trees. As a result of these extreme weather events, respondents indicated that they had to modify their management activities and their costs of operation generally increased. It is anticipated that the magnitude of cost increases will be depend on the management objectives and type of forestry operation (private firms should be affected more directly than government agencies) and the specific geographic location of the respondent. Further analysis will explore these and other hypotheses.

3.2.3 Future Effects of Climate Change

Currently, Mid-Atlantic forests exist under a climatic regime that is relatively hospitable to tree growth and survival. Trees grow in parts of the United States that are significantly hotter or colder, wetter or drier than the Mid-Atlantic region. However, individual tree species could have specific temperature and moisture requirements that will make them vulnerable to climatic change. Or some other factor critical to a species survival (e.g. a particular soil type) may no longer occur where climate is acceptable. In addition, species may be unable to migrate to keep pace with a changing climate. Secondary impacts of climate change, such as changes in pests, fire frequency, and climate-sensitive soil processes, will also be important.

The IPCC 2nd Assessment report (1996) concluded that, although changes in the potential area of temperate forests (which includes the Mid-Atlantic) are projected to be less than for other latitudinal zones, they are likely to undergo significant changes in species composition. Forests will be directly impacted by changes in temperature, solar radiation, soil moisture, and concentrations of atmospheric CO_2. Possible indirect impacts include changes in climate-sensitive soil processes (such as erosion and nutrient leaching) and changes in weeds, insects and disease that are themselves affected by changes in climate and atmospheric constituents. Impacts may be positive or negative, and will likely vary among species. Higher temperatures could increase forest primary production if more moisture is available.

Iverson and Prasad (1998) examined potential changes in the distribution and abundance of 80 tree species in response to climate change in the eastern US using a statistical approach. Predictive models were developed for each of 80 tree species, using regression tree analysis (RTA) combined with data in a geographic information system (GIS) format to relate current species' distributions to environmental factors, including climate. Models were applied to climate change data predicted using two global climate models GCMs (GISS and GFDL) to predict potential changes in tree species' distributions in response to climate changes associated with a doubling of atmospheric CO_2.

As part of the Mid-Atlantic Regional Assessment, Iverson and Prasad extracted results for the Mid-Atlantic region from those of their previous analysis and added prediction results for three additional GCMs--the United Kingdom Meteorological Office (UKMO), Hadley Centre (HAD), and Canadian Climate Centre (CCC) models. As before, the climate scenarios were based on a doubling of CO_2. For comparison with the transient GCM scenarios used in other portions of the Mid-Atlantic study, if greenhouse gases increase at a rate of 1 percent per year (as assumed in developing the transient climate scenarios), a doubling will occur in 71 years, or by year 2064. Of course, because of tree longevity and remnant refugia, it could take centuries for these shifts to be fully realized.

Under all five GCM scenarios, maple-beech-birch forest is no longer a dominant type in the Mid-Atlantic region (Table 3.2.2). Predictions suggest that maple-beech-birch forest would be replaced by oak-hickory forest across the northern regions. Southern pine and mixed oak-pine forest also moves northwest to some degree under each of the scenarios. Results for the UKMO scenario are the most extreme, showing mixed oak-pine forest becoming important as far north as western PA and southern NY. Results under the Hadley scenario show the least areas of pine and mixed pine forest. Overall the predicted diversity of forest types is reduced under all of the climate change scenarios.

Table 3.2.2. Current and Predicted Potential Areas (%) of Selected Forest Types in the Mid-Atlantic Region (Predicted by Iverson and Prasad)

Forest Type	Current Area (%)	Future Areas (%) Predicted with Several Global Climate Models				
		GISS	GFDL	UKMO	HAD	CCC
Maple-beech-birch	37	2	0	0	0	0
Oak-hickory	46	66	68	46	82	72
Oak-pine	4	6	28	50	16	23
Loblolly-shortleaf pine	4	18	4	2	1	6

The above analysis represents one equilibrium approach to modeling the potential effects of climate change on forests due to a doubling of CO_2. However, it does not provide estimates of changes in forest productivity or carbon storage, nor does it incorporate direct effects of elevated CO_2 on plant growth and water use. Model outputs also assume that species would be able to migrate unencumbered into the new habitat. Results must also be extended to the response of individual species, rather than just forest types. Loss of a forest type does not necessarily mean that all species within a type will be lost.

Forest succession models, also known as gap models, have also been applied to simulate the temporal dynamics of changing forest species composition and carbon storage due to climate change, but extensive data requirements prevent application for the Mid-Atlantic region at this time. Earlier VEMAP research (VEMAP members, 1995) compared potential large scale vegetation shifts due to a doubling of CO_2 to show that cool-temperate forests, such as maple-beech-birch in Iverson and Prasad's results, could be displaced by warm temperate forests. VEMAP results thus support findings in the Mid-Atlantic regional studies.

3.2.4 Management/Adaptation Options

To help manage problems caused by gradual tree species shifts to more pine and oak-hickory forests, long-term management and silvicultural plans should encourage species best suited to oak-hickory and oak-pine types and cutting schemes likely to minimize wind and ice damage problems that may occur along with climate change. Increased wildfire and insect/disease problems will also likely occur, which would increase overall forest land management costs.

Land use planning could minimize forest fragmentation. This would make it more likely that tree species and their accompanying wildlife could migrate as climate conditions change.

Possible mitigation to counter potential impacts of climate change that can be adapted to the Mid-Atlantic Region could be sequestering more CO_2 by encouraging more tree planting on urban and marginal agricultural lands or reducing CO_2 emissions by recycling more paper and burning biomass rather than fossil fuels (EPA 1995).

3.2.5 Priorities for Research and Information

To understand the impact of climate change on forestry in the Mid-Atlantic region we need further information and analysis. To complete a comprehensive analysis, we need to compile all county forest inventory data at the county level rather than relying on state-level data such as that included in this report. A more complete statistical analysis of our questionnaire data is also needed to help predict differences in the effects of severe weather on forests managed by private or public agencies and on geographically disparate forests. Finally, the predicted response of individual forest tree species to climate change must be included.

Answers to some of the above research questions also can shed light on how climate change might affect diverse functions provided by forests in the Mid-Atlantic region. For example, little currently is known about how changes in the dominant tree species will affect a forest's capacity to filter water, or the timing of water flows through the forest to groundwater or streams. Similarly, changes in dominant tree species will affect other components of the forest ecosystem in an area. Research on how the forest ecosystem might change could be an input into additional study of how important those changes are.

There is a significant need for analyzing economic and policy responses using integrated ecological and economic modeling approaches. This type of modeling can be used to gain insight into economic consequences of changes in species mix and primary productivity. It can also be used to analyze and evaluate adaptation policy options, and the interaction between biological and economic adaptation. Finally, because of the central role of forests as a source of non-market goods, research on non-market impacts of climate induced change in the regions' forests is crucial.

3.3 Water Resources (Yarnal)

Overall, the Mid-Atlantic Region has abundant fresh water resources. The average annual rainfall total of approximately 43 inches is distributed somewhat evenly throughout the year, suggesting that there are ample quantities of water available in all seasons for public, domestic, commercial, industrial, and other uses.

Fresh-water is withdrawn from both surface and ground water (Solley et al., 1998). In 1995, approximately 92% of all Mid-Atlantic Region withdrawals were from surface water (i.e., lakes, reservoirs, and streams) and 8% were from ground water (i.e., wells). Delaware and Maryland used proportionally more ground water than other Mid-Atlantic states (15% and 17% of their withdrawals, respectively). In contrast, West Virginia and the District of Columbia used much less ground water than other political units in the region (3% and 5% of their respective total withdrawals), relying more heavily on surface water.

As the MAR state with the largest population, Pennsylvania used more fresh water in 1995 than any other state in the Mid-Atlantic Region – 44% of total regional withdrawals. However, Pennsylvania's per capita use was moderate. Virginia (25%), West Virginia (21%), Maryland (7%), and Delaware (3%) followed Pennsylvania in order. To achieve its large withdrawals with its relatively small population, West Virginia had per capita water use that was 2.5 to nearly 9 times that of the other states in the region–primarily because of industry and thermoelectric cooling.

Three categories dominated 1995 fresh-water use in the Mid-Atlantic Region: thermoelectric power generation (62%), industry (17%), and public supply (16%). Domestic supplies only used 2% of the region's fresh water supply. A large proportion of the domestic water supply in the region comes from privately owned wells. For instance, in the Susquehanna River Basin, over one third of all households derive their water from such wells. Irrigation accounts for less than 1% of total fresh-water use.

Despite the fact that water is generally available in the Mid-Atlantic Region, certain stresses affect the quantity and quality of water available to the population. One set of stressors relates to the people of the region, their activities, and the environmental impacts of these activities. Another important stressor is climate variability. The following subsections discuss these.

3.3.1 Human Activity and Environmental Impacts on Water Resources

Before European settlement the native peoples of the Mid-Atlantic Region had little impact on water resources (e.g., Cooper and Brush, 1993). Early European settlers also had minimal influence, but by the late 18th century rapid population growth and associated land clearing, agriculture, and construction produced severe sedimentation of the water bodies of the region. Although land clearing, agriculture, and therefore sedimentation declined rapidly after the Civil War, industrialization and continued population growth resulted in other forms of water pollution. Many of the most severe problems have been cleaned up in the last few decades, although effects linger from acid mine drainage. Nevertheless, since World War II, extensive development around and between urban centers, increased use of fertilizers, and increased atmospheric nitrogen deposition further degraded the waters of the region.

Human activities have affected the nutrient loading of the region's water resources in many ways (Walker et al., 1999a). For example, increased nutrient loading is associated with increased occurrence of hypoxic and anoxic conditions, excessive algal growth, blooms of undesirable algae, and changes in submerged aquatic vegetation. On the one hand, estimated phosphorus loading from the land, through the rivers, and into the estuaries and bays increased slowly between 1900 and 1945, then began a sharp increase that lasted until 1971. The majority of this increase was due to wastewater inputs. Since 1971, a ban on phosphorus in detergents and improvements in wastewater treatment have led to a substantial decline in phosphorus inputs from wastewater. On the other hand, agricultural inputs of nitrogen to the Mid-Atlantic Region's estuaries and bays have risen steadily since World War II. Estimated nitrogen inputs attributable to atmospheric deposition rose steadily until 1970 but have fallen somewhat since then. Direct wastewater contributions of nitrogen have risen systematically throughout the century. The net effect has been a dramatic increase in the nitrogen flowing from the land.

3.3.2 Impact of Climate Variability on Water Resources

Climate variation has a large impact on the water resources of the Mid-Atlantic Region. Figure 3.3.1 shows the close relationship between precipitation and stream flow from the Potomac River Basin (adjusted R^2 of 41% for the *unsmoothed* values) for a recent 13-year period. Note that stream flow values naturally lag precipitation, as water moves over the land or through the soil to streams. The monthly average curves in the figure show the close association between high stream flow and basin-wide weather and climate events, such as the March 1993 "superstorm," the spring melt after the record snow year of 1993-94, the January 1996 flood (Yarnal et al., 1997), and the 1996 record wet year (Yarnal et al., 1999a). In contrast, drought periods, such as the 1991 and 1995 droughts are readily apparent only in the smoothed curves.

Climate variation affects the quality of the region's waters as well as the quantity of water available. For example, Walker et al. (1999b) and Yarnal et al. (1999b) have demonstrated a chain of associations linking the global-scale atmospheric circulation, Mid-Atlantic Region climate, regional stream flow, nutrient flows to the region's estuaries and bays, and oxygen conditions in these water bodies. Cronin and collaborators (personal communication) have found similar associations between the global-scale El Niño-Southern Oscillation, regional climate, stream flow, and sedimentation in the Chesapeake Bay. This is in part due to the role of dilution as a solution to pollution. Low stream flow years typically continue to receive approximately the same waste load discharges from industry and municipal sources. Drought periods then lead directly to water quality impacts. Climate variation also can affect water quality if severe storms cause higher rates of nutrient, pesticide, and sediment runoff into streams than moderate storms. Such impacts could occur even without a change in total expected precipitation. These linkages have clear implications for potential water quality impacts from climate change.

3.3.3 Potential Impact of Climate Change on Water Resources

Climate change projections from the transient Canadian Climate Centre and Hadley Centre GCMs show the Mid-Atlantic region receiving much more precipitation (getting much wetter) in all seasons, with greater increase in the warmer portion of the year. Empirical downscaling by Crane and Hewitson (1998) using the GENESIS GCM in a $2XCO_2$ experiment agrees with these findings. Suggesting that climate change may already be underway, Karl et al., (1996) observed that the region has had a strong increase in precipitation over the past century, including a significant upward trend in the number of intense precipitation events. Models and empirical work show little support for overall drying in the region from climate change.

Because of the close association between water resources and climate variation demonstrated above, it seems likely that water resources management in the future generally will need to address issues associated with increased moisture, rather than decreased moisture. For example, Walker et al. (1999b) suggest that if stream flow rises in the future, then more nitrogen will go to the region's estuaries and bays and general ecological health of these water bodies will decrease. To meet goals of reducing nitrogen inflows and increasing ecological health, it will be necessary to strengthen controls on sources of nitrogen, such as fertilizer use and atmospheric deposition.

Care must be taken, however, not to assume that dry periods will not occur – recent experience suggests that severe drought can be embedded in overall moist regimes. Indeed, future dry periods expected with normal climate variation could be intensified by the higher temperatures projected for the region. Thus, we expect overall wetter conditions punctuated by sharp drought in the future.

Research is underway to project future hydrologic regimes associated with regional climate change projections. Based on the relationships established between regional stream flow and precipitation (e.g., Figure 3.3.1), it is possible to model future stream flow by using the GCM precipitation projections and observed stream flow (Figure 3.3.2). Similar techniques can be used to project future regional ground water trends (Figure 3.3.3).

Each of these relationships must carefully consider use patterns, trends, and projections in order to accurately assess potential scarcity. For example, groundwater levels are affected by groundwater withdrawals. Therefore, projected future groundwater withdrawal will strongly affect future groundwater availability. Use projections should be considered in conjunction with hydrologic supply projections for this purpose. The seasonal timing of use and availability is particularly important.

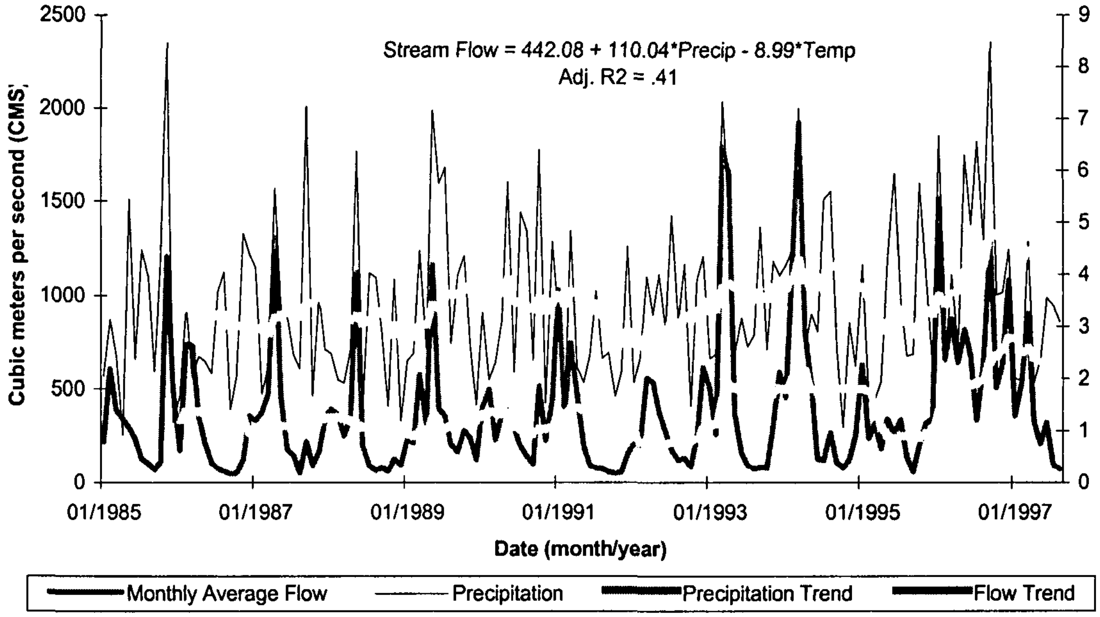
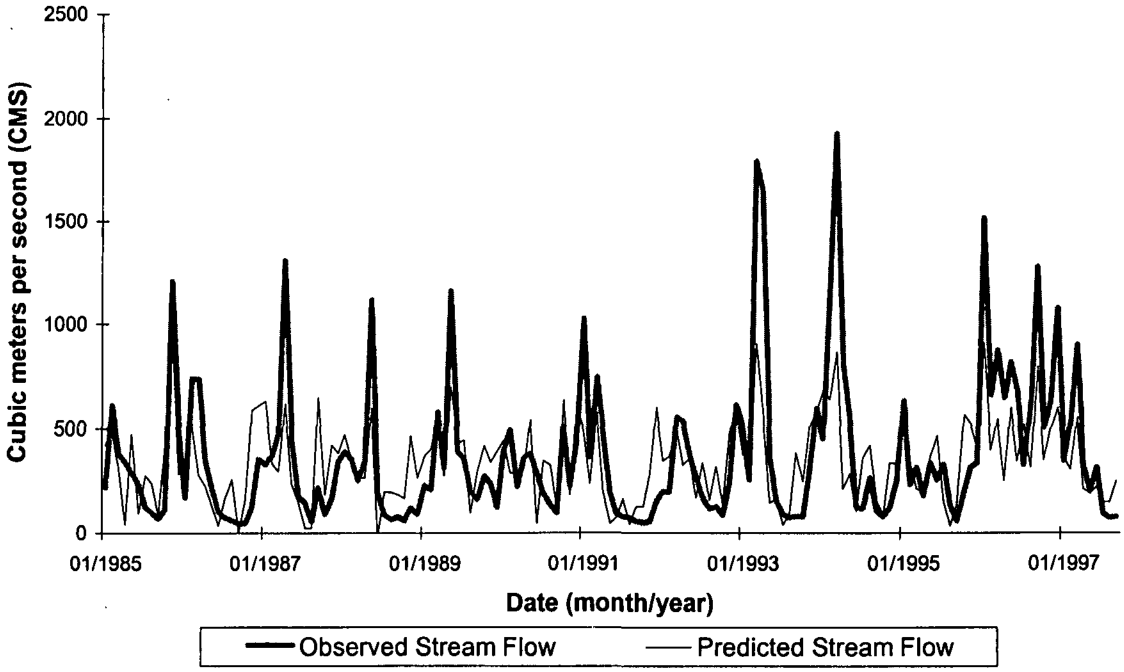
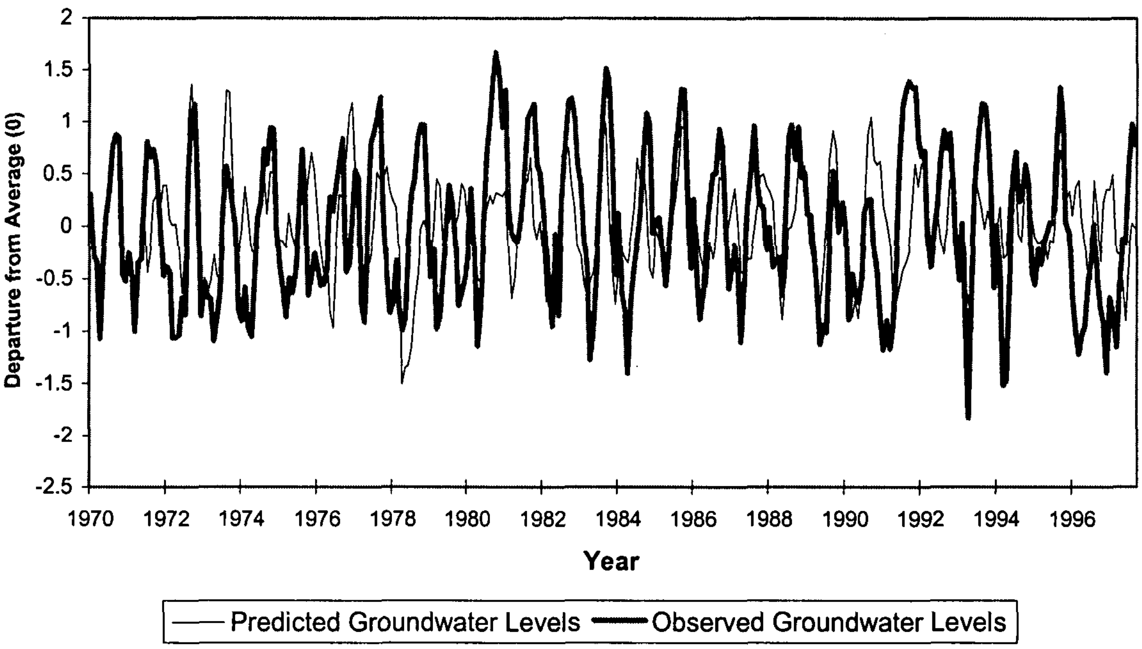


Figure 3.3.1. Monthly stream flow and precipitation for the Potomac River Basin, 1985-97.



3.3.2. Observed vs. predicted stream flow, Potomac River Basin, 1985-1997.



3.3.3. Observed vs. predicted ground water levels for central Pennsylvania.

3.3.4 Management and Adaptation Options

As noted above, water resource management and adaptation strategies should focus on problems resulting from increased moisture, including more severe precipitation events (and associated phenomena, such as wind and lightning) and perhaps more frequent floods. Although emergency management efforts for water resources at the state and inter-state levels have tended to focus on drought contingency plans, greater emphasis should be given to designing storm and flood contingency plans. Commerce, industry, agriculture, and public utilities especially should develop management schemes and adaptation options to deal with wetter conditions, including higher ground water tables, stream levels, and reservoir levels. Stricter enforcement of the Clean Drinking Water Act and increased support of small systems and of private well owners will ensure safer drinking water supplies. It must be remembered that although conditions will be wetter in general, sharp droughts should be expected and must be part of any water management plan.

3.3.5 Priorities for Research and Information

Research must focus on how wetter conditions and severe storms affect water resource management in the Mid-Atlantic Region. Impacts and response strategies for water delivery and water quality must be studied for all primary through tertiary sectors. Because winter 1993-94 was a record snow year throughout most of the region, and because 1996 was by far the wettest year on record in much of the region, there are good opportunities to use these years as analogs for future wet conditions in the Mid-Atlantic.

Case Study

Water Managers Report Systems Are Vulnerable to Weather Variability (O'Connor)

In 1998, 504 managers of water systems in Pennsylvania responded to a mail survey. The table shows that most managers reported that their systems suffer difficulties from weather events in a typical year. Power outages from storms, affecting the ability to pump water, are the most frequent weather-related problems.

The 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?"

The 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 areas	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

Managers who are having problems now expect that they will continue to suffer disruptions in their daily operations in the next 5 years.

Perhaps surprisingly, larger systems report even more weather-related problems than do smaller systems. Larger systems are often able to draw on more than one source of water, yet this very complexity may increase their vulnerability to extreme weather events. In any event, these data call into question assumptions that the current trend of water system consolidation 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 about climate change because it is unlikely to happen. A much larger percentage (21 percent) checked that "global warming is real" and that they are concerned. Still, the highest percentage (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 it is so long-term that adaptations are beyond their planning horizon. Seventy-eight percent of managers indicate their planing horizon is 5 or fewer years.

In summary, most managers of water systems in Pennsylvania today face disruptions from weather events and expect these problems to continue. They report that 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 and, in any event, few plan beyond 5 years. This ambivalence may well change in the direction of concern for adaptation if managers of water systems learn that climate change impacts include more frequent and intense weather events.

Case Study

Recreational Fishing and Climate Change in MAR
(Heberling and Thornton)

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 species 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 of trout is limited to 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. Increasing 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 Mid-Atlantic region 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.

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 for agriculture and poorly managed forestry, continues to have a present day influence on stream invertebrates and fish. Instream sedimentation and loss of gravel spawning areas are difficult to restore, even if the terrestrial watershed is restored to forested land cover.

Thus the prospects for recreational fishing 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. 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). On average they were willing to pay around $4.00 per angler per year to avoid the changes.

Case Study Box PLACEHOLDER

Skiing (Dane)

3.4 Coastal zones (Najjar)

3.4.1 Current status and stresses of the Mid-Atlantic Coastal zone

Three important characteristics are pertinent to understanding the Mid-Atlantic Coastal Zone (MACZ) response to global climate change. First, Mid-Atlantic coastal waters are highly productive, largely due to the region's numerous estuaries, including Chesapeake Bay, the largest and most productive estuary in the United States. Second, the Mid-Atlantic region's coastal counties are densely populated, containing 38% of the Mid-Atlantic population in only 19% of its area. Third, the MACZ already is stressed by sea level rise; this process is likely to accelerate as a result of climate change. Even without climate change, these three characteristics will be important to the future of the MACZ.

3.4.1.1 Land Forms

Sea level has been rising throughout the past 20,000 years, molding the current Mid-Atlantic coastline, which has three primary forms: drowned major river valleys, barrier islands and coastal headlands. Drowned major river valleys, such as Chesapeake and Delaware Bays, accumulate sediment that helps mitigate the impact of sea level rise. Barrier islands are sand accumulations that separate a body of water, such as Pamlico Sound, from the open ocean. Barrier islands have sand beaches, dunes, washover features, and inlets. Estuaries near barrier islands, such as Barnegat Bay, tend to be elongated in a direction parallel to shore. Coastal headlands, such as much of Monmouth county and the northern portion of Ocean County in New Jersey, much of the Delaware ocean shoreline, and Virginia Beach, have cliffs of various heights with a narrow fringing beach and sometimes minor dune forms draped over the bedrock.

Slow sea level rise over the past 2500 years allowed barrier islands to form from sands created by erosion during the previous period of rapid sea level rise. However, the present rates for most of the MACZ are more than twice the rate of sea-level rise in these same locations in the several millennia prior to 2500 years before now, on the order of 0.12 inch (3-4 mm) per year. This present rate is much faster than the delivery of sediment to the barrier islands and estuaries, causing a loss of barrier island mass, with a concomitant loss of wetland area. The larger estuaries have a similar scenario but for different reasons. Clearing land for agriculture peaked in the 19th century, and caused extensive erosion of upland soils. This material was transported to estuaries and near-shore areas, contributing to the maintenance and development of marshes while the rate of sea level rise was increasing. Since 1930, the sediment yields of major mid-Atlantic rivers have decreased due to land abandonment, dam construction and efforts to curb soil erosion. As a result, coastal areas along drowned major river valleys are, like barrier islands, becoming inundated as a result of sea level rise. For example, records of the Cape Henlopen lighthouse in Lewes, Delaware, show that over its 163 year life span, the land it sat on eroded an average of 9 feet per year, finally causing the lighthouse to fall into the sea (Kraft, 1992).

SAY SOMETHING ABOUT HEADLANDS? NOTHING TO WORRY ABOUT?

3.4.1.2 Water quality

Overall, Mid-Atlantic estuaries are high in chlorophyll, nutrients and turbidity and low in SAV. Hypoxic or anoxic conditions exist in at least one salinity zone in half of the 18 estuaries evaluated in the Estuarine Eutrophication Survey of the National Oceanographic and Atmospheric Administration (NOAA, 1997a; NOAA, 1997b). Significant nuisance algae are reported for half of the estuaries, but toxic algal blooms have had resource impacts in only four bays, three of which are in North Carolina. Some water quality parameters show definite trends over the past 25 years. Chlorophyll concentrations are increasing, probably as a result of overenrichment, in Chesapeake Bay and in several of its tributaries. Anoxia is increasing in the Bay and its Choptank River tributary.

3.4.1.3 Coastal ecosystems

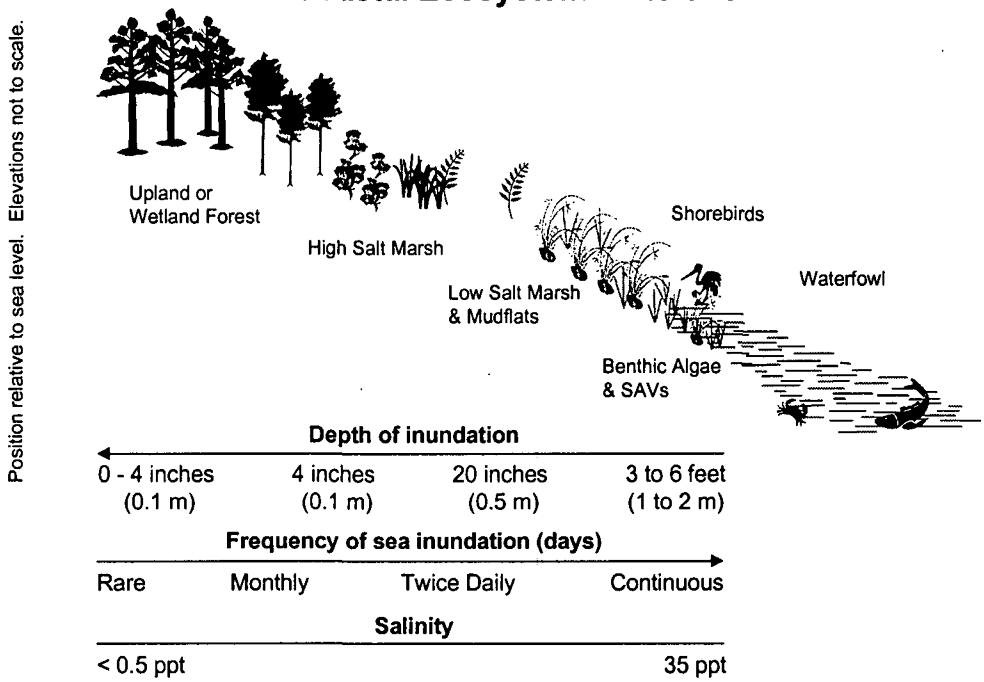
Wetlands (MAY NEED TO SHORTEN)

Wetlands have many biological, physical, hydrological and chemical functions as well as recreational, economical and aesthetic values. For example, wetlands provide coastal protection by buffering storms. About half of normal wave energy is dissipated within the first 10 feet of encountering marsh vegetation such as cordgrass, and completely absorbed within 30 feet (Kesselheim, 1995). Wetlands also help to slow down erosion and buffer against flooding. The roots of wetland plants hold soils in place against tides, waves and wind. In turn, the soils act as giant sponges to soak up additional water from heavy rains and increased river flow. Runoff is slowed by wetlands so that extra nutrients, sediments, and pollutants are trapped before they enter coastal waters.

Because of their high primary productivity, wetlands in the Mid-Atlantic 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 the wetlands of the coast to survive and reproduce.

The dominant wetland ecosystems in the coastal zone (floodplain forest, tidal freshwater marsh, and salt marsh) sort out on the landscape according to gradients in flooding frequency, tidal amplitude and salinity. Floodplain forests occur adjacent to coastal plain rivers in the Mid-Atlantic region. The forests are dominated by deciduous trees that tolerate short to moderate periods of flooding. Southern Virginia and North Carolina have more extensively flooded forests dominated by bald cypress and water tupelo.

Coastal Ecosystem Divisions



Adapted from
Brinson, M.M., R.R. Christian, and L.K. Blum. 1995. *Multiple states in the sea-level induced transition from terrestrial forest to estuary.* Estuaries 18:648-659.

The upper reaches of river-estuarine systems in the Mid-Atlantic region are both tidal and freshwater. Such tidal-freshwater systems are dominated by marshes but may support swamp forests too. They are habitat for diverse plant communities – including many that are rare or endangered – and they are sources of the Chesapeake Bay's shad fisheries.

Salt marsh ecosystems (salinity >0.5 ppt) support little biodiversity compared with tidal freshwater marshes, but there are several distinct community types that are characteristic of particular salinity ranges. Because the salinity gradient in an estuary determines where fresh- and saltwater marshes occur, these ecological communities are sensitive to changes in both sea level and freshwater flow in rivers. Fresh- and saltwater marshes depend on the vertical and horizontal accretion (build up) of the soil surface in order to maintain themselves within the tidal range as sea level rises. The elevation of a sediment surface is a dynamic balance between mineral and organic matter deposition, and subsequent loss through subsidence (land level sinking) or erosion. For wetlands to persist, surface accretion must balance both subsidence and sea level rise over a period of decades. Furthermore, marshes must be able to migrate inland to balance losses to shoreline erosion.

Sediment deposition includes organic and inorganic material settling from flood waters, surface litter, and organic material injected through root growth. Organic matter can account for 50 to 90% of salt marsh sediment volume (Bricker-Urso et al. 1989). However, marshes with low rates of mineral deposition may be particularly sensitive to sea level rise because organic matter is more compressible than mineral matter and it can be lost through decomposition. Such sites (e.g. microtidal marshes) typically lack significant sources of riverine sediment.

Shorebirds (Richards)

Migrating shorebirds depend on the ecosystems of Mid-Atlantic for their survival. The Delaware Bay, for example, is home to the second largest concentration of migratory shorebirds in the Western Hemisphere (WHAT IS THE LARGEST?), with numbers approaching 1.5 million birds stopping at the Bay to feed each spring (EPA, 1997). The predominant species of shorebirds are the red knot, dunlin, sanderling, semipalmated sandpiper, and ruddy turnstone. With up to 70 percent of the entire North American population of the red knot in the Delaware Bay at one time (Sutton, 1996), these birds are extremely vulnerable to any environmental changes to the ecosystem.

SECTION HERE ON OTHER PARTS OF COASTAL ECOSYSTEMS (by VIC)

3.4.1.4 Coastal development and use

The coastal areas of the Mid-Atlantic Region have important aesthetic and economic value. The shore is a focal tourist destination, inviting investment in facilities to serve their needs and desires. For many coastal areas, visitors and temporary residents exceed the permanent resident population by an order of magnitude or more. The annual flux of visitor populations to the coast is concentrated during the peak summer holiday but extends to late Spring and early Fall, as well as weekends, holidays, and even winter when one would expect few visitors. Even without climate change and sea level rise, coastal communities and the natural resources that prove so attractive have been vulnerable to the inexorable forces of nature–storms, coastal erosion, beach dynamics – all anathema to the permanency of investment in such areas.

The intensive development of the MACZ is demonstrated by NOAA's data on building permits for 1970-1989. Some X permits were issued for residential developments and Y for non-residential purposes. While the most development occurred in the metropolitan areas of Chesapeake Bay (Baltimore-Washington), the New Jersey shore, and Virginia Beach, substantial growth also occurred on the Delmarva Peninsula and Outer Banks. The Mid-Atlantic paralleled the nation as a whole in having a majority of the region's single family construction and a significant proportion of new multiple family dwellings occurring in coastal counties.

Location on the shore (versus near the shore) has an important contribution to coastal property values. For Delaware, Parsons and Powell (1998) estimate that $90,000 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. Thus proximity (and vulnerability) have highest market value.
CAN WE FIND SIMILAR DATA FOR ESTUARY LOCATIONS?

Beach communities in Delaware have housing units valued in aggregate at $3.5 billion; 5.1 million annual person-visits to the beaches generate $380 million plus $573 million in trip-related expenditures (Faucett 1998). Beach nourishment to counteract Delaware's annual 2-4 foot erosion rate costs about $1.8 million per year. In Maryland, some 277 miles of shoreland armoring (plus 52.6 miles of replacements) were permitted in the period from 1978-1994 (Titus 1998: 1399). CAN JIM TITUS SEPARATE THIS INTO BAY VERSUS OCEAN? Many homes and businesses are clearly within the limits of designated floodplains (Figure here: FEMA MAPS). The high values of structures built in vulnerable coastal locations are a concern to insurers and to the Federal Emergency Management Agency (FEMA), which subsidizes insurance in these locations.

Public ownership of shoreland differs among the Mid-Atlantic states (Titus, 1998). New Jersey provides for public ownership along the wet beach (i.e., below mean high tide), with access along the dry beach (although communities effectively block such access by parking restrictions for non-residents or those who are not local paying guests). Maryland's public ownership also extends to the wet beach. In Pennsylvania, Delaware and Virginia, the public owns only to the low water mark, but with tideland access for navigation, hunting and fishing. These distinctions affect whether the policies in place can maintain existing shoreline contours and uphold public access to the shore. (TITUS EXPAND?)

Land use and tourist dynamics differ between the estuary shores and the oceanfront of Mid-Atlantic states. Even at the oceanfront, important land use and property gradients apply between oceanfront, inland, canal, and bay locations. The US Geological Survey identifies 14 land use and land cover types in the coastal zone. Of these uses, eight have moderate to high vulnerability to human-induced and natural processes of change. Many of these land uses are subject to natural physical processes that will be exacerbated by sea level rise.

The shores of the Mid-Atlantic region may not be among the nation's most spectacular in terms of scenic beauty, but their proximity to large urban populations gives them special significance. Many of these areas are already under stress from population pressure in sensitive ecological zones. The existing dynamics of the coastal environment already threaten some coastal areas, requiring substantial public investment to maintain a quasi-status quo on the coast.

3.4.2 Climate sensitivity of the Mid-Atlantic Coastal zone

3.4.2.1 Water quality

Coastal water quality is generally correlated with water flow, which in turn depends on precipitation and temperature. Most Mid-Atlantic estuaries have their lowest salinity concentrations at the end of the spring, when high flows have diluted coastal waters. Interannual variations in flow also affect salinity. Gibson and Najjar (1999), for example, show that a 10% increase in the annual flow of the Susquehanna River results in an annual average salinity decrease of 8% at the mouth of the Susquehanna River; the decrease is still 2% at the mouth of Chesapeake Bay. Other water quality variables in Chesapeake Bay, such as nutrients, oxygen and water clarity, all have statistically significant relationships with flow. Flow is positively correlated with chlorophyll and nitrogen concentrations and negatively correlated with phosphorus concentrations and water clarity (as indicated by Secchi depth measurements). These correlations result from the input of nutrient rich water from rivers, which supports plankton blooms. Seliger and Boggs (1988) demonstrated a highly significant correlation between summertime anoxic volume in Chesapeake Bay and the spring flow of the Susquehanna River, arguing that the density stratification induced by lower flow inhibits vertical mixing and the aeration of bottom waters. The types of relationships with flow found in Chesapeake Bay also show up in the Patuxent River (Jody has ref) and Delaware Bay (Sharp et al., 1986).

3.4.3.2 Ecosystems

Temperature and salinity have important effects on ecosystems in the MACZ. (NEEDS TO BE MORE GENERAL. VIC WILL FILL THIS OUT. HERE ARE SOME SPECIFICS.) During the mid-1980s, low riverine flows resulting from low precipitation over the watersheds of Mid-Atlantic states caused estuarine salinities to be higher than normal. Oyster diseases responded positively to these saltier waters and decimated the oyster population in much of the region. On the other hand, oysters cannot tolerate very low salinity. Massive oyster mortality occurred in 1972 when Hurricane Agnes caused extremely high flows into Chesapeake Bay and a corresponding drop in salinity. Rivers also affect the nutrient content, sediment input and circulation of estuaries. All of these play pivotal roles in production of phytoplankton, which lie at the base of food chain in the Mid-Atlantic estuaries.

Temperature variations also influence the MACZ. For example, severe winters in 1977 and 1981 resulted in high mortality of blue crabs in the Delaware estuary, leading to very low catches of this commercially important shellfish. Extremely high temperatures, on the other hand, can cause oxygen concentrations to drop perilously low. Warm events in the late 1980s are thought to be partly responsible for the large menhaden kills in the upper Chesapeake Bay. Recent outbreaks of the fish-killing dinoflagellate, Pfiesteria piscicida, have been partly attributed to nutrient overenrichment and abnormally warm and salty environmental conditions.

3.4.3 Predicted response to climate change

3.4.3.1 Sea level rise

Direct Impacts

The obvious modification of the shoreline with sea-level rise is an inland displacement that is proportional to the amount of rise and the slope across which the water is rising. The displacement is not a linear shift of the shoreline, but depends on the mass of sediment required to establish a new equilibrium beach profile and the source of that sediment (i.e., how much sand will be needed and where will it come from to build the profile). Thus, shorelines with meager sand resources will have greater displacements for any unit of sea-level rise than those with fully developed beaches and dunes. For barrier islands, the situation is compounded because the shoreline is affected on both sides of the island.

Among coastal ecosystems, salt marshes are most vulnerable to sea level rise because of natural, historical and human factors that affect their ability to respond. A key historical factor is reduced sediment yields in major mid-Atlantic rivers, implying less amelioration of natural subsidence. A key human factor is coastal development that can block inland migration of marshes. Wetlands that lack significant inputs of riverine sediments include microtidal marshes of the Chesapeake Bay and wetlands of the Albemarle-Pamlico Peninsula of North Carolina. Such sites are relatively dependent on organic matter storage for accretion of sediment and many have converted to open water in recent decades (Kearney and Stevenson 1991). The Albemarle-Pamlico Peninsula is particularly sensitive due to large areas with less than 6 feet of elevation, very gentle slopes, and the absence of tides (which transport sediments). Thus, coastal wetlands in the southern mid-Atlantic region tend to be unusually dependent on peat formation for vertical accretion. Changes in the net primary production or decomposition will influence their vulnerability to sea level rise.

Changes in storm surge due to sea level rise

Storm surge levels vary as a function of the storm's strength. However, the change in relative sea level through time also affects the level to which any storm can raise the water elevation and penetrate inland. Sea level is rising. Therefore, the base upon which storms have occurred is changing. Recent storms are now capable of reaching historical flood levels with lower surges. In addition, a rise in sea level allows stronger, less frequent events to reach coastal areas that were once safe from storm activity, exposing more areas to the storm erosion and flooding effects.

[SOME OF THESE HAVE BEEN CONVERTED TO "ENGLISH" UNITS; OTHERS ARE METRIC—PLEASE MAKE SURE THE NUMBERS ARE CORRECT, AND THAT INCLUDE THE MORE FAMILIAR ENGLISH UNITS.]. Using the past century's sea level rise rate of 0.0126 ft./yr. (3.84 mm/yr.), the March 1962 storm had water levels equal to that of Hurricane Gloria in 1985, 7.2 ft. above NGVD (DEFINE), a 1 in 35 year water level. With EPA's projected "best estimate" rate of sea level rise of 0.018 ft./yr. to the year 2050 (Titus, 1995), the equivalent storm would reach a water level 8.62 ft. (2.63 m) above NGVD, a 1 in 60 year water level.

3.4.3.2 Water quality

[To be written]

3.4.3.3 Ecosystems

Elevated carbon dioxide (CO_2) could alter carbon storage in wetlands. A Maryland salt marsh exposed to elevated (ambient+340 ppm) levels of CO_2 since 1987 shows an increase in net ecosystem production (net ecosystem production = net primary production - ecosystem respiration). Shoot biomass was largely unaffected by elevated CO_2, but root production increased by an average of 44% (Drake et al. 1996). Assuming that all the "extra" carbon allocated below ground is stored, the surface elevation of the high CO_2 plots should be increasing faster than the ambient CO_2 plots by about 0.4 inch (1 cm) per year. This value can be considered an upper limit for the influence of elevated CO_2 on surface elevation in mid-Atlantic high marshes, because it is clear that such a large effect has not been maintained over the 11 years of this study. Research underway will determine the extent to which elevated CO_2 has stimulated accretion in this experimental system (Megonigal, per. comm.).

The stimulation of carbon cycling by elevated CO_2 has caused other ecosystem changes including an increase of 68% in emissions of methane (CH_4, an important greenhouse gas), an increase in nitrogen fixation and invertebrate activity, and improved plant water-use efficiency. No direct effects on decomposition rates have been observed. The effects of elevated CO_2 on this brackish marsh was different for plants with C3 or C4 photosynthesis. C3 plants use sunlight to make sugar starting with three carbon atoms, and are well suited to climates that are not too hot or too dry. Plants that originated in drier, hotter climates are called C4 plants because their first product from photosynthesis has 4 carbon atoms. C4 plants (such as corn, sugar cane, and lawn grasses) grow rapidly in conditions of high sunlight and use CO_2 efficiently. Increasing atmospheric CO_2 is likely to benefit C3 plants more than the already efficient C4 plants. A community dominated by the C3 sedge Scirpus olneyi responded strongly, while a community dominated by the C4 grass Spartina patens showed no significant changes after 7 years of elevated CO_2 treatment (Drake et al., 1996). In a community composed of both C3 and C4 plants, the density of C3 species increased significantly at the expense of C4 species. Thus, elevated CO_2 could increase the abundance of C3 communities in coastal marshes; the consequences on ecosystem function are uncertain.

Regional warming will likely change the amount of photosynthesis (and therefore carbon storage) in marshes because increasing temperature speed up photosynthesis (until it gets too hot at about 84° F or 29° C). One way to examine potential effects of temperature outside a laboratory is to compare rates at different latitudes. Southern marshes are more productive than more northern ones, but part of the difference is explained by a longer growing season in the South (Turner, 1976). Although higher temperatures usually mean faster decomposition rates, Callaway et al. (1996) found more soil organic matter in Southern marshes, suggesting that accretion rates are likely to be higher at higher temperatures.

There have been relatively few estimates of potential vertical accretion rates in coastal wetlands. Bricker-Urso et al. (1989) suggested an upper limit of 0.63 inch (16 mm) per year, a rate that easily exceeds the highest projections for the mid-Atlantic region of about 0.28 inch (7 mm) per year. Callaway et al. (1996) calibrated a sediment accretion model for a coastal Louisiana marsh and concluded that rates of sea level rise more than 0.12 inch (3 mm) per year would cause a state change toward more flood-adapted plant communities (Brinson et al. 1995) and that rates more than 0.2 inch (5 mm) per year would cause complete wetland loss. More research on vertical accretion rates is needed. Tidal freshwater wetlands may be more stable than saltmarshes in the face of sea level rise because they receive riverine sediments. However, lateral migration of these wetlands will be limited by steep valley slopes in the upper reaches of such river systems, and upriver migration will be limited by increasingly narrow channels. Increasing freshwater flow might increase the area of these wetlands.

SECTION HERE BY VIC ON NON-WETLAND ECOSYSTEMS

[BOXES BY ANDERSON AND SORENSON COULD GO HERE-LATER, GALBRAITH MAY PROVIDE INFO TO LINK SHOREBIRDS' HABITAT TO WATERFOWL]

3.4.3.4 Coastal development and use

Climate change could have both positive and negative impacts on development and use in the MACZ. On the positive side, warming could extend the coastal recreation season, making the northerly areas' seasons as long as those now occurring in North Carolina and Virginia. On the negative side, there appear to be far greater risks. Among these are the ecological and management challenges of increased recreational demand (for water, waste management, traffic, public safety); the threat of sea-level rise; vulnerability to coastal storms and storm surges; AND... Dolan et al. (1980a) illustrate the compounding effects of physical processes at the coast, including storm waves, daily tide, spring or neap tide, storm surges, and sea level rise effects on resultant water levels. The timing of such events–and the structural and non-structural policies in anticipation of them–may be crucial for the well-being of coastal zones. Less direct impacts might also be important. Coastal wetlands are important sites in both estuarine and oceanic food chains, affecting both sport and commercial fishing locally and more widely. [INTERNS BORNSTEIN AND SONG ARE WORKING ON THIS...]

Although the MACZ is not particularly vulnerable to hurricanes, with the exception of the Outer Banks, September is the most common period of direct hits (Pielke 1998). Thus the extension of the peak season into September could mean greater populations vulnerable to storms at that time, with concomitant difficulty in evacuation and disaster management.

3.4.4 Management and adaptation options

Sea level rise poses an important challenge to desirable beach environments and beachfront developments. Parsons and Powell (1998) suggest that based on values of a Delaware coastal location, it will remain sensible for investments to be made in beach nourishment, given the costs of beach retreat over the next fifty years in present value of

$200 million. [NOT CLEAR WHETHER THIS $200M IS JUST FOR THE LOCATION OR FOR MAR, AND IS THIS BASED ON CURRENT SLR WITHOUT CLIMATE CHANGE INCREMENTAL IMPACT?] They argue that beach nourishment remains a viable strategy for the next half-century. Data from Faucett (1998) appear to confirm this conclusion: beach replenishment is far less costly than the present value of permitting beach retreat. Nevertheless, Delaware has taken the stance of allowing "strategic retreat" (NEED TO CONFIRM) for state owned coastal lands.

There are important legal dimensions to the process of beach retreat in coastal areas (Titus 1998). (NEED JIM TITUS TO SUMMARIZE HIS 1998 PIECE)

In general, we may reasonably anticipate that in the ocean coastal areas, society will continue to build structures like seawalls to maintain the status quo, regardless of how ill-founded this strategy may be in the long run. In the estuaries, only socially-significant locations are likely to be protected from submergence, while other lands will be yielded to wetlands and water. All of this, of course, will exact a cost from society that will increase through time.

3.4.5. Research and information priorities [BEING WRITTEN]

Case study

Riparian Forest Loss
(Anderson)

Figure *n*: Future coastline map of Chesapeake Bay in 2100 overlaid on land use map from 1993.

The predicted average sea level rise (SLR) of 70 cm by the year 2100 is likely to have major impacts on coastal ecosystems, especially in terms of habitat loss. There is a potential for species migration, but it is limited by the concentration of human populations and urban/suburban development in coastal counties. In addition, the speed with which habitat is lost has a major impact on the ability of slow moving species (such as most plants) to migrate to new, appropriate habitats. Although this study is based on the loss of forest to coastal flooding, it is possible that forest areas will have been lost to human development long before the sea rises over them.

Rising sea levels could flood marshes and push back coastal vegetation without eliminating any vegetation types. That is, unless soil and hydrological conditions change or unless a barrier to this migration exists. For example, steep slopes, sea walls and bulkheads, or upland construction could squeeze coastal ecological communities. Coastal forests are especially vulnerable to the squeeze because they are often found nearest to human development projects. People often recognize the value of these wetland forests as habitat for wildlife, as filtration systems for excess nutrients from agricultural runoff and atmospheric deposition of acid rain, and as sponges for soaking up heavy metals, but this environmental value may not overcome human demand for dwelling and recreational spaces.

To understand the potential loss of coastal forests, assuming the best case (no loss of forest and no increase in development since 1993), we analyzed the land use map along with the map of coastal flooding to determine the loss of forest land in coastal counties (those counties defined as coastal by NOAA): In 1993, *X* acres within the Chesapeake region were covered by forests. The predicted forest land cover in 2100 (based only on SLR with no increase in other land use types) is *Y* acres. Of course, species that thrive in coastal wetland forests require special growing conditions found in the wetter soils to which they have adapted. Even if there is room for forests to migrate inland, they might not survive if inland is too far upland where hydrological conditions favor different plant species. Migration is also more likely if the flooded forest is adjacent to other forests or even agricultural land rather than abutting developed areas.

Case Study

Impacts of Global Warming on Waterfowl Wintering in the Chesapeake Bay (Sorenson)

The Chesapeake Bay is a famous waterfowl wintering site. Nearly 1 million ducks, geese and swans use this estuary to feed and rest during the winter and thousands more use it as a migration stopover point. The commercial hunting that once took place here and nearly decimated the populations has been replaced by managed hunting (numbers of harvested ducks in recent years, economic values of hunting). Table 3.4.1 shows recent average population sizes for species wintering in the Bay. Wintering population sizes of most duck species have declined since the 1950s while population sizes of Canada Geese and Snow Geese have increased (Perry and Deller 1995). Most of these changes are attributed to changes in waterfowl food resources in and around the Bay, particularly the widespread decline of submerged aquatic vegetation (SAV), a prime waterfowl food (Perry and Deller 1996). Loss of SAV is attributed to excessive nutrients and sedimentation. The resulting high turbidity shades SAV and limits its growth (Hurley 1991). Some species have been able to adapt by changing their diet. For example, swans and geese now feed largely in upland agricultural areas on waste corn and winter cover crops (Munro 1980, 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 that were apparently unable to adapt to the loss of SAV have shown drastic declines in numbers; the Northern Pintail, Redhead, and American Wigeon have largely abandoned the Bay as a major wintering site (Haramis 1991b, Perry and Deller 1995).

Global warming is likely to have a major impact on waterfowl populations in the coming decades, with changes projected to occur in both breeding and wintering habitats. Warmer and drier conditions are projected for the Prairie Pothole Region (PPR) of the north-central US and south-central Canada, an area known as the continent's "duck factory" (Sorenson et al. 1998; Sorenson et al. in prep). These changes could reduce the number of pothole wetlands and correspondingly, the number of ducks breeding in the region and their reproductive success. Diminished population size and productivity on the breeding grounds 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. Breeding population sizes of these species fluctuate from year to year depending on conditions on the breeding grounds. Historical fluctuations in numbers of birds using the Bay reflect, in part, these continental trends (Perry and Deller 1995).

Approximately Xx% of Canvasbacks wintering in Chesapeake Bay come from the PPR. Band recovery data show that the Chesapeake Bay population represents xx% of the Atlantic Flyway wintering population and xx% of the total number of birds counted in the mid-winter surveys. If ponds on the breeding grounds dry up causing declines in breeding population sizes and numbers of young produced, then we can expect similar declines in the number of ducks using the Chesapeake Bay (give range of numbers for different GCM scenarios).

Discuss caveats accompanying the analysis:
A. Don't know how birds will move around on breeding grounds and how probable changes in habitat use will influence productivity and sizes of wintering populations.

B. Need to know how SLR from global warming as well as future management of the Bay will impact Chesapeake Bay as wintering habitat for waterfowl (how will distribution and abundance of SAV be affected). This will be an equally or perhaps more important determinant of future waterfowl numbers in the Bay.

Table 3.4.1. Fifteen year average (1984-1998) population sizes for 9 species of waterfowl wintering in Chesapeake Bay

Species	1984-1998 averages (SE)
American Black Duck	43,411 (1462)
Mallard	58,059 (2391)
Northern Pintail	2335 (277)
American Wigeon	
Canvasback	57,271 (2,488)
Redhead Scaup	50,869 (6,808)
Goldeneye	
Bufflehead	
Ruddy Duck	
Canada Goose	392,896 (29,696)
Snow Goose	85,018 (9,089)
Brant	21,102 (2,564)

Case Study Box PLACEHOLDER

Marine Fishing

3.5 **Ecosystems** (Rogers and McCarty)

3.5.1 What is the status of resources and what are the current stresses?

Human activities in the Mid-Atlantic are changing the structure and functioning of ecosystems, "interacting systems of biological communities and their non-living surroundings" (US EPA 1999). The impacts upon ecosystems of changes in long-term climate patterns and climatic variability need to be assessed in the context of other stresses, such as habitat loss, pollution, and non-indigenous invasive species. Impacts may take the form of changes in ecosystem composition, including the species that inhabit them and the relative abundance, distribution, and density of those species. Ecosystems function in ways that confer a variety of benefits that are valued by human populations. For example, forested ecosystems provide valuable recreation opportunities and habitat for wildlife; wetlands can help clean water pollution and filter heavy metals. Benefits from ecosystem functions range from being very specific, such as crop pollination, to being very general, such as waste decomposition. Changes in ecosystem structure may lead to changes in their valuable functions (Chapin et al. 1997).

Criteria for evaluating the status and stresses of Mid-Atlantic ecosystems depend partly on what aspects of ecosystems are important to people in the region. The Mid-Atlantic region includes a variety of ecosystems ranging from deciduous forests and mountain streams, to agricultural, suburban and urban dominated areas in the lowlands, to wetlands and estuaries near the Atlantic coast. The Chesapeake Bay's most valued ecological attributes are different from those for Shenandoah National Park, which in turn differ from those for a farmer's field or the center of a major city or a suburban neighborhood. We hypothesize that particular regional populations of species, ecosystem functions, and places are valued by stakeholders in the Mid-Atlantic Region (as explained in Appendix C). Our hypotheses can be refined as we learn more about stakeholder perspectives and values, and as the scientific understanding of how people and their activities depend upon ecosystems improves.

The Mid-Atlantic region, with its mountains, valleys and coastal plains, is among the most diverse physical and ecological regions in the United States (US EPA 1997, Landscape Atlas). The region is especially notable for the diversity and endangerment of its freshwater fauna. Nationwide, the four groups of species with the greatest proportion of species at risk (40-67%, compared to birds, mammals and reptiles, with imperilment rates of 15-20%) are freshwater mussels, crayfish, amphibians, and freshwater fish, all of which depend upon freshwater habitats (Stein and Flack 1997). The US ranks first in the world in the number of described species of freshwater mussels, crayfish, freshwater snails, and several aquatic insects: stoneflies, mayflies and caddisflies; and ranks seventh in freshwater fish species (Master et al. YEAR?). Of the Mid-Atlantic states, Virginia has the greatest number of historically occurring freshwater mussels, the greatest percentage of imperiled mussels and fish, and the greatest number of at-risk fish species (Table 3.5.1). Virginia has also lost the greatest number of species (terrestrial and aquatic) to extinction. Of the 2,100 small watersheds in the US, 87 are hot spots with 10 or more at-risk freshwater fish and mussels species. Of these 87, 6 are located in NC, 4 in VA, and 2 in WV) (Master et al. YEAR?).

Table 3.5.1.

State	Total # Species: Presumed + Possibly Extinct (Stein & Flack 1997)	# At-Risk Freshwater Fishes (% Imperiled) (Master et al. Year?)	# Freshwater Mussels Historically Known to Occur (% Imperiled) (Williams and Neves 1995)
NC	5 + 9	39 (18%)	50 (60%)
VA	8 + 17	41 (20%)	80 (71%)
WV	2 + 3	16 (11%)	50 (46%)
MD	6 + 2	3 (3%)	19 (68%)
DE	1 + 1	5 (5%)	12 (58%)
PA	2 + 5	13 (8%)	63 (49%)
NJ	3 + 2	3 (4%)	12 (58%)
NY	3 + 5	13 (8%)	30 (47%)

For eastern fishes and mussels, altered sediment loads from agriculture, and non-native invasive species are the dominant threats (Richter et al. 1997). Eastern fishes are also threatened by municipal sources of nutrients and sediments, while eastern mussels face greater threats from altered nutrient input associated with both agriculture and hydroelectric dams.

The history of sediment and nutrient pollution through the present is discussed in section 3.1 above. Sediment pollution from agricultural and urban lands reduces water clarity, smothers bottom organisms, and clogs waterways, affecting freshwater and estuarine ecosystems. Nitrogen, phosphorus and sediments from agricultural and urban areas are the greatest threats to the Chesapeake Bay (US EPA 1995). Excess quantities of these nutrients feed algal blooms, which contribute to low oxygen conditions in bottom waters and to losses of submerged aquatic vegetation. This, in turn, has reduced the ability of the Bay and associated wetlands to support fish, crabs and waterfowl (See section 3.4).

River and stream ecosystems are adapted to naturally varying levels of stream-flow, but are stressed by human alterations of flow regimes (Karr et al. 1986; see also Part 2: A View of the Mid-Atlantic Region in 2030). Urban development alters flow regimes because while rain falling on a vegetated surface can be absorbed into the ground and slowly released to streams, rain falling on paved surfaces in urban areas cannot be absorbed. This can lead to sharply increased peak flows during storms, and to very low flows during dry periods. Peak flows can be physically destructive, while low flows can significantly reduce available habitat for fish and aquatic insects. Withdrawals of water for human uses can further deplete baseflows.

Freshwater and other ecosystems of the Mid-Atlantic are stressed by non-native invasive species. Nine of the twelve non-native invasive species identified by the Nature Conservancy (1996) as posing great threats to US ecosystems occur in the Mid-Atlantic region: zebra mussels, flathead catfish, and hydrilla in freshwaters; purple loosestrife in wetlands; balsam wooly adelgid, leafy spurge and tamarisk in terrestrial; and Green Crab and Chinese Tallow pose threats to small parts of the region. Up to 10,000 zebra mussels can adhere to a single native mussel, interfering with the native mussels' feeding, growth, movement, respiration and reproduction. Non-native invasive species are believed to have contributed to the decline of 42% of US threatened and endangered species, and to the extinction of 27 of 40 North American freshwater fishes (Nature Conservancy 1996). Non-native invasive agricultural weeds, pests and pathogens threaten agriculture, and European starlings, ragweed, and gypsy moths cause various kinds of damage in both natural and more human-dominated landscapes. While some introduced species (e.g., wheat, rice, corn, cattle, poultry) are valued parts of agricultural ecosystems, 79 non-native invaders were estimated to cause approximately $97 billion in damages from 1906 to 1991 (OTA 1993). $764 million of damage were attributed to European gypsy moths by the US Department of Agriculture, and zebra mussels could cause up to $5 billion in damages by 2002 (Nature Conservancy 1996). In addition, invasive species may impair valued ecosystem functions (Vitousek and Walker 1989, Vitousek et al. 1996).

Freshwater ecosystems have been degraded by other stresses, including toxic chemical pollution, acid deposition and physical alterations, such as dams, road crossings and channelization. Each of these stresses is related to human activities. Lifestyles in the Mid-Atlantic are associated with the generation of sewage and trash, and with demands for transportation, electricity, manufacturing, food, water, recreation and a variety of services. Although primarily a by-product of manufacturing and agricultural pesticide applications, toxic chemical pollution also is associated with services such as dry-cleaning and automotive maintenance. The Elizabeth River, the Patapsco and Back Rivers of the Baltimore Harbor area, and the Anacostia River have sediment contamination concentrations in excess of hazardous levels (PELs or Probable Effect Levels) (US EPA 1995). Nitrogen and sulfur emissions from cars and power plants, along with mine drainage, contribute to the acidification of lakes and streams. Rivers and streams are physically altered for human convenience. Natural, meandering forest streams are often replaced in urban and suburban neighborhoods by straightened channels with frequent road crossings, and are sometimes routed into underground drainage pipes. These alterations tend to make the flow faster and "flashier" as well as degrading or eliminating shoreline habitat.

The human presence in the Mid-Atlantic region has altered all of the region's ecosystems to varying degrees. Forested, agricultural and coastal ecosystems are discussed in other sections (3.1-3.4), as are human health issues that arise in human-populated ecosystems (3.6). Some natural forests, wetlands and other systems have essentially been lost when they have been converted into urban, suburban and agricultural areas to meet the growing population's growing demands for homes, offices, shops, transportation and recreation. Cities in the Mid-Atlantic generally support large human populations and provide more amenities for people than less human-dominated systems, and agricultural lands produce large quantities of food. Unfortunately, these landscape changes also result in losses of habitat for many non-human species and losses of the functions performed by these ecosystems. The fragmentation of forests into isolated patches exacerbates the problem of habitat loss for Mid-Atlantic species that require large, connected areas to thrive.

Ecosystems are interconnected. Human activities within urban and agricultural ecosystems are responsible for many stresses on freshwater and estuarine ecosystems, including disrupted hydrologic cycles, sedimentation and eutrophication. Most, or perhaps all, of the region's ecosystems have somewhat diminished capacities to support their natural composition and functions. Appendix F lists all species on the federal list of endangered species that occur within the MAR. It also summarizes stresses on declining species within the Chesapeake Bay Region.

PLACEHOLDER: Could add overharvesting, native pests and pathogens to list of stresses. Could add that climate currently stresses Mid-Atlantic ecosystems through temperature extremes, droughts, floods, and other variations in the timing and geographic distribution of precipitation. Could add discussion of current status and stresses for national parks and other federal, state, local and private (including nonprofit) nature reserves. Current stresses are a problem for these areas, e.g., non-native invasive species, runoff from adjacent urban and agricultural lands, acid deposition. Climate stress will interact with current stresses in ways that may be very detrimental to lands protected for nature.

3.5.2 How might climate change and changes in climate variability exacerbate or ameliorate current conditions?

Predictions for the Mid-Atlantic for the next 100 years suggest that temperature and precipitation patterns will change – probably in the direction of a warmer, wetter climate – and that sea level will rise (Part 2.4). These changes can be expected to affect Mid-Atlantic ecosystems. Studies not specific to the Mid-Atlantic have linked changes in the distribution and ecology of species to the climate warming of the last century (Barry et al. 1995, Beebee 1995, Parmesan 1996, Crick et al. 1997). During rapid climatic changes occurring in the last 100,000 years, many species' ranges shifted in conjunction with global temperature changes (Pitelka et al. 1997). For instance, spruce trees shifted their ranges from Southeastern to Northeastern North America (but at a time when there were few man-made barriers such as cities and farms). Researchers have linked local climate conditions to survival and reproduction in many plants and animals (Huntley et al. 1989, Visser et al. 1998) and have established that climate directly or indirectly determines the geographic ranges of many species (Root 1988, Huntley et al. 1995; Shao and Halpin 1995).

Changes in carbon dioxide concentration, temperature, precipitation, and sea level in the Mid-Atlantic will affect individual species differently – benefiting some species, while harming others. For example, see section 3.4 discussion of how carbon dioxide has differential impacts on plant species within a marsh. While some species may be physiologically well suited to new conditions, others will need to adapt. The speed and success of adaptation will vary across species. If temperature extremes, droughts, and floods increase in frequency or intensity, these conditions could be particularly stressful for many species. Species that can evolve rapidly are more likely to cope effectively with environmental changes (Cronin and Schneider 1990, Geber and Dawson 1993). Significant adaptive evolution is more likely in species with short generation times, such as microbes, insects and annual plants than in long lived species, such as trees. Rapid evolution is also favored in species that possess high levels of genetic variability for traits related to climate tolerance (Geber and Dawson 1993). Some species will shift their geographic range by invading more hospitable climates. Other species will fail because they can not move fast enough to keep pace with change, because landscape features (such as cities) block their movement, or because new suitable habitats are simply not available (Pitelka et al. 1997). A species may fail to colonize a prospective habitat with a newly favorable climate if it can not adapt to that habitat's soils, terrain, level of human development, or compete with other species already in residence. Since species will be affected differently by climatic changes, relationships among species will be altered. [PLACEHOLDER: discussion of effects on parks and nature reserves.]

Invasive species share a set of traits that predispose them to successfully invade pre-existing communities. Successful invaders such as agricultural weeds and pests, European starlings, ragweed, gypsy moths and purple loosestrife tend to have these traits, including a high rate of population growth, which contributes to rapid colonization; ability to move long distances, which contributes to colonizing distant habitats; tolerance of close association with humans, which is important in increasingly human-dominated landscapes; and tolerance of a broad range of physical conditions (Ruesink et al. 1995, Rejmánek and Richardson 1996). The same traits that allow these species to invade communities might enable them to adapt to climate changes and other types of human disturbances. Thus, climate change could accelerate the loss of species already imperiled by pre-existing stresses yet fail to exert the same negative pressures upon invasive, weedy species. Climate change could work in concert with other stresses to further reduce populations of rare and endemic species while increasing populations of already abundant, widespread species.

Climate change will interact with pre-existing stresses. Ecosystems of the Mid-Atlantic are already experiencing severe stress from habitat loss, degradation and fragmentation. Losses of coastal habitats are predicted consequences of sea level rise. For example, see case study boxes on forests subject to sea-level rise, waterfowl in the Chesapeake Bay, [later shore birds in the Delaware Bay], and the discussion of the effects of CO_2, sea level rise, and sediment accretion on marsh grasses of Chesapeake Bay wetlands, all in Section 3.4.

Intensive human development of coastal areas exerts stresses on coastal ecosystems and can prevent coastal wetlands from migrating inland as sea level rises. Adaptation measures to protect developed areas from sea level rise, such as increased use of sea-walls, can directly harm ecosystems. In upland habitats, such as forests, populations of plants and animals isolated by habitat fragmentation will be stressed by climate changes and their small size and isolation can make it more difficult for those populations to survive (Peters and Darling 1985).

Increased precipitation in the Mid-Atlantic might ameliorate the impacts of urban reductions of baseflows, but more intense storms could exacerbate existing problems of flooding, erosion and other stresses. The combined effects of increased carbon dioxide, precipitation and temperature need to be considered to understand the overall impact on ecosystems. Dissolved oxygen concentrations (vital, for example, to fish) depend upon temperature and streamflow. (See recreational fishing case box in Section 3.3.) Temperature increases would tend to lower dissolved oxygen concentrations, as would decreases in turbulent streamflow. A warmer climate would, therefore, increase the problem of low dissolved oxygen concentrations. A wetter climate might moderate this type of stress if resulting flows increase streamflow turbulence during critical periods when dissolved oxygen concentrations were low.

The movement of soils, nutrients and pesticides from terrestrial systems to aquatic ones is a complex process influenced by a variety of human and natural factors. In the absence of adaptive human intervention, increases in overall precipitation and/or storm intensity might increase runoff from agricultural and urban areas, exacerbating stresses on aquatic systems. The same processes might increase acidic drainage from mines. The effects of climate change on the acidification of lakes and streams remain speculative due to uncertainties regarding the effects of climatic changes on acid deposition and hydrology. The timing of rainfall is an important factor in determining the impacts of climate change.

3.5.3 What are the potential strategies for coping with risk and taking advantage of new opportunities?

The key to effective ecosystem management is a strategy that addresses existing stresses as well as additional stresses from climate change. The dynamic and interactive nature of ecosystems is revealed in the network of pathways by which multiple current stresses interact with climate stresses and natural processes to produce ecosystem changes. Action is needed to protect highly valued regional populations of species, ecosystem functions, and special places. Management strategies that reduce the impacts of other stresses (such as preserving forests and wetlands, minimizing urban and agricultural soil erosion and nutrient runoff, conserving energy and water, protecting stream habitat, and reducing waste and the release of toxic chemicals) already have been identified. The flip side of multiple pathways for doing harm is multiple pathways for reducing harm. For example, some agricultural practices reduce the use of toxic chemicals, reduce soil erosion and nutrient runoff, and conserve energy and water. In doing so, these practices protect soil fertility and reduce harmful impacts on terrestrial and aquatic plants and animals. Some strategies that promote energy conservation (such as insulation in buildings or energy-efficient transportation) reduce emissions of nitrogen and sulfur and greenhouse gases, thereby addressing acid rain, atmospheric nitrogen deposition, and climate change simultaneously. Many opportunities are available that would protect, and sometimes restore, attributes of ecosystems that are important to stakeholders in the Mid-

Atlantic. (Appendix F suggests key locations for which protecting small watersheds would reduce substantial threats to imperiled freshwater fish and mussels.) Research and public education can contribute to developing a public understanding of the value of ecological resources, the most serious threats to those resources, and the possibilities for protection and restoration. Improved protection of ecological resources will then depend upon people evaluating the economic, social, and ecological consequences of various alternatives and then taking action.

3.5.4 What are the policy-relevant research gaps?

Policy-relevant research could improve the foundation for decision-making in the Mid-Atlantic region. We have a very incomplete understanding of how we depend upon ecosystems, how ecosystems sustain themselves, and how human activities alter ecosystem processes. Because innumerable aspects of ecosystems contribute to human health and well-being in ways that are still poorly understood, it is difficult to set priorities for protecting or restoring ecosystem components and processes (e.g., Daily et al. 1997). There is a critical need for research into ecosystem processes.

Valuation of ecosystem components and processes poses another challenge: linking a scientific understanding of ecosystems to a characterization of stakeholder values. This requires identifying how ecological attributes change in response to human activities (including ecological attributes that change as a result of a cascading set of effects originally caused by human activity), describing ecosystem changes in terms that relate to human values, and providing stakeholders with adequate information upon which to base decisions. Preliminary plans for investigating these topics are described in Appendix C.

The study of how particular attributes of ecosystems change in response to human activities is an interdisciplinary endeavor. Economists and other social scientists contribute information about human behavior, while ecologists, climatologists, hydrologists, biologists, and chemists provide insights into natural processes and how they can be altered by human actions. To improve our understanding of how ecosystems might respond to climate change, collaboration among ecologists, climatologists and hydrologists is needed to identify and characterize those aspects of climate of the greatest relevance to ecosystems. Key issues for freshwater ecosystems in the Mid-Atlantic include potential changes in the amount, geographic distribution and timing of rainfall; in interactions of precipitation patterns with current and future landscapes on already varying streamflow levels and water quality; and the consequences of these changes on the abundance and distribution of fish and other aquatic organisms. Similarly, a key issue for the Chesapeake Bay is how changes in rainfall and water quality might affect nutrient inputs to the Bay. Future assessments of the impacts of climate change on forests could benefit from improved understanding of the sensitivity of terrestrial ecosystems to changes in carbon and nutrient cycles caused by increased carbon dioxide concentrations as well as to changes in temperature and rainfall. These assessments also need better characterization of how temperature and rainfall might change. Since climate change and other stresses can be expected to have negative effects on some species and ecosystems, it would be useful to improve our ability to predict which species or ecosystems are least likely to be replaced by functionally equivalent components. Focusing some research effort upon the study of how non-native species invade new ecosystems might improve this predictive ability.

Ecosystems are, by definition, interactive systems. The emphasis here on assessing current status and stresses is a useful baseline, but baseline research should be continued to improve our understanding of ecosystem structure and functioning. This will serve as a firmer foundation for research needed on the interactive effects of multiple current and climatic stresses, and the effectiveness of alternative management strategies. Because natural ecosystems play a role in the global carbon cycle, research into feedbacks between ecosystems and climate change would be helpful for evaluating management strategies.

Case Study

Climate Change and Bird Distributions in the Mid-Atlantic Region
(Price)

There are both economic and ecological reasons to care about the birds of the Mid-Atlantic region. Birdwatching is big business: non-consumptive bird 'use' (watching and feeding birds) generates $884.7 million in annual retail sales in the states within the Mid-Atlantic region (Southwick Associates 1991). This, in turn, supported more than 23,000 jobs in those states (Bird Conservation 1997). While people care about birds, it is difficult to estimate how changes in bird distributions might affect the economics of non-consumptive bird use. Shifts in regional spending on this activity are likely as some birdwatching sites become less favorable and different sites become more favorable. Although many bird watchers might simply adjust to the reduction in species richness in their areas, they will experience the loss of well-being that accompanies a reduction in their preferred activities.

Also of concern are the potential indirect economic 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 have been known to eat up to 98% of the overwintering codling moth larvae in orchards.
- Several species of wood warblers are largely responsible for holding down numbers of spruce budworm larvae, eating up to 98% of the non-outbreak larvae.
- While birds are not the principal vertebrate predator of gypsy moths, they do play a role in holding down numbers of this pest.

The results presented in Tables 3.5.2 and 3.5.3 came from logistic regression models developed to associate bird distributions with current climatic conditions (1985-1989). These models were then coupled either to a sensitivity analysis where temperatures were increased by 1.8° F (1° C) or to equilibrium output from the Canadian Climate Center (CCC) general circulation model (in press; 1995).

Models have been developed for almost all perching (passerine) bird species except the thrushes and some miscellaneous species. The results in Table 3.5.2 show how climate change might change the number of species found in the Mid-Atlantic region and for each of its states. The gross change represents the overall loss of species currently found in the area. The net change represents the loss of species currently found in an area offset by species moving into the area from outside of the region. For example, even a 1° C increase in temperature could lead to a loss of 11% of the passerine species currently found in the states of the Mid-Atlantic region. These losses would be somewhat offset by birds colonizing from outside the region so the net change would be 5% fewer species than currently found there. Table 3.5.3 provides data on a subset of the species from Table 3.5.2, the wood warblers. These colorful species are popular among bird watchers, are important predators of insects and may be especially sensitive to climate change. Even a 1° C increase in temperature could lead to a gross loss of 29% of the warblers in the region. 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 a 19% reduction in the number of warbler species currently found in the region.

Table 3.5.2. Changes in number of perching bird species under a 1° C temperature change and under the equilibrium conditions from the Canadian Climate Center GCM.

	With 1° C temperature increase		Under conditions of CCC -GCM	
	Gross Change (%)	Net Change (%)	Gross Change (%)	Net Change (%)
Region	- 11	- 5	- 36	- 18
Delaware	- 9	- 6	- 29	- 21
Maryland	- 8	- 3	- 33	- 18
New Jersey	- 8	- 2	- 24	- 11
New York	- 14	- 5	- 41	- 18
North Carolina	- 8	- 4	- 26	- 16
Pennsylvania	- 13	- 6	- 40	- 17
Virginia	- 10	- 6	- 34	- 21
West Virginia	- 12	- 7	- 38	- 20

How quickly these changes might occur is unknown. It is possible they could occur relatively quickly. For example, the average latitude of occurrence of 43% of the warblers has shifted north in the last 20 years, by an average of more than 70 km (Price, unpublished data). Only three species (6%) were found significantly farther south and these represented overall expansions of the species' ranges. In most of the remaining species, the range showed a northward trend but it was not enough to be statistically significant.

In summary, climate change will cause changes in the distributions of birds. These changes could occur (and probably are occurring) relatively quickly. While these changes will have ecological effects and possible economic effects, the magnitude of these effects is unknown.

Table 3.5.3. Changes in number of warbler species under a 1° C temperature change and under the equilibrium conditions from the Canadian Climate Center GCM.

	With 1° C temperature increase		Under conditions of CCC -GCM	
	Gross Change (%)	Net Change (%)	Gross Change (%)	Net Change (%)
Region	- 29	- 19	- 63	- 45
Delaware	- 22	- 19	- 52	- 46
Maryland	- 29	- 28	- 58	- 47
New Jersey	- 19	- 7	- 52	- 31
New York	- 31	- 15	- 72	- 43
North Carolina	- 19	- 14	- 48	- 43
Pennsylvania	- 31	- 17	- 68	- 47
Virginia	- 29	- 28	- 59	- 51
West Virginia	- 29	- 24	- 57	- 44

Section 3.6 MAR Draft Preliminary Human Health Sector Assessment (Shortle, Benson, Kocagil, Wang)

Interest in the impacts of climate change on human health was strongly expressed at the US GCRP Workshop on Climate Change Impacts in the Mid Atlantic Region (MAR) (Fisher et al., 1999). Concerns included increased illness and mortality related to more frequent and/or severe extreme heat events, new or re-emergent diseases because of changes in the dynamics of transmission, distribution and resistance of disease agents, and increased contamination of public and private water supplies due to increased flooding. Our goal is to examine the potential effects of climate change and variability on the health of the people in the MAR population over the next twenty to one hundred years, recognizing possible positive, as well as negative effects.

3.6.1 Current Health Status and Stresses

Climate is one of many factors that influence human health. Other factors are lifestyle choices (e.g., cigarette and alcohol consumption, diet, fitness), access to medical care (availability, quality and price of care and health insurance status), medical technology, genetic endowment (predisposition to certain diseases), and characteristics of the built and natural environment. The current health status of the region's population reflects the combined effects of climate and nonclimatic factors, and provides a backdrop for evaluating the potential impacts of climate change in the region. We present selected health assessment measures for four physiographic subregions of the MAR: Coastal, Piedmont, Plateau and Ridge and Valley (R&V). County level data was collected and aggregated by state and physiographic region.

Mortality

Table 3.6.1 presents crude mortality rates for the top 10 causes of death in the US and in the region. It also includes crude mortality rates from homicides, and motor accidents, and deaths directly attributable to cold, heat, lightning, storms, and flooding. We use crude mortality and morbidity rates for 1995, the most recent year for which comprehensive data is available to examine causes of death. Age-adjusted mortality rates are the preferred measure but crude mortality rates are adequate for our purposes and more easily obtained.

The three leading causes of death in the MAR, are heart disease, cancer and stroke. This ranking is the same as for the US but the MAR mortality rate is somewhat higher than the national rate for all three causes of death. In addition, the mortality rates for death by all causes, lung disease, pneumonia/influenza, and diabetes exceed the US national death rates. However, the MAR has lower mortality rates for AIDS, cirrhosis/liver disease, homicide, suicide, accidents, and motor vehicle accidents than the US.

Within the MAR, the Plateau and R&V regions have death rates that are much higher than the national mortality rate for heart disease, cancer, stroke, pneumonia, diabetes, and death by all causes while the Piedmont and Coastal regions have death rates similar to the

US rate. A comparatively large percentage of the population in the later years of life may explain these higher mortality rates in the Plateau and R&V regions. More than 15% of the population in these two regions is aged 65 and older as compared to the national average of 12.8%. For AIDS, liver disease, and homicide, the Coastal region has a higher mortality rate than the US, while the other regions have lower mortality rates.

Climate related conditions can be an aggravating or contributing factor in many of the leading causes of death (WHO 1990; IPCC 1996). We are currently unable to quantify the magnitude of the climate effect, but the literature indicates that lifestyle choices, genetic endowment and age are the most important contributing factors.

Table 3.6.1. 1995 Death Rates per 100,000 Population by Physiographic Region for Selected Causes of Death

Cause of Death	US	Coastal	Piedmont	Ridge and Valley	Plateau	MAR
All Causes	880.00	913.11	871.90	1049.09	1058.03	951.53
Top 10 Causes:						
Heart Disease	280.70	276.91	265.57	366.06	367.29	305.42
Cancer	204.90	220.35	209.00	239.53	254.48	227.66
Stroke	60.10	57.64	61.73	68.25	66.60	62.14
Lung Disease	39.20	33.51	35.23	45.25	50.35	39.44
Accidents	35.50	33.94	30.32	34.83	32.85	32.71
Motor Accidents *	16.50	12.34	12.98	13.24	13.54	12.92
Pneumonia/Influenza	31.60	28.59	29.80	37.61	37.66	32.13
Diabetes	22.60	24.44	23.00	26.33	26.89	24.84
AIDS/HIV	16.40	25.04	14.61	4.19	5.49	15.02
Suicide	11.90	9.28	10.80	11.08	10.01	10.08
Cirrhosis/Liver	9.60	9.95	7.18	5.60	7.56	8.12
Selected Other Causes:						
Homicide	8.70	12.34	6.49	2.24	2.44	7.15
Cold Related	0.21	0.17	0.18	0.43	0.29	0.23
Heat Related	0.27	0.32	0.12	0.03	0.09	0.18
Storm/Flood/Lightning	0.06	0.02	0.01	0.03	0.00	0.01

Crude death rates for 1995. Source: Office of Analysis and Epidemiology, National Center for Health Statistics, Centers for Disease Control and Prevention.. Data collected July 1998 from cdc.wonder.gov. Missing values have been converted to zeros.

* Motor accidents are a subset of all accidents and are included in the accident category.

Currently, very little mortality in the MAR is directly attributable to cold, heat, storms, flooding or lightning. The death rate from mortality directly attributable to cold in MAR was similar to that of the US in 1995. The highest death rate from cold in MAR in 1995 occurred in the R&V region. Death rates from heat in the MAR were lower than the US rate but the death rate. There is, however, significant variation within the region, with much lower rates in the Piedmont, R&V and Plateau regions than in the Coastal region. Death rates from storms, floods, and lightning in the MAR were much lower than in the US as a whole.

Because heat, cold, storm, flood, and lightning related mortality is likely to show more year to year variability than the leading causes of death, we examined MAR and US crude mortality rates for these causes of death for the years 1990-1996. The average annual mortality rate in the MAR was 0.20, 0.07, and 0.02 per 100,000 population for the cold, heat and combined storm/flood/lightning category, respectively. Death rates from these causes in the MAR are less than the corresponding US mortality rates of 0.24, 0.12, and 0.06. Although these data exhibit a degree of year to year variability, especially at the sub-regional level, the mortality rates are consistently minuscule by comparison to the major causes of death.

Morbidity

Our analysis of morbidity focuses on selected diseases that have direct or indirect linkages with climatic conditions and for which regional data was available. Three of the diseases, Cryptosporidiosis, Giardiasis and Cholera, are water/food borne diseases. Four of the diseases, Malaria, Lyme Disease, Hanatavirus and Dengue Fever, are vector-borne diseases. Importantly, we do not have data on heat related morbidity or weather-related accident morbidity.

Table 3.6.2. MAR Morbidity Baseline Assessment: 1995 CDC & State Data
\# of reported cases
# of cases per 100,000 population

Region	Giardiasis	Crypto-sporidiosis	Cholera	Lyme Disease	Malaria	Dengue Fever	Hantavirus
Coastal	568 *4.48*	5 *.03*	1 *.007*	1231 *9.72*	91 *.71*	0 *0*	0 *0*
Piedmont	719 *7.12*	1 *.009*	0 *0*	2098 *20.78*	47 *.46*	1 *.009*	0 *0*
Ridge & Valley	231 *6.64*	0 *0*	0 *0*	44 *1.26*	1 *.02*	0 *0*	0 *0*
Plateau	1140 *12.75*	66 *.73*	0 *0*	471 *5.27*	20 *.22*	0 *0*	0 *0*
North	2658 *9.98*	72 *.27*	1 *.003*	3782 *14.20*	128 *.48*	0 *0*	0 *0*
South	0 (*) *0*	0 *0*	0 *0*	62 *.72*	31 *.36*	1 *.003*	0 *0*

The limitations of the morbidity baseline are:

1. Giardiasis cases are missing for North Carolina and Virginia in 1995. Therefore, the number of cases could be under reported.
2. West Virginia AIDS cases were reported at the state-level. We calculated a population-weighted average to determine how the cases would be distributed. Thus, the figures may not reflect actual cases in the different regions (plateau - ridge & valley).
3. Cryptosporidiosis was not a reportable disease for 1995.
4. We can not distinguish between imported and autochthonous (local) cases.
5. There were no cases of Hantavirus in the MAR in1995, however, there have been 6 cases in the region since 1994.

There were 6,735 reported cases of communicable diseases of interest in the MAR, of which 59.5% were vector borne and 40.5% were water-food borne diseases (Table 3.6.2).

The R&V subregion had the fewest (276 cases) of these communicable disease while the Piedmont had nearly half of the total (2865 cases).

Giardiasis was the most prevalent water-borne disease and found throughout the MAR. Most of these cases (1140) occurred in the Plateau region. Lyme Disease was the most prevalent vector-borne disease in the MAR with 3,844 cases. Nearly 60% of the Lyme Disease cases were clustered in fifteen counties along or near the New Jersey-Pennsylvania border. In 1995, there was one case of imported dengue fever, one case of imported cholera and no cases of hantavirus.

Key Trends Affecting Health Status in the MAR

While some of the factors that influence health status are likely to remain fairly constant in the next several decades, such as the genetic endowment of the general population, others are likely to change with potentially large impacts on health in the region. For example, managed care will continue to have a strong influence on the payment and provision of health care services.

Factors that we expect to greatly influence future scenarios include changes in the total population of the region, age distribution of the population, per capita income, employment status, health insurance, medical technology, public health systems. Changes will have various positive and/or negative impacts on health status and the vulnerability of the MAR population. While the dynamic nature of the health sector makes future changes difficult to predict, some future trends that may occur are (the impact on health status indicated with a + (positive) or – (negative)):

- An increase in per capita income in the region (+)
- Population growth in the Coastal and Piedmont regions, maintenance in Plateau and R&V regions (+ & –)
- An increase in the total and proportion of the population aged 65+ (+)
- Continued growth in cost of medical care (–)
- Continued growth of managed care systems (+ & –)
- Continued movement of care from the hospital to the home (+)
- Technological improvements (genetic engineering, biotechnology, medical devices, provision of services, etc.) will continue to improve disease prevention and treatment (+)
- Transfer of responsibility for health care costs to individuals (e.g. higher insurance rates for smokers) (+)
- Improvements in public insurance programs (e.g., Medicare and Medicaid) will influence the health of recipients, such as the elderly and the indigent (+)

3.6.2 Effects of Climate Variability

Climate variability clearly affects human health in the MAR. Temperature extremes and extreme weather events such as storms or floods currently do cause some death and injury in the region. However, the risk of death from extreme heat or other events is quite low when compared to death by other causes. Important factors protecting the MAR population from climate variability include:

- Most people in the MAR live and work in structures that protect them from the elements, and many in structures with sophisticated climate control systems. These structures can be viewed as adaptations to the existing climate.
- Most people in the MAR have access to water and sanitation systems that provide potable water and treat wastes. The region also has significant regulation to protect the safety of drinking water and foods. These systems reduce risks from water borne and other diseases.
- Most people in the MAR have access to modern medical services that can provide them with vaccines and treatments against most communicable disease that may migrate to the region.
- The region has modern food and energy distribution systems that disconnect food and energy supplies from local production and climate for most people.

However, some factors leave the population vulnerable to climate variability. These include:

- MAR has a relatively older population. The elderly tend to be more sensitive to infectious diseases and thermal extremes.
- There areas within the MAR of significant poverty (e.g. Appalachia).
- MAR has numerous small water supply systems that do not provide customers the safegaurds of large systems.
- MAR has significant coastal populations and narrow, flood prone valleys.
- The primary disease vector of concern is the deer tick, which transmits Lyme disease. The disease vectors that transmit malaria, dengue fever, and hantavirus are present in the MAR even though the diseases are not currently present.

Human health sensitivity to climate variability in the MAR has diminished historically with changes in the economy, characteristics of the population, medical technology, and a range of other factors. In the absence of climate change, we would expect climate-related risks to continue to diminish.

3.6.3 Impacts of Climate change

Following the IPCC format, the impacts of climate change on human health can be subdivided into *direct effects* and *indirect effects* (WHO 1990; IPCC 1996). Direct effects would occur predominantly through changes in the frequency and severity of weather events (e.g., temperature, wind, precipitation) that have direct impacts on the human physiology or psychology. Examples include changes in the incidence of illnesses or deaths from exposure to thermal extremes or extreme weather events. Indirect impacts would occur predominantly through the effect of climate on other biological or geophysical systems that influence human health. For example, climate change could influence the range and activity of disease vectors and infective parasites, the ecology of waterborne and food borne infectious agents, the levels and biological impacts of air pollutants, and the productivity of food systems. Factors affecting regional vulnerability to climate change include 1) the nature and extent of the change in regional climatic variables that directly or indirectly affect human health, 2) the degree to which humans or our biophysical support systems are sensitive to these changes, and 3) the ability of humans and our biophysical support systems to adapt to new climates.

We do not attempt a comprehensive assessment of the range of risks in this report. Instead we focus on heat-related illness, cryptospridiosis, malaria, and cholera. These cases are of special interest in the region and involve major direct and indirect health impacts. A more complete assessment is found in Kocagil et al., 1999.

Heat-Related

In general, temperature has a u-shaped relationship with mortality: very cold and very warm temperatures are related with higher mortality. If climate change causes higher temperatures in the MAR, as predicted by the Hadley Center climate model, there may be reductions in cold related mortality and morbidity and increases in heat related mortality and morbidity. The Hadley Center climate model predicts an increase in annual mean temperature in the MARA region of 4.5° F for the period from 1990 to 2099 with minimum and maximum temperatures increasing 4° F and 5° F respectively. By 2030, minimum and maximum temperatures are expected to increase by 2° F with much of the change occurring in the summer. Recognizing that a significant proportion of the MAR population lives in urban areas and that this population is more susceptible to warmer temperatures because urban areas act as heat traps, the predicted change in temperature is likely to increase heat related mortality and morbidity in the Mid-Atlantic region.

Kalkstein and Swift (1998) and Kalkstein and Greene (1997) examine the relationship between weather and mortality in several Mid-Atlantic cities: Baltimore, Greensboro, Philadelphia, Pittsburgh, Washington, DC. They identify air masses currently associated with high mortality during summer and winter months. Using three GCMs (the Geophysical Fluid Dynamics Laboratory (GFDL), the United Kingdom Meteorological Office, and the Max Planck Institute for Meteorology models) they predict how the frequency of these high-risk air masses might change in 2020 and 2050 with climate change. They apply the current mortality-climate relationships assuming full acclimatization to the future scenarios to estimate excess mortality due to the high-risk air masses. For instance, summer mortality for the 5 cities combined either decreases by 21% or increases by 26% or 126% for the 2020 scenarios and increases by 71% to 181% for the 2050 scenarios, depending on the GCM used.

Examination of the individual cities reveals that Washington, DC is the least vulnerable to summer high risk air masses. Kalkstein and Swift (1998) and Kalkstein and Greene (1997) estimate that for Philadelphia, excess deaths in 2050 could increase by 91 to 270% over current levels depending on the GCM used. Summer mortality would increase 48 to 95% for Baltimore, 56 to 144% for Pittsburgh, and 32 to 105% for Greensboro. Winter mortality is not found to be as strongly associated with air mass as summer mortality.

The decreases in winter mortality are not large enough to offset the increases in summer mortality.

It is important to note that the results vary widely depending on the GCM used. In addition, adjustments for future demographic changes are not included in the analysis. Changes in the age distribution of the population may be especially important for heat related mortality.

Cryptosporidiosis: In the past twenty years, *Cryptosporidium parvum* has gained attention as a potentially deadly protozoan infecting water supplies. Since the first reported case, in 1976, Cryptosporidium has been confirmed as the cause of several waterborne and foodborne illness outbreaks. The most devastating outbreak to date is the 1993 Milwaukee, Wisconsin outbreak causing several deaths and more than 400,000 illnesses. Waterborne outbreaks have been confirmed in all regions of the United States from both ground and surface water sources.

Some researchers believe the health risks from Cryptosporidium could increase if environmental conditions change. Warmer and wetter conditions in the United States may increase oocysts viability or increase the transportation of oocysts. A wetter climate projection may be more consequential because Atherholt et al. (1998: 78) found most of the Cryptosporidiosis outbreaks "occur during or following rainfall." These outbreaks may occur because of greater water run off through livestock pastures and/or a severe influx of storm water leading to a failure of waste water treatment plants. If the MAR climate change scenarios hold true, people could have more chances to come in contact with Cryptosporidium. More exposure opportunities would likely increase the number of Cryptosporidiosis cases within the region.

Changes in "crypto" risks for a water system are extremely difficult to predict. They will depend on the way that climate (e.g., temperature and precipitation) changes in the source watershed, characteristics of the watershed (e.g., location of cattle or other crypto pools in hydrologically active areas), water supply system characteristics (e.g., ground and/or surface supplies, location of surface intakes or well fields, types and management of source water treatment). These characteristics are highly system specific.

The impacts of climate change on crypto risks for the MAR region are highly speculative at this time. Because humans and animals are the source of Cryptosporidium, we expect risks to continue to be present in the MAR. Dairy, swine, and poultry are important agricultural activities in the region and often occur in highly populated watersheds. We do not expect significant growth in these activities, and significant decline is plausible. In either case, we anticipate increased regulation of agriculture to reduce contamination of surface and ground water supplies. A critical factor affecting the incidence of the disease is water treatment. Effective water treatment limits the risk of massive outbreaks. Under current and proposed EPA regulations, water systems classified as large or very large should, theoretically, have filtration systems that greatly reduce the threat of Cryptosporidiosis.

Although additional research is needed to better understand crypto risks and how they may change, our preliminary assessment is that climate change will not lead to Cryptosporidiosis becoming a primary health risk to the citizens of the MAR. We are working present case studies of the potential risk from Cryptosporidium within the Delaware River Basin and Lancaster County, PA. These case studies illustrate linkages between climate change and crypto risks, the economic costs of contamination events, and adaptation strategies and their costs.

Malaria

Malaria is the most consequential insect transmitted disease in the world. Latest WHO estimates between 300-500 million cases of clinical malaria per year, with 1.4-2.6 million deaths, mainly among African children. Malaria remains the only insect-borne, parasitic disease comparable in impact to the world's major killer transmissible diseases. Previously extremely widespread, the disease is now mainly confined to the poorer tropical areas of Africa, Asia and Latin America. Inadequate health structures and poor socioeconomic conditions aggravate the problems of controlling malaria in these countries. During the late 1940s, a combination of improved socioeconomic conditions, water management, vector-control efforts, and case management successfully interrupted malaria transmission in the United States. A malaria case surveillance program is operational to detect locally acquired cases. Most of the Malaria cases documented within the MAR are imported cases. An imported case is when a person contracts the disease while traveling in a malaria endemic area.

Since the 1940s, there have been fifty-seven outbreaks of probable mosquito-transmitted malaria in the United States. Some outbreaks, especially those in the northern parts of the US (e.g., Michigan, New York and New Jersey), are associated with above-average periods of temperature and precipitation. Climate change projections indicate a warmer and wetter climate, thereby improving the conditions for parasite reproduction. Examination of the 1995 Malaria case location reveals two important points. First, 50 percent (79 cases) of the malaria cases occur in the Baltimore-Washington, D.C. metropolitan area. Second, six counties in New Jersey had 16.3 % of the total cases in the MAR. These two facts could be significant with the development of autochthonous or localized cases in the MAR.

Even if climate change does lead to improved conditions for malaria transmission, there are measures that could prevent malaria from becoming a serious health risk. Australia provides a useful analogue. Australia has had localized cases of malaria, and still has mosquitoes capable of transmitting malaria, yet has not been considered a malaria risk area since 1981. The success of Australia's antimalarial program has been based to a large degree on the rapid diagnosis and treatment of humans with malaria. Similar public health measures could be implemented in the MAR.

Cholera

Cholera is currently thought to be a disease of the tropics. However, this was not always the case. John Snow conducted one of the first epidemiological investigations with his examination of an 1854 cholera outbreak in London, England. Although endemic cholera is generally confined to the tropics, a warmer and wetter climate could improve the conditions for cholera to thrive in the MAR waters.

No major outbreaks of this cholera have occurred in the United States since 1911. The majority of cases that occurred between 1973 and 1996 in the US are imported or when people contract cholera while traveling in a cholera endemic area. Many of the cholera outbreaks that have occurred in the Western Hemisphere are associated with the consumption of raw, improperly cooked or recontaminated shellfish. However, sporadic cases occurred between 1973 and 1991, suggesting the possible reintroduction of the organism into the US marine and estuarine environment. Analysis of the localized outbreaks from 1978-1999 shows that the Louisiana delta region has had 5 localized outbreaks and Florida 3 outbreaks of cholera cases.

In 1991, outbreaks of cholera in Peru quickly grew to epidemic proportions and spread to other South American and Central American countries, including Mexico. They have reported more than 340,000 cases and 3,600 deaths in the Western Hemisphere since January 1991. Environmental studies have shown that strains of this organism may be found in the temperate estuarine and marine coastal areas surrounding the United States. Thus, the potential for a serious outbreak does exist, although proper water treatment and shellfish preparation greatly reduces the risk.

3.6.4 Management Options and Strategies

Policy makers, governmental agencies, private organizations and even individuals can take various actions to respond to climate related problems. There is the potential for humans to create adaptive capabilities to mitigate health consequences from climatic changes in the MAR. For example, the recent introduction of a Lyme Disease vaccine will diminish the increased risk that may occur from a climate change conducive to spirochete production. Patz (1996) categorizes adaptive measures into administrative/legislative, engineering and personal behavior. Table 3.6.3, adapted from Patz's Table 1 (1996: 456), shows potential responses to climate related problems. Comparison of costs with benefits (e.g., improved health) should dictate which response(s) should be chosen. The most cost effective method may vary by disease and by the anticipated disease incidence under climate change. For example, in instances where the number of cases is likely to be small, it may be cost effective to treat people who become ill rather than develop a new vaccine. Kocagil et al., (1999) present a framework for evaluating and categorizing adaptive responses by based on effectiveness, complexity and cost.

Table 3.6.3 Responses to climate-related problems

Adaptive Measure	Heat-Related Illness	Cryptosporidiosis	Malaria
Administrative/ Legislative	Implement weather watch/warning systems Plant trees in urban areas Implement education campaigns Transport high risk individuals (i.e. elderly) to air conditioned locations during peak periods	Regulate water/sewer treatment systems Provide funding for development of treatment pharmaceuticals Maintain a disease surveillance system Mandate agricultural waste disposal Issue Boil Water Advisories	Monitor breeding sites Maintain disease surveillance system Implement education campaigns to eliminate breeding sites Fund research for development of a vaccine Implement provider awareness program on non-endemic diseases
Engineering	Insulate buildings Install high-albedo materials for roads	Install Cryptosporidium specific filtration/treatment systems	Install window screens Release sterile males Apply spot pesticides
Personal behavior	Maintain hydration Schedule work breaks peak daytime temperatures	Drink bottled water Use proper and frequent handwashing techniques	Use topical insect repellents Use pyrethroid-impregnated bed nets

3.6.5 Conclusions

Currently, mortality directly attributed to heat, cold, storms, flooding and lightning is very small in the MAR. Even if climate change greatly increased the risk of such mortality over current levels, the risks would remain small. The leading causes of death in the region are heart disease, cancer, and stroke. Climate can be an aggravating or contributing factor in these diseases, and climate change can be expected to have some effect on mortality risks. However, it reasonable to believe that lifestyle choices, such as smoking, diet, and fitness, and genetic endowment will remain much more important to the health status of the region.

Research suggests that projected climate changes for the region will increase heat-related mortality, although not by a large factor. We know less about the impact of climate on heat-related morbidity. We expect climate change will influence heat-related morbidity but are unable to quantify the change at this time.

We expect climate change to affect health risks through affects on water borne and vector borne diseases. Scenarios can be constructed in which risks are increased, however, this is a highly speculative area because of the uncertainty about local climates, the impacts of those changes on biological and geophysical systems influencing infectious disease pathogens and organisms that spread infectious diseases. We are guardedly optimistic that the current and future MAR health infrastructure has significant capability and adaptability to cope with increased health risks from a climate change. Even in this case, however, there are groups who would be disproportionately affected. These would be mainly the elderly and those with limited access to health care.

There are events (scenario breakers) that would alter our preliminary conclusions. Examples include:

- Unanticipated health impacts from climate-induced changes in ecosystems.
- A large influx of environmental refugees from outside the MAR. A sudden increase of refugees, for example from Africa, could over tax the health care delivery system, especially if these refugees bring native diseases to the MAR.
- Economic or other events that cause collapse of the region's public health infrastructure.
- Collapse of Medicare that left elderly populations extremely vulnerable to many types of health risks.

3.6.6 Research Priorities

In order to identify and prioritize the risks faced by the population, research on comparative risk assessment is needed. A preliminary illustration based on Viscusi (1993) and the current research shows that the relative risk of climate related mortality and morbidity is quite low in the MAR in comparison to risk of fatality due to cigarette smoking, fire, or car or plane accident (Appendix B). However, more research is needed to understand and quantify climate change impacts on health. Research issues include:

- epidemiological research to better understand the linkage between human health and climate (e.g., how changes in temperature and humidity may affect the human immune system).
- how climate change will affect ecosystems and how ecosystem changes will in turn affect disease vectors.
- research on the costs and benefits of various adaptation options to determine the optimal policy choice.
- how shifts in health policy may affect vulnerability to climate change.

Part 4: Where Do We Go from Here?

4.1 Summary of Key Findings (Fisher)

This report's earlier sections demonstrate many uncertainties in projecting, for 30 years from now and for 100 years from now, a) how the socioeconomic/ecological structure of the MAR will change, b) how the region's climate will change, and c) how changes in the region's climate will affect the socioeconomic/ecological picture, particularly because different people, organizations, species and ecosystems have differing capabilities to adapt to the additional opportunities or stresses accompanying climate change. Despite these uncertainties, we are able to derive significant results that the region's citizens and decision makers can use to improve near-term decisions that affect the future of the MAR.

4.1.1 Impacts/consequences from increased climate variability and change

Because of its advanced state of economic and social development, diverse topography, and land cover, the Mid-Atlantic region has the good fortune of being reasonably resilient to changes ranging from population growth and redistribution within the region to rapid evolution in the types of goods and services people want to dramatic changes in the technology for producing commodities. This resilience also will help the MAR adapt to increased climate variability and climate change. On the other hand, 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 because rising incomes increase the demand for recreation, including outdoor recreation in natural areas. These features--substantial overall resilience in concert with pressure on ecosystems--summarize the region's basis for taking advantage of new opportunities created by climate change and for coping with negative impacts from climate change.

MARA's preliminary results suggest the following impacts from increased climate variability and change:

Agriculture

Agriculture has declined in importance within the MAR (reflecting national trends) as well as adapting rapidly to changes in production and processing technology and to changing demands for different agricultural products. Because farmers are adaptable, climate change is likely to increase production of soybeans and tree fruits, and possibly corn. Climate change could have negative impacts on the region's tobacco, primarily because of increased competition from outside the MAR. The region's other two major agricultural categories, dairy and poultry, are not expected to be affected by climate change. The main environmental side effects from agricultural production are nutrient and pesticide runoff, and erosion. If raising livestock continues to be as important in the MAR, nutrient leaching and runoff could increase. Risk from some waterborne diseases, such as Cryptosporidiosis, could also be affected. The 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 is little research for identifying threats or opportunities.

Forests

Whether forests are managed for watershed protection, harvesting of sawtimber, or maintenance of forest aesthetics, their managers report increased operating costs when extreme weather occurs. These costs would be higher if extreme weather becomes more frequent or intense. 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. This could decrease the competitiveness of the many small hardwood processors (e.g., for furniture and cabinetry).

Fresh water quantity and quality

Rapid development in some parts of the MAR that rely more heavily on ground water wells, especially for residential use, has created stresses because of potential surface water infiltration, or in the coastal zone, salt water intrusion. The potential for a wetter regional climate, punctuated by droughts, suggests higher water supply management costs, to accommodate source protection (for water quality of both surface water and ground water) and more storage capacity. Smaller water systems and individual well owners have the disadvantage of not being able to spread these costs over large numbers of users. There is, however, significant potential for improved efficiency of water use through innovations in demand management. The effects of changed climate on the MAR hydrology also are likely to stress ecosystems, because "flashier" runoff will carry more contaminants and sediment to streams that simultaneously are somewhat warmer because of higher average air temperatures. Changes in the amount, timing, and quality of water might affect ecosystems from the headwaters and throughout the drainage basins until they reach the estuaries and bays of the MAR. Land use decisions can have a large impact on the quantity and quality of runoff. Because these decisions have long-lasting effects, future vulnerability related to water resources will be influenced by decisions now and in the near future.

Coastal zones

The MAR coastal zone's dense population puts people in harm's way from storm surges that will be exacerbated by the combined effects of sea level rise from climate change and subsidence. The costs of protecting valued infrastructure or natural areas could be quite high. The benefit of longer coastal recreation seasons could be more than offset, if severe storms become more frequent or intense. The very diverse and productive ecosystems in salt marshes are vulnerable to sea level rise, because sediments and organic matter are not deposited fast enough to allow them to keep up with sea level rise and barriers often prevent inland migration.

Ecosystems

Many ecosystem components are quite resilient, while others are very fragile. In many locations, the MAR ecosystems already are stressed. Changes in carbon dioxide concentration, temperature, precipitation and sea level in the MAR will affect individual species differently. 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 the ecosystem functions that are crucial for ordinary ecosystem evolution as well as functions that people value, such as pollinating crops, moderating and purifying water flows, and providing diverse wildlife to observe.

Human health

Morbidity and mortality directly related to heat, cold, storms, flooding and lightning are likely to continue to be very small in the MAR, although climate change could increase these somewhat. Climate change could aggravate or contribute to the region's leading causes of death (heart disease, cancer, strokes), but lifestyle choices (smoking, diet, fitness) and genetic endowment are likely to continue dominating the health status of the region. Although more speculative, climate change could increase the region's risk from water borne and vector borne diseases. The region's current and future health infrastructure are expected to be able to cope with these risks, but the elderly and those with limited access to health care still could be disproportionately affected.

4.1.2 Win-win strategies identified for early action

- Education and public information strategies so that people in the MAR will know what they can do to capitalize on benefits and ameliorate damages from climate change.

- In agriculture, continued adaptation, especially for biotechnology and precision agriculture. This requires disseminating information in a form farmers can use.

- Extend provisions of the Clean Water Act beyond small community water systems to help individual well owners reduce their vulnerability to potential variability in the amount and quality of water.

- Water demand management policies to increase the efficiency of water use.

- Land use planning procedures and ordinances that reduce risks from flooding and runoff pollution, and protect well fields.

- Watershed-based water quality protection programs, especially for nonpoint sources.

- For ecosystems, strategies that address current stresses also will reduce potential stresses from climate change. These include preserving forests and wetlands, minimizing urban and agricultural soil erosion and nutrient runoff, protecting stream habitat, and reducing the release of toxic chemicals.

- Beach nourishment is cost-effective for protecting some coastal developments; allowing coastal retreat is more cost-effective in other areas (although this would be accompanied by net losses in coastal ecosystems if barriers prevent their migration).

- Silvicultural practices to encourage species that thrive in pine and oak-hickory forest types, including cutting to minimize wind and ice damage, and monitoring for potential increases in any pests and diseases expected to be more prevalent under climate change conditions.

- (- Monitoring for disease vectors identified as moderate-to-high risk in the MAR.)

4.2 Next Steps

4.2.1 Maintaining and enhancing the mechanism for public involvement (O'Connor)

The guiding philosophy of the MARA team has been to work with stakeholders to design and implement the assessment. The process has been dynamic and interactive, with this report a milestone, not an endpoint. With this milestone completed, the challenge is to engage stakeholders in responding to its findings and to move ahead to elicit new information and deliver it to stakeholders. We will continue to work with our Advisory Committee as well as use other mechanisms to enhance the two-way flow of information. Identifying win-win strategies for specific stakeholder groups will have little impact on the Mid-Atlantic region unless those groups get this information in a manner they find credible and useful. We have three mutually supportive types of activities planned: Advisory Committee involvement, public information materials, and focused efforts at identifying stakeholder informational needs and preferences.

Advisory Committee

Advisory Committee members will continue to work on a one-on-one basis with MARA team members to address specific concerns and interests. In early May 1999 the Advisory Committee will meet at Penn State to review the initial assessment, discuss next steps in assessment, and work on planning a dissemination strategy. During the next year the Advisory Committee will continue to review documents and work on dissemination.

Public Information Materials

The MARA team does not have the resources to mount a full public information campaign. Nevertheless, the team is committed to develop materials and distribute them to interested groups and the media. Where we have identified win-win strategies applicable to particular stakeholder groups, we will work with organizations associated with those groups to ensure that they get this information in a form that is appropriate, timely, and useful. For the general public, we are working with public information specialists at Penn State and on our Advisory Committee (e.g., Bud Ward of the National Safety Council) to devise a strategy that will leverage our resources by providing materials to groups and the media. Materials may include real-time computer simulations to demonstrate potential impacts.

Focus Groups and Scientific Surveys

The initial assessment shows that certain groups in the region face significant stress from growth and other factors having nothing to do with climate change, but that climate change adds an additional element of uncertainty and concern. There may be win-win strategies for these groups that would reduce risks and help to preserved a valued way of living. We intend to carry out a number of focus groups with members of these groups (e.g., barrier island residents, commercial anglers) to learn what information they would like in what form, and what research they think needs to be done. We will work with the Advisory Committee in designing this work and recruiting some participants. The results of these focus groups will both help inform additional assessment activities and feed into the design and implementation of scientific surveys of different stakeholder groups as well as the general population of residents of the Mid-Atlantic region. We expect to learn how better to communicate with stakeholders about climate change in the context of planning for themselves and their communities. We expect this work to produce important substantive findings as well as methodological advances that can be used for ongoing assessments here and outside this region.

One research priority is to identify stakeholder preferences for ecological assessment and protection. The ecology of the region faces many stresses, with some ecologically valued places and objects more vulnerable than others to climate change impacts. The initial assessment produced much information on how and where the ecological is threatened, but little information on exactly *what* stakeholders value about the ecology to a greater or lesser degree. The research task is to use what we have already learned to ascertain how residents of the Mid-Atlantic Region understand and value the ecology. A vast array of ecological changes is likely, but we do not know how to focus resources on particular places or species to reflect societal values.

Still to be addressed are issues of a) How to better communicate uncertainty. Insurance companies do this..., and b) How to better relate potential climate change impacts on people and the environment to their everyday lives.

4.2.2 Identified research priorities and information needs (Fisher)

- Improved ability to project frequency, timing and intensity of extreme weather events at a regional level
    - impacts on agriculture, forests, ecosystems, and coastal zones

- impacts on environmental side effects from agriculture, silviculture, development patterns

- How climate change would affect weeds, and insects and diseases in crops, livestock, and forests.

- How climate change would affect environmental side effects from agriculture

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

- Research into ecosystem processes, how people depend on them, and how human activities alter them.

- Specific research on how changes in climate variables affect different types of ecosystems (with respect to ecosystem function, especially fragile components that might be replaced by invasive species or affected by indirect impacts because of changes in nutrient runoff, how ecosystem changes affect disease vectors).

- Valuation of ecosystem components and processes.

- Research on the linkage between human health and climate, such as how temperature and humidity affect the immune system

- Identification of methods for evaluating how proposed shifts in policy (e.g., health policy, land use policy, agricultural policy) would affect vulnerability to climate change.

- Research on the benefits and costs of alternative adaptation options, so that efficiency can be considered in management and policy decisions.

4.2.3 Types of issues still to be addressed [add issues that can and should be addressed in the next phase of the first MARA, or in future assessments]

4.3 Summary

Positive impacts:

- Overall benefits to agriculture in the region, especially soybean and tree fruit production, and possibly corn.

- Extended outdoor recreation seasons, particularly for those visiting coastlines.

- Decreased cold-related mortality

- Increased primary forest productivity
- Increased water supply

Negative impacts:

- Reduction in biodiversity and ability of ecosystems to function effectively for societal values such as water storage and purification, fish and wildlife for recreation,
- Shorter winter outdoor recreation seasons, particularly for the snow skiing resorts in the MAR.
- Increased heat-related mortality risks in some cities.
- Increased probability of floods.
- Property and ecosystem damages from sea level rise.

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Appendix A:

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As part of the national assessment process, the regional and sectoral teams also receive diverse types of information, data, input and feedback from NAST, NACO and NAWG.

Appendix B:

Introduction

The MARA team has used a variety of research methods to prepare the results for this report and in their ongoing work. These methods include:

- *Empirical downscaling* to improve the regional resolution of changes in temperature and precipitation available from the models and projections provided by NAST, NAWG, and NACO.
- *Statistical estimation of models* for examining relationships between climate and water resources, forest resources, ecosystems and health risks.
- *Geographic Information Systems* for processing and displaying baseline and other data.
- *Social Accounting Matrices, Input-Output Models, General Equilibrium Models* for characterizing the regional economy and analyzing economy-wide impacts of climate change.
- *Comparative Risk Assessment* and *Event Trees* for analyzing impacts of climate change on disease risks.
- Collection and analysis of primary data from targeted groups such as community water system managers and forest managers.

Below we provide additional detail on selected methods and topics.

Agricultural Baseline

This section discusses baseline futures for agriculture in the Mid-Atlantic region – in other words, how agriculture might change between now and 2030 independent of any impacts due to climate change. As discussed in Part 3, the uncertainties surrounding the year 2100 are so overwhelming that it is very difficult to think about baseline agricultural scenarios for that year.

Key Socioeconomic Variables

In thinking about key socioeconomic variables for Mid-Atlantic agriculture that determine future baseline scenarios, the focus should be on variables that are highly relevant to the future of agriculture in the region. Key socioeconomic variables for Mid-Atlantic agriculture can be grouped into four broad categories:

1. ***Markets for agricultural commodities in the Mid-Atlantic region.*** This can in turn be grouped into two subcategories:

   a. *Real (inflation-adjusted) prices of tradable agricultural commodities.* These are commodities that the Mid-Atlantic region either imports or exports to other regions of the U.S. or other countries.

b. *Demands within the Mid-Atlantic region for nontraded agricultural commodities.* These are commodities that are produced and then entirely consumed within the Mid-Atlantic region.

Most agricultural commodities produced in the Mid-Atlantic, and certainly the ones accounting for the vast majority of farm income, are tradable between the Mid-Atlantic and other regions and countries. Major tradable commodities currently produced in the region include dairy products, beef, pork, poultry, eggs, corn, wheat, other grains, soybeans, tobacco, mushrooms, other greenhouse products, apples, and peaches. Given probable future developments in transportation and communications, we anticipate that the degree of tradability of agricultural commodities in the Mid-Atlantic will increase even further.

The Mid-Atlantic region is an important producer of many tradable agricultural commodities. Nevertheless, even for commodities such as milk, the Mid-Atlantic region currently accounts for a small percentage of total US production and an even smaller percentage of global production and trade. For this reason, supplies and demands for these commodities in the Mid-Atlantic are unlikely to have significant effects on prices of these commodities. The Mid-Atlantic region, in other words, is a price taker for these commodities.

The most important commodity for which little or no interregional or international trade occurs at present is hay. Other commodities in this same category include some seasonal fresh fruits and vegetables, for which it is uneconomic at the present time to ship them interregionally or internationally. Demands for these commodities are likely to depend on population growth in the region, per capita income growth in the region, and trends in prices of substitute commodities.

2. ***Markets for agricultural inputs in the Mid-Atlantic region.*** This can be broken down into two subcategories:

    a. *Real prices of capital, labor, and purchased materials.* Labor includes both farm operator labor and hired labor, while purchased materials include seeds, processed livestock feed, fertilizers, pesticides, and energy.

    b. *Competing demands within the Mid-Atlantic region for nontraded inputs, principally land.*

Capital and labor, at least in the long run, are highly mobile between Mid-Atlantic agriculture and other sectors of the Mid-Atlantic economy. They also tend to be quite mobile between regions of the country, and in the case of capital also quite mobile internationally. In the short run, capital and labor do not tend to move quickly between sectors or regions of an economy. However, over the long time horizons contemplated for climate change, these short-run rigidities disappear. At the same time, Mid-Atlantic agriculture is a small part of the Mid-Atlantic labor force and economy, and a trivial part of the entire U.S. labor force and economy. For these reasons, returns to capital and labor in agriculture are determined by economic forces in the U.S. and global economies as a whole (Johnson, 1991). The Mid-Atlantic region, in other words, is a price-taker for capital and labor.

Purchased materials also tend to be highly mobile between Mid-Atlantic agriculture and agriculture in other regions and countries. Furthermore, in the long run, the capital, labor, and natural resources used to produce purchased agricultural materials can be withdrawn at relatively low cost for use in other sectors of the economy. For these reasons, Mid-Atlantic agriculture is also a price-taker for purchased materials.

Mid-Atlantic agriculture is definitely not a price taker for land, since it accounts for about one-fourth of total land use in the region. Forests and urban development are major competing land uses. Historically, much abandoned agricultural land in the region has gone back into forests, while in more recent years significant areas of agricultural land have been converted into urban uses.

Another input that would fall into the same category as land in many other regions of the US is water, since agriculture is a major user of water for irrigation in many parts of the country. As discussed in Part 2, however, irrigation is of negligible importance in the Mid-Atlantic at the present time.

3. ***Technologies available to agricultural producers within the Mid-Atlantic region.*** This can be divided into three subcategories:

   a. *New technologies for producing existing agricultural commodities.*

   b. *Technologies that lead to the production of new agricultural commodities.* These could be either commodities that do not yet exist or commodities that exist but are not currently being produced in the Mid-Atlantic.

   c. *Technologies that lead to the use of new agricultural inputs.* These could be inputs that do not yet exist or inputs that exist but are not currently being used in the Mid-Atlantic.

For the Mid-Atlantic region, available technologies are largely exogenous because most technologies are developed for national or global markets, and the Mid-Atlantic is too small economically to significantly affect national and global rates of technical change. Of course, the fact that a technology is available does not mean that it must or will be used. Individual farmers, companies, households, and organizations within the Mid-Atlantic will make choices about what technologies to adopt among the available set of options.

4. ***Public policies and institutions.*** This is potentially a very broad category, but some key components would include:

   a. *Agricultural price and income support policies.*

   b. *Environmental policies facing agricultural producers.*

   c. *Agricultural land preservation policies, land retirement and set-aside policies, and land use regulations and institutions.*

   Among all the policies and institutions that could be listed here, these three stand out as particularly important because of (1) their large, or potentially large, impacts on farmers and farm management decisions, and (2) the high likelihood that these policies will change significantly over the next 25-50 years.

   Agricultural price and income support policies in the U.S. are almost exclusively the province of the federal government. For the Mid-Atlantic region, public policies and institutions at the federal level are largely exogenous because the Mid-Atlantic is too small (in economic and political terms) to influence the structure of overall policies or institutions at this level.

   Environmental policies toward agriculture have traditionally been the province of the states, rather than the federal government, with the notable exception of pesticide regulation. All three levels of government (federal, state, and local) have traditionally had some authority over land use. Local governments within the Mid-Atlantic region can influence land use through zoning, tax, and other policies. State governments in the region have policies designed to foster the preservation of agricultural land. At the federal level, land retirement and set-aside policies have long been a part of agricultural price and income support programs.

Agricultural Commodity Markets

A number of near-term futuring exercises have been conducted in recent years for world agricultural commodity markets, with time horizons ranging from 2008 to 2030. These studies include economic simulation models constructed by the International Food Policy Research Institute (Islam, 1995) and the U.S. Department of Agriculture (1999), as well as more qualitative analyses by Crosson and Anderson (1992).

Baseline projections by the International Food Policy Research Institute (Islam, 1995) and the U.S. Department of Agriculture (1999) suggest that real prices for major agricultural commodities such as wheat, corn, other grains, soybeans, dairy products, beef, pork, chicken, and eggs are all likely to decline in the coming decade, perhaps significantly. These projections imply that productivity growth in world agriculture is likely to outstrip growth in food demand caused by population growth and growth in per capita income. As Johnson (1998) notes, estimates of future population growth have dropped since these baseline projections were constructed, suggesting even larger declines in agricultural commodity prices. These projections are consistent with trends in global agricultural prices since the end of World War II. In real terms, prices of agricultural commodities as a whole stand today at about one-fourth of their 1950 levels. The more qualitative analyses by Crosson and Anderson (1992) for the year 2030 are consistent with these projections.

Others, such as Tweeten (1998) and Brown (1996), are more pessimistic about the potential for productivity growth in world agriculture to outstrip the growth in global food demand. They suggest that real prices of agricultural commodities could rise somewhat over the next few decades. However, as Johnson (1998) emphasizes, such projections have consistently been proven wrong in the past.

These price projections are particularly important for the Mid-Atlantic region because the region is a marginal producer of a number of agricultural commodities. Unlike many parts of the Corn Belt, Great Plains, or numerous other countries, agricultural land in the Mid-Atlantic has a number of competing uses. Many other regions and countries can produce grains, dairy products, poultry, and other commodities at lower prices than the Mid-Atlantic and still remain profitable because there are few economically viable alternative uses for their agricultural land.

Demand could potentially grow in the Mid-Atlantic region over the coming decades for fresh fruits and vegetables, in particular organically grown fruits and vegetables. A growing demand for organic produce is already evident in Western Europe and, to a lesser extent, the United States (Thompson, 1998). Given costs of transporting fruits and vegetables, much of the demand in the Mid-Atlantic region may be satisfied by production within the region. However, the nature of fruit and vegetable production is that significant amounts can be grown on small parcels of land. Thus, we do not anticipate that fruit and vegetable production will become a dominant part of Mid-Atlantic agriculture.

Agricultural Input Markets

There probably will not be significant long-term changes in real interest rates facing the Mid-Atlantic region, while a continuation of the long-term upward trend in real wages and salaries is probable. The U.S. economy appears to be close to an economic steady state in which long-term real interest rates are constant and the long-term growth rate in real wages and salaries is also constant (Barro and Sala-i-Martin, 1995). This means that Mid-Atlantic farmers, and prospective farmers, will face increasingly better earnings prospects outside of agriculture, and thus returns to labor in agriculture will have to rise to keep pace. Historically this has meant larger farm sizes and fewer farmers, a trend that is likely to continue.

Future increases in population in the Mid-Atlantic region may lead to additional conversion of farmland to residential and commercial uses. Future increases in per capita income could manifest themselves in larger homes and lot sizes, and thus more residential land use, a tendency evident over the last 30 to 40 years. Studies of land use confirm that population and per capita income are important determinants of the conversion of farmland and forestland to urban uses (Hardie and Parks, 1997; Bradshaw and Muller, 1998).

Probable futures for the spatial pattern of development within the Mid-Atlantic region are more difficult to assess than an overall tendency toward urbanization. There may be a "fill in" of areas between existing major urban centers, such as the area between Baltimore and Washington, DC (Bockstael and Bell, 1998; Bockstael and Irwin, 1997). Some have speculated that future information technologies could render cities obsolete, leading to spatial population dispersion. However, this presumes that information technologies are a substitute for the regular face-to-face interactions that a city makes possible, when they in fact could be complements (Gaspar and Glaeser, 1998). Friendships and business relationships that begin with an e-mail message may continue over lunch or dinner.

Agricultural Technologies

Technology is a "wild card," both because of its unpredictability and because of its potential to trump other changes in Mid-Atlantic agriculture, including climate change. Based on what we know now, three technologies would appear to have significant implications for Mid-Atlantic agriculture: biotechnology, precision agriculture, and improved weather forecasting.

The basic science of biotechnology is progressing very rapidly, and already tens of millions of crop acres in the U.S. have been planted with genetically modified organisms (GMOs). Corn has had the most GMO releases to date, and should have substantially more during the next decade. Plant biotechnology has the potential to yield crops with significantly greater resistance to a whole host of pests, greater resilience during periods of temperature and precipitation extremes, and even cereal varieties that fix atmospheric nitrogen in the same manner as legumes (Plucknett and Winkelmann, 1996; Huttner, 1996). Work is also underway to engineer pest vectors into beneficial insects as part of integrated pest management (IPM) strategies. Animal biotechnology has the potential to yield livestock that process feed more efficiently, leading to reduced feeding requirements and fewer nutrients in animal wastes. Feed may also be genetically modified so as to reduce nutrients in livestock wastes. Genetically engineered vaccines and drugs could significantly reduce livestock mortality and increase yields. Plant biotechnology is already being used to develop higher quality crops that have attributes desired by consumers, and the same may occur with animal biotechnology.

We recognize that many people, such as Rifkin (1998), are very skeptical about the effectiveness and environmental consequences of agricultural biotechnology. For example, GMOs with tolerance to herbicides are also being developed and released, and concerns have been raised that these may promote herbicide usage. The challenge here will be to encourage herbicide-tolerant GMOs only insofar as they lead to use of more effective and more environmentally benign herbicides.

Precision agriculture has the potential to significantly increase agricultural productivity by giving farmers much greater control over microclimates and within-field variations in soil conditions, nutrients, and pest populations (National Research Council, 1997). This may be accompanied by significant improvements in computer-based expert systems to aid farmers with production decision-making (Plucknett and Winkelmann, 1996). The environment could also benefit insofar as precision agriculture permits fertilizers and pesticides to be applied more precisely where they are needed at the times of the year when they are needed.

Future improvements in computer technology and in modeling smaller scale climatic processes such as thunderstorms can be expected to lead to improved weather forecasts (Tribbia, 1997). Improved forecasts may lead farmers to make better choices about what crops to plant, when to plant and harvest, when to protect temperature-sensitive crops such as tree fruits, when to fertilize, and other farm management decisions (Johnson and Holt, 1997; Mjelde et al., 1998). This can be expected to increase agricultural production.

Public Policies and Institutions

With respect to agricultural price and income support policies, there appears to be slow trend toward global agricultural trade liberalization. Accompanying this may be a dismantling of traditional agricultural price and income support policies and a move toward direct payments to farmers that are not tied directly to their current production. Agricultural trade liberalization should have modest effects on prices of most agricultural commodities (Goldin et al., 1993; Hertel, 1996). An exception may be dairy products. Dairy markets in most countries, including the U.S., are highly protected from imports at present. Trade liberalization could significantly reduce prices of dairy products, which is significant given the current importance of dairy production in the Mid-Atlantic region. Dairy production could shift to other regions and countries that have a comparative advantage in dairy.

The future of environmental policies toward agriculture in the Mid-Atlantic is uncertain. To the extent that growth occurs in large-scale, highly intensive livestock operations in the Mid-Atlantic, and to the extent that population growth within the region places more people in close proximity to these operations, state and federal environmental regulations may increase. Prospects for changes in regulation of less intensive livestock operations or of grain farms are more difficult to assess.

All eight states in the Mid-Atlantic region have programs such as agricultural protection zoning, differential property assessment, and conservation easements that are designed to protect farmland from development (American Farmland Trust, 1997). However, these programs may have limited impact because the lands enrolled are generally ones that would not have been developed anyway (Bockstael and Bell, 1998).

Two Future Baseline Scenarios for Mid-Atlantic Agriculture

As discussed in Part 2 of this report, the purpose in constructing future baseline scenarios cannot and should not be to assemble an exhaustive list of all possible futures. Nor should the purpose be confined to single point forecasts of future baseline socioeconomic conditions. Instead, a relatively small number of scenarios should be chosen. When taken as a whole, the scenarios should, with some reasonable degree of confidence, yield upper and lower bounds on potential climate change impacts. With this in mind, we consider two future baseline scenarios for Mid-Atlantic agriculture:

1. ***Smaller, More Environmentally Friendly Agriculture (SEF).*** Under this scenario, real prices of most agricultural commodities continue their historical downward trend, reducing the profitability of agriculture in the Mid-Atlantic region. Agricultural production shifts to a large extent to other regions and countries. The downward trend in production within the region is accelerated by a growing demand for land in urban uses. The decline in dairy production is also accelerated by trade liberalization, which leads to an even greater shift in production to other countries.

   The decline in agricultural production is accompanied by a significant decrease in both the amount of land in agriculture and the agricultural labor force. Agricultural production as a percentage of the region's total economic output also declines. However, the farmers that remain enjoy significantly higher living standards than do farmers within the region today. Overall economic growth raises wages and salaries in competing economic sectors, meaning that returns to labor in agriculture must rise to keep pace. The farms that remain are significantly larger (in acreage and in the number of livestock) than are farms within the region today.

   Development and adoption of precision agriculture permits Mid-Atlantic farmers to better adjust their production practices to microclimates and to variations in other growing conditions within and between farm fields. Because of biotechnology, the crops that are grown in the region are more tolerant of temperature and precipitation extremes, and have substantially improved resistance to pests and diseases. Livestock within the region consume feeds designed to reduce content of animal wastes, and livestock are also genetically engineered to produce wastes with lower nutrient contents. Pesticide use decreases significantly. There are stricter environmental regulations over intensive livestock operations.

2. ***Continuation of the Status Quo (SQ).*** We consider this scenario not because we think it is likely that agriculture in the Mid-Atlantic will continue as it is now. Indeed, this is an exceedingly unlikely scenario. However, this scenario in conjunction with the SEF scenario helps to establish bounds on climate change impacts.

The upper and lower bound established by each scenario are listed in Table B.1. The SQ scenario establishes an upper bound on negative climate change impacts on production simply because agriculture is much larger in the SQ scenario than in the SEF scenario.

The SEF scenario establishes an upper bound on positive climate change impacts on production because, even though agriculture is smaller than in the SQ scenario, it is much better equipped to take advantage of positive climate developments. The SQ scenario establishes upper bounds on positive and negative environmental side effects because agriculture in this scenario is larger than in the SEF scenario. In addition, biotechnology and precision agriculture in the SEF scenario that are unavailable in the SQ scenario help minimize negative environmental side effects.

Table B.1. Upper and Lower Bounds Established by the Two Agricultural Baseline Scenarios

	Negative Impacts on Production	**Positive Impacts on Production**	**Negative Environmental Side Effects**	**Positive Environmental Side Effects**
Upper Bound	SQ	SEF	SQ	SQ
Lower Bound	SEF	SQ	SEF	SEF

SQ = Status Quo Scenario
SEF = Smaller, More Environmentally Friendly Scenario

Methods for Assessing the Potential Impacts of Climate Change on Coastal forests of the Chesapeake Bay Region

The study site for this GIS analysis was the area defined by coastal counties of the Chesapeake Bay. We determined land uses from 1993 MRLCs for the Chesapeake and based coastal flooding projections on an estimated sea level rise (SLR) of 73 cm. This is the mean slr estimated from the EPA report, *The Probability of Sea Level Rise*, in which vertical accretion of 2mm/year by marshes was [or was not] included.

Elevation data were gathered from 7.5 minute (1:24,000) digital elevation models (DEMs) from the U. S. Geological Survey (USGS). DEMs are digital elevation data sets in raster format. The DEMs used in this analysis were manipulated with Arc Info software. The 7.5 minute DEMs use spacings of 30 x 30 m on a UTM (Universal Transverse Mercator) projection. Most of the analysis contains 30 m DEMs [, but a few were 90 m–if any of the 90 m DEMs are within Eric's boundaries]. The reliability of our projection and analysis of potential impacts relies on the quality of the maps that were available from USGS. We did no ground truthing nor systematic corrections of these maps. Our efforts to predict the effects of sea level rise on coastal forests also depended on 1993 MRLC land use data for the Chesapeake Bay. These data were also collected for 30 x 30 m grids.

Using ArcView software, our team calculated the amount of forest likely to be lost to coastal flooding by 2100 with a predicted SLR = 73 cm. If the future coastline indicates an area described as "forest" on the MRLC land use map will be under water in 2100, then that forest is considered "lost" as a land use. If a 30 x 30 m area on the MRLC map has mixed use, it is assigned a forest category if over 50% of the area is forested.

Comparative Health Risks

As part of the MARA health sector assessment, we are attempting to compare climate related health risk to other sources of health risk. A preliminary analysis is presented below.

Appendix B.2. Comparative Risks

Source of Risk	Annual Risk
Risk of fatality in the US:	
Cigarette smoking (per smoker) [a]	1 / 150
Motor Vehicle Accident [a]	1 / 5,000
Asteroid impact (doomsday rock) [a]	1 / 6,000
Fire [a]	1 / 50,000
Aviation Accident [a]	1 / 250,000
Approximate mortality risk within MAR derived from 1995 mortality rates:	
Cold	1 / 450,000
Heat	1 / 600,000
Storm/Flood/Lightning	1 / 10,000,000
Approximate risk of contracting disease in MAR derived from 1995 morbidity rates:	
Lyme Disease	1 / 9,500
Giardia	1 / 13,500

[a] Viscusi (1993).

Coastal Assessment

The current status of Mid-Atlantic estuaries has been evaluated by the Estuarine Eutrophication Survey of the National Oceanographic and Atmospheric Administration

(NOAA, 1997a; NOAA, 1997b). The descriptor ratings (typically low, medium or high) were based on discussions with eutrophication experts and reflect comparison with nationwide averages. The survey includes 18 estuaries in the Mid-Atlantic Region. Based on their salinity in parts per thousand (ppt), estuaries are characterized as follows: tidal fresh (0-0.5 ppt), mixing (0.5 to 25 ppt) and seawater (>25 ppt). Other water quality parameters include: turbidity, total dissolved nitrogen and phosphorus concentration, and dissolved oxygen concentration. Chlorophyll concentration (an indicator of phytoplankton biomass), the presence of nuisance and toxic algal blooms, and the amount of submerged aquatic vegetation (SAV) are included because of their effects on the upper trophic levels of estuarine ecosystems.

Appendix C:

Communication, Outreach, and Education

The MARA team involved stakeholders even before beginning the actual assessment work in 1998. In September 1997 the group that was to become the MARA team convened a meeting of stakeholders for the Chesapeake Bay and Delaware River Basin. Held at Penn State, the participants included both researchers and representatives of groups likely to be particularly affected by climate change. Participants identified those issues they judged deserving of special attention in an assessment of potential climate change impacts for the region. It was at this meeting that the potential importance of health effects emerged as a significant issue.

One group of stakeholders is the climate change research community. As soon as we received funding for the assessment, we convened a June 1998 meeting of researchers, held at Penn State. Working for universities and government agencies, this group provided a state-of-the-art explanation of available knowledge and resources. The researchers also participated in formal and informal interchanges regarding the structure and process of the assessment.

These researchers are one component of the MARA Advisory Committee. Researchers however, are certainly not 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 a myriad of experiences, including members 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.

A number of individuals want to help with the assessment, but are 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. They are Corresponding members of the Advisory Committee. The regular and corresponding members are listed in Appendix A.

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 are reviewing chapter outlines and potential scenarios to be used in writing the report.
- At completion of the draft assessment report, the Committee will review the document and suggest ways to improve it.
- Members are advising the MARA team regarding ways to disseminate the results in the region.

The stakeholders already have helped us 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 are scheduled to meet again on May 2-3, 1999, to review their draft preliminary assessment and offer 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.

One of the next steps is to develop and implement a process of selecting priorities for ecological assessment that involves stakeholders and researchers in the MAR. The initial MARA shows that climate change has potentially significant ecological impacts. 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 to what they want us to assess would reflect their mental maps and values. 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). Our Advisory Committee and some of our earlier work (Lazo et al. in press) has convinced us that this is not true, that 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.

Appendix D:

[To be provided by NACO, NAST, and NAWG.]

Appendix E:

Glossary

accretion: An increase in land area because of sediments deposited by flowing water, especially along shores. If accretion keeps pace with sea level, then relative sea level rise has little impact on coastal wetlands. If sea level rises faster than organic matter and mineral deposits can accumulate (or if sediments are trapped behind dams) coastal land can be inundated, especially during spring tides when tides are highest, for example at full moon.

algal blooms: A population explosion of aquatic plants, often as the result of nutrient-rich runoff

anoxic: Without oxygen

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

benthic: Bottom dwelling aquatic or marine organisms

biomass: The mass of living matter in an area (for example, grams of leaves and stems per cubic meter)

dinoflagellate: A group of marine protozoans (single-celled organisms) with two flagella (whip-like filaments used for propulsion)

downscaling: Reducing the scale of the model from global to regional scale

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 can cause them to experience a population explosion that can quickly cover the surface of the water and block sunlight from larger plants growing underwater and deplete dissolved oxygen.

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

flora: Plant life or vegetation of a region

geomorphology: The study of land configuration and evolution, primarily by geologists

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.

human capital: refers to the knowledge, information, skills, and abilities possessed by people. Physical capital refers to machines, transportation and communications infrastructure, water resource management structures, buildings, and other tangible investment goods. Physical capital is usually just known as "capital," but referring to it as physical capital helps distinguish it from other forms of capital. Natural capital encompasses all renewable and nonrenewable natural resources, and all market and nonmarket natural resources. It includes not only conventional commodity resources, such as fossil fuels, metals, fisheries, and forests, but other elements of nature that directly or indirectly affect human welfare (e.g., genetic material, the ozone layer, and hydrologic and carbon cycles).

hypoxia: A condition of having low levels of oxygen, often too low to support animal life

invertebrate: An animal without a backbone

mesoscale models: Models that focus on a regional, rather than a global or local, level

nutrient: An element that is necessary for growth and replacement of tissues, such as nitrogen, phosphorus, and potassium

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

physiographic region: Area with similar land form

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

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.

sediment: Fine grains of solid material suspended in water or settled out of water to be deposited on land

surficial: Taking place on or relating to the surface of the earth

topography: The physical features, such as elevation, of an area or the representation of its features on a map

transpiration: Evaporation from plant foliage

trophic level: Trophic levels refer to particular positions in a food web. Eutrophic means well nourished (or over fed); oligotrophic means underfed or with low nutrient levels.

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.

List of Acronyms and Abbreviations

AgSci: College of Agricultural Sciences (PSU)

CBP: Chesapeake Bay Program (EPA)

CCC: Canadian Climate Center (global climate model)

CDIAC: Carbon Dioxide Information Analysis Center

CENR: Committee on Environmental and Natural Resources (NSTC)

CIESIN: Consortium for International Earth Science Information Network

CIRA: Center for Integrated Regional Assessment (PSU)

CO_2: carbon dioxide (a greenhouse gas)

CWC: Cooperative Wetlands Center (PSU)

DHHS: Department of Health and Human Services

DOD: Department of Defense

DOE: Department of Energy

DOI: Department of Interior

EHC: Environmental Health Center (National Safety Council)

EMS: College of Earth and Mineral Sciences (PSU)

EPA: U.S. Environmental Protection Agency

EPIC: Environmental Planning Information Center

ERRI: Environmental Resources Research Institute (PSU)

ESSC: Earth Systems Science Center (PSU)

FEMA: Federal Emergency Management Agency

FIPS: Federal Information Processing System (a code that identifies counties)

FS: Forest Service (USDA)

GCLP: Global Change/Local Places

GCM: General circulation model; also global climate model

GCOS: Global Climate Observing System

GEIA: Global Emissions Inventory Activity

GENESIS: a global climate model

GFDL: Geophysical Fluid Dynamics Laboratory (NOAA, Princeton)

GHCN: Global Historical Climatology Network (at CDIAC)

GHG: Greenhouse Gas(es)

GIS: Geographic Information System

GISS: Goddard Institute for Space Studies (NASA)

HAD: Hadley Centre global climate model

HDGC: Human Dimensions of Global Change

IPCC: Intergovernmental Panel on Climate Change

JSTC: Joint Scientific and Technical Committee (of GCOS)

MACZ: Mid-Atlantic coastal zone

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

MAIA: Mid-Atlantic Integrated Assessment (EPA/ORD)

MAR: Mid-Atlantic region

MARA: Mid-Atlantic Regional Assessment

MLRA: Major Land Resource Area (with uniform soil, climate, water resources and land use)

MPE: Mission to Planet Earth (NASA)

MSA: Metropolitan Statistical Area

NACO: National Assessment Coordination Office

NAS: National Academy of Sciences

NAST: National Assessment Synthesis Team

NASA: National Aeronautics and Space Administration

NAWG: National Assessment Working Group

NCAR: National Center for Atmospheric Research

NCDC: National Climatic Data Center

NCEDR: The National Center for Environmental Decision-Making Research

NGVD: National Geodetic Vertical Datum

NIEHS: National Institute for Environmental Health Services (DHHS)

NIGEC: National Institute for Global Environmental Change

NOAA: National Oceanic and Atmospheric Administration

NO_x: oxides of nitrogen

NPA: NPA Data Services, Inc.

NSF: National Science Foundation

NSTC: National Science and Technology Council

OMB: Office of Management and Budget

OPPE: Office of Policy, Planning and Evaluation (EPA)

ORD: Office of Research and Development (EPA)

ORNL: Oak Ridge National Laboratory (TN)

OSTP: Office of Science and Technology Policy

Penn State (PSU): Pennsylvania State University

PPR: Prairie Pothole Region

ppt: parts per thousand

RTA: Regression Tree Analysis

RTP: Research Triangle Park, NC

SAV: submerged aquatic vegetation

SEF: smaller environmentally friendly

SGCR: Subcommittee on Global Change Research (in NSTC's CENR)

SO_x: oxides of sulfur

SQ: status quo

UCAR: University Corporation for Atmospheric Research

UKMO: United Kingdom Meteorological Office (global climate model)

UNEP: United Nations Environmental Program

USGCRP: U.S. Global Change Research Program

USFS: U.S. Forest Service (USDA)

USGS: U.S. Geological Survey

USDA: U.S. Department of Agriculture

WMO: World Meteorological Organization

The Counties of the Mid-Atlantic Region with FIPS Codes and Physiographic Regions

Fips	State	County	Regionname
10001	DE	Kent County	Coastal Plain
10003	DE	New Castle County	Coastal Plain
10005	DE	Sussex County	Coastal Plain
11001	DC	District of Columbia	Coastal Plain
24001	MD	Allegany County	Ridge and Valley
24003	MD	Anne Arundel County	Coastal Plain
24005	MD	Baltimore County	Piedmont
24009	MD	Calvert County	Coastal Plain
24011	MD	Caroline County	Coastal Plain
24013	MD	Carroll County	Piedmont
24015	MD	Cecil County	Piedmont
24017	MD	Charles County	Coastal Plain
24019	MD	Dorchester County	Coastal Plain
24021	MD	Frederick County	Piedmont
24023	MD	Garrett County	Plateau
24025	MD	Harford County	Piedmont
24027	MD	Howard County	Piedmont
24029	MD	Kent County	Coastal Plain
24031	MD	Montgomery County	Piedmont
24033	MD	Prince George's County	Coastal Plain
24035	MD	Queen Anne's County	Coastal Plain
24037	MD	St. Mary's County	Coastal Plain
24039	MD	Somerset County	Coastal Plain
24041	MD	Talbot County	Coastal Plain
24043	MD	Washington County	Ridge and Valley
24045	MD	Wicomico County	Coastal Plain
24047	MD	Worcester County	Coastal Plain
24510	MD	Baltimore City	Piedmont
34001	NJ	Atlantic County	Coastal Plain
34005	NJ	Burlington County	Coastal Plain
34007	NJ	Camden County	Coastal Plain
34009	NJ	Cape May County	Coastal Plain
34011	NJ	Cumberland County	Coastal Plain
34015	NJ	Gloucester County	Coastal Plain
34019	NJ	Hunterdon County	Piedmont
34021	NJ	Mercer County	Coastal Plain
34025	NJ	Monmouth County	Coastal Plain
34027	NJ	Morris County	Piedmont
34029	NJ	Ocean County	Coastal Plain
34033	NJ	Salem County	Coastal Plain
34037	NJ	Sussex County	Plateau
34041	NJ	Warren County	Piedmont
36003	NY	Allegany County	Plateau

36007	NY	Broome County	Plateau
36011	NY	Cayuga County	Plateau
36015	NY	Chemung County	Plateau
36017	NY	Chenango County	Plateau
36023	NY	Cortland County	Plateau
36025	NY	Delaware County	Plateau
36039	NY	Greene County	Plateau
36043	NY	Herkimer County	Plateau
36051	NY	Livingston County	Plateau
36053	NY	Madison County	Plateau
36065	NY	Oneida County	Plateau
36067	NY	Onondaga County	Plateau
36069	NY	Ontario County	Plateau
36071	NY	Orange County	Plateau
36077	NY	Otsego County	Plateau
36095	NY	Schoharie County	Plateau
36097	NY	Schuyler County	Plateau
36101	NY	Steuben County	Plateau
36105	NY	Sullivan County	Plateau
36107	NY	Tioga County	Plateau
36109	NY	Tompkins County	Plateau
36111	NY	Ulster County	Plateau
36123	NY	Yates County	Plateau
37001	NC	Alamance County	Piedmont
37005	NC	Alleghany County	Ridge and Valley
37013	NC	Beaufort County	Coastal Plain
37015	NC	Bertie County	Coastal Plain
37029	NC	Camden County	Coastal Plain
37033	NC	Caswell County	Piedmont
37041	NC	Chowan County	Coastal Plain
37053	NC	Currituck County	Coastal Plain
37055	NC	Dare County	Coastal Plain
37065	NC	Edgecombe County	Coastal Plain
37067	NC	Forsyth County	Piedmont
37069	NC	Franklin County	Piedmont
37073	NC	Gates County	Coastal Plain
37077	NC	Granville County	Piedmont
37081	NC	Guilford County	Piedmont
37083	NC	Halifax County	Coastal Plain
37091	NC	Hertford County	Coastal Plain
37095	NC	Hyde County	Coastal Plain
37117	NC	Martin County	Coastal Plain
37127	NC	Nash County	Coastal Plain
37131	NC	Northampton County	Coastal Plain
37135	NC	Orange County	Piedmont
37137	NC	Pamlico County	Coastal Plain
37139	NC	Pasquotank County	Coastal Plain

37143	NC	Perquimans County	Coastal Plain
37145	NC	Person County	Piedmont
37147	NC	Pitt County	Coastal Plain
37157	NC	Rockingham County	Piedmont
37169	NC	Stokes County	Piedmont
37171	NC	Surry County	Piedmont
37177	NC	Tyrrell County	Coastal Plain
37181	NC	Vance County	Piedmont
37185	NC	Warren County	Piedmont
37187	NC	Washington County	Coastal Plain
37195	NC	Wilson County	Coastal Plain
42001	PA	Adams County	Piedmont
42003	PA	Allegheny County	Plateau
42005	PA	Armstrong County	Plateau
42007	PA	Beaver County	Plateau
42009	PA	Bedford County	Ridge and Valley
42011	PA	Berks County	Piedmont
42013	PA	Blair County	Ridge and Valley
42015	PA	Bradford County	Plateau
42017	PA	Bucks County	Piedmont
42019	PA	Butler County	Plateau
42021	PA	Cambria County	Plateau
42023	PA	Cameron County	Plateau
42025	PA	Carbon County	Ridge and Valley
42027	PA	Centre County	Ridge and Valley
42029	PA	Chester County	Piedmont
42031	PA	Clarion County	Plateau
42033	PA	Clearfield County	Plateau
42035	PA	Clinton County	Plateau
42037	PA	Columbia County	Ridge and Valley
42039	PA	Crawford County	Plateau
42041	PA	Cumberland County	Ridge and Valley
42043	PA	Dauphin County	Ridge and Valley
42045	PA	Delaware County	Coastal Plain
42047	PA	Elk County	Plateau
42049	PA	Erie County	Plateau
42051	PA	Fayette County	Plateau
42053	PA	Forest County	Plateau
42055	PA	Franklin County	Ridge and Valley
42057	PA	Fulton County	Ridge and Valley
42059	PA	Greene County	Plateau
42061	PA	Huntingdon County	Ridge and Valley
42063	PA	Indiana County	Plateau
42065	PA	Jefferson County	Plateau
42067	PA	Juniata County	Ridge and Valley
42069	PA	Lackawanna County	Plateau
42071	PA	Lancaster County	Piedmont

42073	PA	Lawrence County	Plateau
42075	PA	Lebanon County	Piedmont
42077	PA	Lehigh County	Piedmont
42079	PA	Luzerne County	Ridge and Valley
42081	PA	Lycoming County	Plateau
42083	PA	Mc Kean County	Plateau
42085	PA	Mercer County	Plateau
42087	PA	Mifflin County	Ridge and Valley
42089	PA	Monroe County	Plateau
42091	PA	Montgomery County	Piedmont
42093	PA	Montour County	Ridge and Valley
42095	PA	Northampton County	Piedmont
42097	PA	Northumberland County	Ridge and Valley
42099	PA	Perry County	Ridge and Valley
42101	PA	Philadelphia County	Coastal Plain
42103	PA	Pike County	Plateau
42105	PA	Potter County	Plateau
42107	PA	Schuylkill County	Ridge and Valley
42109	PA	Snyder County	Ridge and Valley
42111	PA	Somerset County	Plateau
42113	PA	Sullivan County	Plateau
42115	PA	Susquehanna County	Plateau
42117	PA	Tioga County	Plateau
42119	PA	Union County	Ridge and Valley
42121	PA	Venango County	Plateau
42123	PA	Warren County	Plateau
42125	PA	Washington County	Plateau
42127	PA	Wayne County	Plateau
42129	PA	Westmoreland County	Plateau
42131	PA	Wyoming County	Plateau
42133	PA	York County	Piedmont
51001	VA	Accomack County	Coastal Plain
51003	VA	Albemarle County	Piedmont
51005	VA	Alleghany County	Ridge and Valley
51007	VA	Amelia County	Piedmont
51009	VA	Amherst County	Piedmont
51011	VA	Appomattox County	Piedmont
51013	VA	Arlington County	Coastal Plain
51015	VA	Augusta County	Ridge and Valley
51017	VA	Bath County	Ridge and Valley
51019	VA	Bedford County	Piedmont
51021	VA	Bland County	Ridge and Valley
51023	VA	Botetourt County	Ridge and Valley
51025	VA	Brunswick County	Piedmont
51027	VA	Buchanan County	Ridge and Valley
51029	VA	Buckingham County	Piedmont
51031	VA	Campbell County	Piedmont

51033	VA	Caroline County	Coastal Plain
51035	VA	Carroll County	Ridge and Valley
51036	VA	Charles City County	Coastal Plain
51037	VA	Charlotte County	Piedmont
51041	VA	Chesterfield County	Coastal Plain
51043	VA	Clarke County	Ridge and Valley
51045	VA	Craig County	Ridge and Valley
51047	VA	Culpeper County	Piedmont
51049	VA	Cumberland County	Piedmont
51051	VA	Dickenson County	Ridge and Valley
51053	VA	Dinwiddie County	Coastal Plain
51057	VA	Essex County	Coastal Plain
51059	VA	Fairfax County	Coastal Plain
51061	VA	Fauquier County	Piedmont
51063	VA	Floyd County	Ridge and Valley
51065	VA	Fluvanna County	Piedmont
51067	VA	Franklin County	Piedmont
51069	VA	Frederick County	Ridge and Valley
51071	VA	Giles County	Ridge and Valley
51073	VA	Gloucester County	Coastal Plain
51075	VA	Goochland County	Piedmont
51077	VA	Grayson County	Ridge and Valley
51079	VA	Greene County	Piedmont
51081	VA	Greensville County	Coastal Plain
51083	VA	Halifax County	Piedmont
51085	VA	Hanover County	Coastal Plain
51087	VA	Henrico County	Coastal Plain
51089	VA	Henry County	Piedmont
51091	VA	Highland County	Ridge and Valley
51093	VA	Isle of Wight County	Coastal Plain
51095	VA	James City County	Coastal Plain
51097	VA	King and Queen County	Coastal Plain
51099	VA	King George County	Coastal Plain
51101	VA	King William County	Coastal Plain
51103	VA	Lancaster County	Coastal Plain
51105	VA	Lee County	Ridge and Valley
51107	VA	Loudoun County	Piedmont
51109	VA	Louisa County	Piedmont
51111	VA	Lunenburg County	Piedmont
51113	VA	Madison County	Piedmont
51115	VA	Mathews County	Coastal Plain
51117	VA	Mecklenburg County	Piedmont
51119	VA	Middlesex County	Coastal Plain
51121	VA	Montgomery County	Ridge and Valley
51125	VA	Nelson County	Piedmont
51127	VA	New Kent County	Coastal Plain
51131	VA	Northampton County	Coastal Plain

51133	VA	Northumberland County	Coastal Plain
51135	VA	Nottoway County	Piedmont
51137	VA	Orange County	Piedmont
51139	VA	Page County	Ridge and Valley
51141	VA	Patrick County	Piedmont
51143	VA	Pittsylvania County	Piedmont
51145	VA	Powhatan County	Piedmont
51147	VA	Prince Edward County	Piedmont
51149	VA	Prince George County	Coastal Plain
51153	VA	Prince William County	Piedmont
51155	VA	Pulaski County	Ridge and Valley
51157	VA	Rappahannock County	Piedmont
51159	VA	Richmond County	Coastal Plain
51161	VA	Roanoke County	Ridge and Valley
51163	VA	Rockbridge County	Ridge and Valley
51165	VA	Rockingham County	Ridge and Valley
51167	VA	Russell County	Ridge and Valley
51169	VA	Scott County	Ridge and Valley
51171	VA	Shenandoah County	Ridge and Valley
51173	VA	Smyth County	Ridge and Valley
51175	VA	Southampton County	Coastal Plain
51177	VA	Spotsylvania County	Piedmont
51179	VA	Stafford County	Piedmont
51181	VA	Surry County	Coastal Plain
51183	VA	Sussex County	Coastal Plain
51185	VA	Tazewell County	Ridge and Valley
51187	VA	Warren County	Ridge and Valley
51191	VA	Washington County	Ridge and Valley
51193	VA	Westmoreland County	Coastal Plain
51195	VA	Wise County	Ridge and Valley
51197	VA	Wythe County	Ridge and Valley
51199	VA	York County	Coastal Plain
51510	VA	Alexandria City	Coastal Plain
51515	VA	Bedford City	Piedmont
51520	VA	Bristol City	Ridge and Valley
51530	VA	Buena Vista City	Ridge and Valley
51540	VA	Charlottesville City	Piedmont
51550	VA	Chesapeake City	Coastal Plain
51560	VA	Clifton Forge City	Ridge and Valley
51570	VA	Colonial Heights City	Coastal Plain
51580	VA	Covington City	Ridge and Valley
51590	VA	Danville City	Piedmont
51595	VA	Emporia City	Coastal Plain
51600	VA	Fairfax City	Coastal Plain
51610	VA	Falls Church City	Coastal Plain
51620	VA	Franklin City	Coastal Plain
51630	VA	Fredericksburg City	Piedmont

51640	VA	Galax City	Ridge and Valley
51650	VA	Hampton City	Coastal Plain
51660	VA	Harrisonburg City	Ridge and Valley
51670	VA	Hopewell City	Coastal Plain
51678	VA	Lexington City	Ridge and Valley
51680	VA	Lynchburg City	Piedmont
51683	VA	Manassas City	Piedmont
51685	VA	Manassas Park City	Piedmont
51690	VA	Martinsville City	Piedmont
51700	VA	Newport News City	Coastal Plain
51710	VA	Norfolk City	Coastal Plain
51720	VA	Norton City	Ridge and Valley
51730	VA	Petersburg City	Coastal Plain
51735	VA	Poquoson City	Coastal Plain
51740	VA	Portsmouth City	Coastal Plain
51750	VA	Radford City	Ridge and Valley
51760	VA	Richmond City	Coastal Plain
51770	VA	Roanoke City	Ridge and Valley
51775	VA	Salem City	Ridge and Valley
51790	VA	Staunton City	Ridge and Valley
51800	VA	Suffolk City	Coastal Plain
51810	VA	Virginia Beach City	Coastal Plain
51820	VA	Waynesboro City	Ridge and Valley
51830	VA	Williamsburg City	Coastal Plain
51840	VA	Winchester City	Ridge and Valley
54001	WV	Barbour County	Plateau
54003	WV	Berkeley County	Ridge and Valley
54005	WV	Boone County	Plateau
54007	WV	Braxton County	Plateau
54009	WV	Brooke County	Plateau
54011	WV	Cabell County	Plateau
54013	WV	Calhoun County	Plateau
54015	WV	Clay County	Plateau
54017	WV	Doddridge County	Plateau
54019	WV	Fayette County	Plateau
54021	WV	Gilmer County	Plateau
54023	WV	Grant County	Ridge and Valley
54025	WV	Greenbrier County	Plateau
54027	WV	Hampshire County	Ridge and Valley
54029	WV	Hancock County	Plateau
54031	WV	Hardy County	Ridge and Valley
54033	WV	Harrison County	Plateau
54035	WV	Jackson County	Plateau
54037	WV	Jefferson County	Ridge and Valley
54039	WV	Kanawha County	Plateau
54041	WV	Lewis County	Plateau
54043	WV	Lincoln County	Plateau

54045	WV	Logan County	Plateau
54047	WV	McDowell County	Plateau
54049	WV	Marion County	Plateau
54051	WV	Marshall County	Plateau
54053	WV	Mason County	Plateau
54055	WV	Mercer County	Plateau
54057	WV	Mineral County	Ridge and Valley
54059	WV	Mingo County	Plateau
54061	WV	Monongalia County	Plateau
54063	WV	Monroe County	Plateau
54065	WV	Morgan County	Ridge and Valley
54067	WV	Nicholas County	Plateau
54069	WV	Ohio County	Plateau
54071	WV	Pendleton County	Ridge and Valley
54073	WV	Pleasants County	Plateau
54075	WV	Pocahontas County	Plateau
54077	WV	Preston County	Plateau
54079	WV	Putnam County	Plateau
54081	WV	Raleigh County	Plateau
54083	WV	Randolph County	Plateau
54085	WV	Ritchie County	Plateau
54087	WV	Roane County	Plateau
54089	WV	Summers County	Plateau
54091	WV	Taylor County	Plateau
54093	WV	Tucker County	Plateau
54095	WV	Tyler County	Plateau
54097	WV	Upshur County	Plateau
54099	WV	Wayne County	Plateau
54101	WV	Webster County	Plateau
54103	WV	Wetzel County	Plateau
54105	WV	Wirt County	Plateau
54107	WV	Wood County	Plateau
54109	WV	Wyoming County	Plateau

Appendix F:

F.1. Ecosystem Stresses

Complete Inventory of Federally Listed Endangered Species within the Mid-Atlantic Region

US Fish and Wildlife Service Division of Endangered Species (http://www.fws.gov/r9endspp/endspp.html)

T = threatened or E = endangered

Delaware

Animals–5 species
T - Eagle, bald (*Haliaeetus leucocephalus*)
E - Falcon, American peregrine (*Falco peregrinus anatum*)
T - Plover, piping (*Charadrius melodus*)
E - Squirrel, Delmarva Peninsula fox (*Sciurus niger cinereus*)
T - Turtle, bog (=Muhlenberg) (*Clemmys muhlenbergii*)

Plants–4 species
T – Swamp pink (*Helonias bullata*)
T – Small whorled pogonia (*Isotria medeoloides*)
E – Canby's dropwort (*Oxypolis canbyi*)
T – Knieskern's beaked-rush (*Rhynchospora knieskernii*)

Maryland

Animals–10 species
E – Bat, Indiana (*Myotis sodalis*)
T – Beetle, northeastern beach tiger (*Cicindela dorsalis dorsalis*)
T – Beetle, Puritan tiger (*Cicindela puritana*)
E – Darter, Maryland (*Etheostoma sellare*)
T – Eagle, bald (*Haliaeetus leucocephalus*)
E – Falcon, American peregrine (*Falco peregrinus anatum*)
T – Plover, piping (*Charadrius melodus*)
E – Squirrel, Delmarva Peninsula fox (*Sciurus niger cinereus*)
T – Turtle, bog (=Muhlenberg) (*Clemmys muhlenbergii*)
E – Wedgemussel, dwarf (*Alasmidonta heterodon*)

Plants–6 species
T – Sensitive joint-vetch (*Aeschynomene virginica*)
E – Sandplain gerardia (*Agalinis acuta*)

T – Swamp pink (*Helonias bullata*)
E – Canby's dropwort (*Oxypolis canbyi*)
E – Harperella (*Ptilimnium nodosum (=fluviatile)*)
E – Northeastern (=Barbed bristle) bulrush (*Scirpus ancistrochaetus*)

New Jersey

Animals–7 species
E – Bat, Indiana (*Myotis sodalis*)
T – Beetle, northeastern beach tiger (*Cicindela dorsalis dorsalis*)
T – Eagle, bald (*Haliaeetus leucocephalus*)
E – Falcon, American peregrine (*Falco peregrinus anatum*)
T – Plover, piping (*Charadrius melodus*)
E – Tern, roseate (*Sterna dougallii dougallii*)
T – Turtle, bog (=Muhlenberg) (*Clemmys muhlenbergii*)
E – Wedgemussel, dwarf (*Alasmidonta heterodon*)

Plants–5 species
T – Sensitive joint-vetch (*Aeschynomene virginica*)
T – Swamp pink (*Helonias bullata*)
T – Small whorled pogonia (*Isotria medeoloides*)
T – Knieskern's beaked-rush (*Rhynchospora knieskernii*)
E – American chaffseed (*Schwalbea americana*)

New York

Animals–9 species
E – Bat, Indiana (*Myotis sodalis*)
E – Butterfly, Karner blue (*Lycaeides melissa samuelis*)
T – Eagle, bald (*Haliaeetus leucocephalus*)
E – Falcon, American peregrine (*Falco peregrinus anatum*)
E – Plover, piping (*Charadrius melodus*)
T – Snail, Chittenango ovate amber (*Succinea chittenangoensis*)
E – Tern, roseate (*Sterna dougallii dougallii*)
T – Turtle, bog (=Muhlenberg) (*Clemmys muhlenbergii*)
E – Wedgemussel, dwarf (*Alasmidonta heterodon*)

Plants–6 species
T – Northern wild monkshood (*Aconitum noveboracense*)
E – Sandplain gerardia (*Agalinis acuta*)
T – Seabeach amaranth (*Amaranthus pumilus*)
T – American hart's-tongue fern (*Asplenium scolopendrium* var. *americanum*)
T – Leedy's roseroot (*Sedum integrifolium* ssp. *leedyi*)
T – Houghton's goldenrod (*Solidago houghtonii*)

North Carolina

Animals–23

E – Bat, Indiana (*Myotis sodalis*)
E – Bat, Virginia big-eared (*Corynorhinus* (=*Plecotus*) *townsendii virginianus*)
E – Butterfly, Saint Francis' satyr (*Neonympha mitchellii francisci*)
T – Chub, spotfin (=turquoise shiner) (*Cyprinella (=Hybopsis) monacha*)
T – Eagle, bald (*Haliaeetus leucocephalus*)
E – Elktoe, Appalachian (*Alasmidonta raveneliana*)
E – Falcon, American peregrine (*Falco peregrinus anatum*)
E – Heelsplitter, Carolina (*Lasmigona decorata*)
E – Manatee, West Indian (*Trichechus manatus*)
E – Pearlymussel, littlewing (*Pegias fabula*)
T – Plover, piping (*Charadrius melodus*)
E – Shiner, Cape Fear (*Notropis mekistocholas*)
T – Shrew, Dismal Swamp southeastern (*Sorex longirostris fisheri*)
T – Silverside, Waccamaw (*Menidia extensa*)
T – Snail, noonday (*Mesodon clarki nantahala*)
E – Spider, spruce-fir moss (*Microhexura montivaga*)
E – Spinymussel, Tar River (*Elliptio steinstansana*)
E – Squirrel, Carolina northern flying (*Glaucomys sabrinus coloratus*)
T – Tern, roseate (*Sterna dougallii dougallii*)
T – Turtle, loggerhead sea (*Caretta caretta*)
E – Wedgemussel, dwarf (*Alasmidonta heterodon*)
E – Wolf, red (*Canis rufus*)
E – Woodpecker, red-cockaded (*Picoides borealis*)

Plants–26 species

T – Sensitive joint-vetch (*Aeschynomene virginica*)
T – Seabeach amaranth (*Amaranthus pumilus*)
E – Small-anthered bittercress (*Cardamine micranthera*)
E – Smooth coneflower (*Echinacea laevigata*)
E – Spreading avens (*Geum radiatum*)
E – Rock gnome lichen (*Gymnoderma lineare*)
E – Roan Mountain bluet (*Hedyotis purpurea var. montana*)
E – Schweinitz's sunflower (*Helianthus schweinitzii*)
T – Swamp pink (*Helonias bullata*)
T – Dwarf-flowered heartleaf (*Hexastylis naniflora*)
T – Mountain golden heather (*Hudsonia montana*)
T – Small whorled pogonia (*Isotria medeoloides*)
T – Heller's blazingstar (*Liatris helleri*)
E – Pondberry (*Lindera melissifolia*)
E – Rough-leaved loosestrife (*Lysimachia asperulaefolia*)
E – Canby's dropwort (*Oxypolis canbyi*)
E – Harperella (*Ptilimnium nodosum (=fluviatile)*)
E – Michaux's sumac (*Rhus michauxii*)

E – Bunched arrowhead (*Sagittaria fasciculata*)
E – Green pitcher-plant (*Sarracenia oreophila*)
E – Mountain sweet pitcher-plant (*Sarracenia rubra ssp. jonesii*)
E – American chaffseed (*Schwalbea americana*)
E – White irisette (*Sisyrinchium dichotomum*)
T – Blue Ridge goldenrod (*Solidago spithamaea*)
T – Virginia spiraea (*Spiraea virginiana*)
E – Cooley's meadowrue (*Thalictrum cooleyi*)

Pennsylvania

Animals–13 species
E – Bat, Indiana (*Myotis sodalis*)
E – Clubshell (*Pleurobema clava*)
T – Eagle, bald (*Haliaeetus leucocephalus*)
E – Falcon, American peregrine (*Falco peregrinus anatum*)
E – Mucket, pink (pearlymussel) (*Lampsilis abrupta*)
E – Pearlymussel, cracking (*Hemistena lata*)
E – Pigtoe, rough (*Pleurobema plenum*)
E – Pimpleback, orangefoot (pearlymussel) (*Plethobasus cooperianus*)
E – Pink, ring (mussel) (*Obovaria retusa*)
E– Plover, piping (*Charadrius melodus*)
E – Riffleshell, northern (*Epioblasma torulosa rangiana*)
T – Turtle, bog (=Muhlenberg) (*Clemmys muhlenbergii*)
E – Wedgemussel, dwarf (*Alasmidonta heterodon*)

Plants–3 species
T – Small whorled pogonia (*Isotria medeoloides*)
E – Northeastern (=Barbed bristle) bulrush (*Scirpus ancistrochaetus*)
T – Virginia spiraea (*Spiraea virginiana*)

Virginia

Animals–40 species
E – Bat, gray (*Myotis grisescens*)
E – Bat, Indiana (*Myotis sodalis*)
E – Bat, Virginia big-eared (*Corynorhinus (=Plecotus) townsendii virginianus*)
E – Bean (mussel), purple (*Villosa perpurpurea*)
T – Beetle, northeastern beach tiger (*Cicindela dorsalis dorsalis*)
E – Blossom, green (pearlymussel)(*Epioblasma torulosa gubernaculum*)
T – Chub, slender (*Erimystax (=Hybopsis) cahni*)
T – Chub, spotfin (=turquoise shiner) (*Cyprinella (=Hybopsis) monacha*)
E – Combshell, Cumberlandian (*Epioblasma brevidens*)
E – Darter, duskytail (*Etheostoma percnurum*)
T – Eagle, bald (*Haliaeetus leucocephalus*)
E – Falcon, American peregrine (*Falco peregrinus anatum*)

E – Fanshell (*Cyprogenia stegaria*)
E – Isopod, Lee County cave (*Lirceus usdagalun*)
T – Isopod, Madison Cave (*Antrolana lira*)
E – Logperch, Roanoke (*Percina rex*)
T – Madtom, yellowfin (*Noturus flavipinnis*)
E – Monkeyface, Appalachian (pearlymussel)(*Quadrula sparsa*)
E – Monkeyface, Cumberland (pearlymussel)(*Quadrula intermedia*)
E – Mucket, pink (pearlymussel) (*Lampsilis abrupta*)
E – Mussel, oyster (*Epioblasma capsaeformis*)
E – Pearlymussel, birdwing (*Conradilla caelata*)
E – Pearlymussel, cracking (*Hemistena lata*)
E – Pearlymussel, dromedary (*Dromus dromas*)
E – Pearlymussel, littlewing (*Pegias fabula*)
E – Pigtoe, finerayed (*Fusconaia cuneolus*)
E – Pigtoe, rough (*Pleurobema plenum*)
E – Pigtoe, shiny (*Fusconaia cor (=edgariana)*)
T – Plover, piping (*Charadrius melodus*)
E – Rabbitsfoot, rough (*Quadrula cylindrica strigillata*)
E – Riffleshell, tan (*Epioblasma florentina walkeri*)
E – Salamander, Shenandoah (*Plethodon shenandoah*)
T – Shrew, Dismal Swamp southeastern (*Sorex longirostris fisheri*)
E – Snail, Virginia fringed mountain (*Polygyriscus virginianus*)
E – Spinymussel, James (=Virginia) (*Pleurobema collina*)
E – Squirrel, Delmarva Peninsula fox (*Sciurus niger cinereus*)
E – Squirrel, Virginia northern flying (*Glaucomys sabrinus fuscus*)
E – Tern, roseate (*Sterna dougallii dougallii*)
E – Wedgemussel, dwarf (*Alasmidonta heterodon*)
E – Woodpecker, red-cockaded (*Picoides borealis*)

<u>Plants–13 species</u>
T – Sensitive joint-vetch (*Aeschynomene virginica*)
E – Shale barren rock-cress (*Arabis serotina*)
T – Virginia round-leaf birch (*Betula uber*)
E – Small-anthered bittercress (*Cardamine micranthera*)
E – Smooth coneflower (*Echinacea laevigata*)
T – Virginia sneezeweed (*Helenium virginicum*)
T – Swamp pink (*Helonias bullata*)
E – Peter's Mountain mallow (*Iliamna corei*)
T – Small whorled pogonia (*Isotria medeoloides*)
T – Eastern prairie fringed orchid (*Platanthera leucophaea*)
E – Michaux's sumac (*Rhus michauxii*)
E – Northeastern (=Barbed bristle) bulrush (*Scirpus ancistrochaetus*)
T – Virginia spiraea (*Spiraea virginiana*)

West Virginia

Animals–14 species
E – Bat, gray (*Myotis grisescens*)
E – Bat, Indiana (*Myotis sodalis*)
E – Bat, Virginia big-eared (*Corynorhinus (=Plecotus) townsendii virginianus*)
E – Blossom, tubercled (pearlymussel) (*Epioblasma torulosa torulosa*)
E – Clubshell (*Pleurobema clava*)
T – Eagle, bald (*Haliaeetus leucocephalus*)
E – Falcon, American peregrine (*Falco peregrinus anatum*)
E – Fanshell (*Cyprogenia stegaria*)
E – Mucket, pink (pearlymussel) (*Lampsilis abrupta*)
E – Riffleshell, northern (*Epioblasma torulosa rangiana*)
T – Salamander, Cheat Mountain (*Plethodon nettingi*)
T – Snail, flat-spired three-toothed (*Triodopsis platysayoides*)
E – Spinymussel, James (=Virginia) (*Pleurobema collina*)
E – Squirrel, Virginia northern flying (*Glaucomys sabrinus fuscus*)

Plants–6 species
E – Shale barren rock-cress (*Arabis serotina*)
T – Small whorled pogonia (*Isotria medeoloides*)
E – Harperella (*Ptilimnium nodosum (=fluviatile)*)
E – Northeastern (=Barbed bristle) bulrush (*Scirpus ancistrochaetus*)
T – Virginia spiraea (*Spiraea virginiana*)
E – Running buffalo clover (*Trifolium stoloniferum*)

The District of Columbia

Animals–3 species
E – Amphipod, Hay's Spring (*Stygobromus hayi*)
T – Eagle, bald (*Haliaeetus leucocephalus*)
E – Falcon, American peregrine (*Falco peregrinus anatum*)

Plants–0 species

draft

F.2.

Summary of identified stresses for currently or previously declining species within the Chesapeake Bay Region
Consult 'Description of stresses. . .Chesapeake Bay Region' for interpretation and discussion of values for parameters.

Rank: 1 Major Stress 2 Moderate Stress 3 Minor Stress * Recovering from Stress
Blank boxes indicate insufficient data available or not applicable to the species.

ORGANISM	HABITAT STRESS				SPECIES STRESS			
	Agriculture	Industry & Commerce	Tourism	Water Pollution	Overharvesting	Disease	Introduced species/ predation	Weather Disturbances
SAV: Eelgrass *(Ruppia maritima)* & Widgeon grass *(Zostera marina)*	2	2	3	1	3	3*		3*
Striped Bass *(Morone saxatilis)*	2	3		1	1*			3
American Shad *(Alosa sapidissima)*	3	1		1	1*			
Blue Crab *(Callinectes sapidus)*			3	1	3*	3	3	3
American Oyster *(Crassostrea virginica)*	2			1	2	2	3	
Swamp Pink *(Helonias bullata)*	1	1		2	3			
Black Duck *(Anas rubripes)*	1	1	2	2	3		3	
Mallard *(Anas platrhynchos)*	1	1*	2*	2	3*		3	
Piping Plover *(Charadrius melodus)*		1	1	3			3	3
Bald Eagle *(Haliaeetus leucocephalus)*	1*		3		1*			

F.3. Description of stresses on target species in the Chesapeake Bay Region

Submerged Aquatic Vegetation:
Eelgrass (*Ruppia maritima*)
Widgeon grass (*Zostera marina*)
Habitat Stress
Agriculture and water pollution: fertilizer runoff and municipal wastewater discharge increase turbidity, reducing available light for underwater plants to grow and reproduce (EPA 1998)

Industry and commerce: commercial clam dredging uproots SAV and increases turbidity and its effects (Funderburk 1991)

Tourism: as boat traffic increases, plants are more often uprooted by boat propellers; development of marinas and construction of waterfront properties causes loss of shallow water habitat, reducing potential habitat for underwater plants to recolonize (Funderburk 1991)

Species Stress
Overharvesting: foraging by localise waterfowl reduces underwater plant distribution and abundance (http://www.fws.gov/r5cbfo/savpage.htm)

Disease: in the 1930s, infestation of slime mold (*Labyrinthala*) almost eliminated eelgrass (http://www.fws.gov/r5cbfo/savpage.htm)

Weather disturbances: in 1972, Hurricane Agnes caused reductions in salinity of the bay, impeding the recolonization of underwater plants; temperature fluctuations such as warm winters inhibit plant growth and reproduction (http://www.fws.gov/r5cbfo/savpage.htm)

Current status: total acreage of SAV increased in 1996 and 1997 after a decline in 1994 to 1995 (http://www.chesapeakebay.net/bayprogram/indicatr/measure/indover.htm)

Striped Bass (*Morone saxatilis*)
Habitat Stress
Agriculture and water pollution: fluctuation of water temperature disturbs spawning grounds for hatchery; toxic heavy metals that include arsenic, copper, cadmium and aluminum, and a commonly used pesticide, malathion, reduce the number of larval stripped bass (http://www.fws.gov/r5cbfo/striper.htm)

Industry and commerce: chlorination of effluent from sewage plants and electric power stations reduces zooplankton leading to starvation of young hatchlings (http://www.fws.gov/r5cbfo/striper.htm)

Species Stress
Overharvesting: between the late 1970s and the early 1980s, increased fishing pressures have reduced the number spawning female striped bass (http://www.fws.gov/r5cbfo/striper.htm)

Weather: acid rain reacts with soil aluminium, which then runs off into the bay water and reduce hatchlings survival (http://www.fws.gov/r5cbfo/striper.htm)

Current status: since 1995 an increase in interim stocking programs and implementing harvest limits has restored stocks (http://www.chesapeakebay.net/bayprogram/indicatr/measure/indover.htm)

American Shad (*Alosa sapidissima*)
Habitat Stress
Water pollution: nutrient inputs from stormwater runoff and atmospheric deposition stimulate phytoplankton growth which leads to increased water temperatures, low dissolved oxygen, and eutrophication hindering upstream migration to spawning grounds (http://www.fws.gov/r5cbfo/SHAD.HTM)

Industry and commerce: since the early to mid-1900s, construction of feeder dams and hydroelectric dams have caused blockage of spawning grounds and an increase in turbine mortality (http://www.fws.gov/r5cbfo/SHAD.HTM)

Agriculture: improper farming practices, timber harvest and stream channelization accelerates erosion of surface soils and further degrades rivers and streams (http://www.fws.gov/r5cbfo/SHAD.HTM)

Species Stress
Overharvesting: between the late 1800s and the 1940s, commercial and recreational fishing decreased stocks to extremely low levels (Funderburk 1991)

Current status: in the 1980s, prohibiting stock harvesting has been effective but stocks have yet to be restored (http://www.chesapeakebay.net/bayprogram/indicatr/measure/indover.htm)

Blue Crab (*Callinectes sapidus*)
Habitat Stress
Water pollution: exposure to high levels of heavy metals , PCBs, PAHs, and pesticides in the sediment, to runoff from urban, suburban, and agricultural areas, and to contaminated food sources has cause a major decline in blue crab populations (Funderburk 1991)

Tourism: pollution from marinas and paint, mechanical disturbances, and direct contact disturbs near-shore habitats, thus decreasing populations somewhat (Funderburk 1991)

Species Stress
Overharvesting: increased fishing pressure is a potential stress (EPA 1998)

Introduced species/predation: species such as the American eel, croaker, trout, and bass have been linked to an increase in mortality of juvenile and adult crabs (Funderburk 1991)

Weather disturbances: periodic severe wind generates currents that disturb spawning (EPA1998)

Disease: marine fungus (*Lagenidium callinectes*) and nemertean worm (*Carcinonemertes carcinophilia*) prevalent in some years and in some localities reduce the number of eggs hatched (Funderburk 1991)

Current status: spawning stock has increased to 1970s level (http://www.chesapeakebay.net/bayprogram/indicatr/measure/indover.htm)

American Oyster (*Crassostrea virginica*)
Habitat Stress
Water pollution and agriculture: major contaminates include heavy metals, pesticides, PCBs, PAHs, chlorine-produced oxidants, and petroleum hydrocarbons from agricultural runoff and wastewater effluent discharge causes mortality of oysters (Funderburk 1991)

Species Stress
Overharvesting: since the late 1800s, increases in annual harvest has severely depressed the oyster population, degrading oyster grounds, and a reduction of these "filter feeders" increases water turbidity and contributes to the decline in SAV (EPA 1998)

Disease: over the past 40 years, pathogens (*Haplosporidium nelsoni* and *Perkinsus marinus*) are known to cause mortality and inhibited growth and gemetogenesis in oyster populations (Funderburk 1991)

Introduced species/predation: predation by ctenophores and benthic carnivores such as the sea anemones cause great loss of gametes, fertilized eggs, and larvae (Funderburk 1991)

Current status: reproduction has declined significantly and the survival of stock to harvestable size is severely hampered by disease (http://www.chesapeakebay.net/bayprogram/indicatr/measure/indover.htm)

Swamp Pink (*Helonias bullata*)
Habitat Stress
Agriculture and industry & commerce: urban and agricultural development and off-site disturbances have increased siltation from uncontrolled soil erosion, discharge from

sewage treatment plants, and deposition of nutrients and chemicals into the water, thus, causing an increase in natural succession of competing species (e.g. common reed and mountain laurel) (http://www.fws.gov/r9endspp/i/q/saq54.html)

Water pollution: fertilizer runoff and wastewater discharge change soil conditions necessary for plants to grow and reproduce (http://www.fws.gov/r9endspp/i/q/saq54.html)

Species Stress
Overharvesting: attractiveness of the plant makes it vulnerable to illegal collectors (http://www.fws.gov/r9endspp/i/q/saq54.html)

Black Duck (*Anas rubripes*)
Mallard (*Anas platyrhynchos*)
Habitat Stress
Agriculture and water pollution: toxic substances and excess nutrient loading are principal factors in the decline of food resources (e.g. submerged aquatic vegetation); decline in duck populations correlates with the decline in SAV unless substitute food sources are found (Funderburk 1991)

Tourism and industry & commerce: with the increase in development since the early 1970s, an increase in dredging, shoreline erosion, marina developments, and marshland filing and draining disturbances have affected duck habitat selection and use (Funderburk 1991)

Species Stress
Overharvesting: in spite of annual harvest regulations, seasonal hunting has affected waterfowl populations (EPA 1992)

Introduced species/predation: increase in development introduces predatory species such as raccoons, foxes, and crows all of which destroy waterfowl nests (Brooke 1982)

Current status: black duck populations have not been restored; mallard populations have been restored and exceeded expected levels (http://www.chesapeakebay.net/bayprogram/indicatr/measure/indover.htm)

Piping Plover (*Charadrius melodus*)
Habitat Stress
Tourism and industry & commerce: growing human population increases recreational, housing, and seawall development accompanied by irreversible loss of breeding habitats (http://bluegoose.arw.r9.fws.gov/NWRSFiles/WildlifeMgmt/SpeciesAccounts/Birds/AtlPipingPlover/AtlPipingPloverIndex.html)

Water pollution: oil spills pose a serious threat to plovers (http://bluegoose.arw.r9.fws.gov/NWRSFiles/WildlifeMgmt/SpeciesAccounts/Birds/AtlPipingPlover/AtlPipingPloverIndex.html

Species Stress
Introduced species/predation: urbanisation and recreational pressures encourage predators (e.g. skunks, raccoons & gulls) which prey on plover chicks and eggs and often resulting in abandonment of nest sites (http://bluegoose.arw.r9.fws.gov/NWRSFiles/WildlifeMgmt/SpeciesAccounts/Birds/AtlPipingPlover/AtlPipingPloverIndex.html

Weather: extended cold weather, storms, and hurricanes result in direct mortality and habitat loss; if population is low enough or remains sparse, population recovery may be impaired. (http://bluegoose.arw.r9.fws.gov/NWRSFiles/WildlifeMgmt/SpeciesAccounts/Birds/AtlPipingPlover/AtlPipingPloverIndex.html

Bald Eagle (*Haliaeetus leucocephalus*)
Habitat Stress
Tourism: transformation of shoreline forest to housing development and marinas reduces trees used for nesting and perching and an increase in contact between humans and eagles reduces and potentially eliminates eagles' use of those areas (Funderburk 1991)

Agriculture: post WWII (late 1960s), use of DDT to control mosquitoes contaminated food resources, DDE (breakdown product of DDT) caused birds to lay thin-shelled eggs, thus, causing reproductive failure; in 1972, the use of DDT was banned in the United States (http://www.fws.gov/r5cbfo/baldeagl.htm)

Species Stress
Overharvesting: pre-1940, hunting reduced eagle population; in 1940, the Bald Eagle Protection Act was passed which made it illegal to kill, harm, harass, or possess bald eagles (http://www.fws.gov/r5cbfo/baldeagl.htm)

Current status: August 11, 1995, the bald eagle was reclassified from endangered to threatened; during the past 25 years of recovery, bald eagles have responded to the 1972 DDT ban and the protection sustained by the Bald Eagle Protection Act of 1940; the Chesapeake Bay area now has one of the highest concentrations of bald eagles in the United States (http://www.fws.gov/r5cbfo/baldeagl.htm)

F.4. Watersheds Key to Conserving At-Risk Fish and Mussels

Remarkably, the Nature Conservancy has determined that at least 2 populations of all imperiled freshwater fish and mussels could be conserved by protecting only 15% of the 2,100 small watersheds in the continental United States (Master et al. YEAR?). Many of these key watersheds are in the Mid-Atlantic; 19 are in NC and 14 are in VA. Thus, a strategy to protect freshwater fish and mussels from current and climatic stresses could prioritize protection of the key watersheds. If further research suggests that these key watersheds are threatened by climate change, strategies could focus upon preventing negative climatic impacts in these watersheds or upon locating other more climate-resilient watersheds to protect imperiled species.

State	Critical Watersheds to Conserve At-Risk Fish and Mussel Species (Master et al. YEAR?) (Some watersheds include parts of more than 1 state.)
NC	19: Upper Tar, Upper Neuse,Waccamaw, Upper Little Tennessee, Fishing, Lower Yadkin, Deep, Rocky, Lower Cape Fear, Black, Lumber, Little Pee Dee, Albemarle, Lynches, Lower Catawba, Nottoway, Upper Dan, Meherrin, Upper New
VA	14: Cacapon-Town, Upper Clinch, Powell, South Fork Holston, North Fork Holston, Upper Roanoke, Nottoway, Upper James, Upper Dan, Meherrin, Upper New, Middle James-Buffalo, Pamunkey, Middle New
WV	7: Cacapon-Town, Upper James, Upper Kanawha, Middle New, Greenbrier, Cheat, Tygart Valley
MD	2: Cacapon-Town, Cheat
DE	
PA	6: Cacapon-Town, Lower Delaware, Middle Delaware-Mongaup-Brodhead, French, Middle Allegheny-Tionesta, Cheat
NJ	2: Lower Delaware, Middle Delaware-Mongaup-Brodhead
NY	2: Middle Delaware-Mongaup-Brodhead, French