Appendix F – Climate Change and the Cost of Inaction in Maryland: A 2011 Review (CIER)

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List of Acronyms

ARWG	Adaptation and Response Working Group
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
MCCC	Maryland Commission on Climate Change
PJM	Pennsylvania Jersey Maryland Interconnection, LLC
STWG	Science and Technical Working Group

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Executive Summary

This report updates a prior study conducted by the Center for Integrative Environmental Research on the costs associated with not implementing policies to combat the impacts of climate change (Williamson et al., 2008), which was included as chapter three in the 2008 Maryland Climate Action Plan. An estimation of such costs is important to guide investment and policy making for two key reasons. First, all too often, the cost of action – such as paying for energy efficiency in homes or investing in renewable energy sources – can be easily calculated and may suggest that programs to cut emissions of greenhouse gases (GHGs), including increased availability of mass transit and use of smart-growth policies, are too costly, given the other needs of society, such as affordable housing, educating children and improving healthcare. Yet, not acting to prevent the impacts of climate change has its costs, which must also enter the decision process. It is the cost of inaction upon which this report focuses. Only if the costs of action are compared to the costs of inaction can policy-makers make informed decisions.

Second, acknowledging and avoiding the costs of inaction will have clear local and regional benefits. Without recognizing these benefits, decision-makers may be misled by the notion that stabilizing or reverting global climate change is a futile exercise for local jurisdictions that can only impose costs on their citizens, their economy and their environment. In reality, knowing about the impacts of climate variability and change on a region's economy, society, and environment is an important precondition for determining the viability and profitability of investments in economy, society and environment, be it through investments in institutions, infrastructure or the preservation of natural systems.

ES.1 Key Findings

In this updated report, we present new information and substantiate the findings of our previous report. None of the issues presented in the previous report as important to the State of Maryland have declined in their importance, though many have become more pronounced. At least the following six factors may have contributed to the rise in potential cost of inaction and add to the urgency of addressing climate change:

1. Research on climate impacts and response options has progressed significantly in the last few years. New data and better models confirm that past predictions of global climate change impacts were on the conservative side for both severity and cost. We now know that the average temperature of the Chesapeake Bay has warmed by 2°F over the past half-century, which is consistent with observed increases in air temperatures. By mid-century, under a business-as-usual scenario, additional atmospheric warming will surpass 3ºF, and the number of days with temperatures exceeding 90ºF is expected to triple to 90 days per year. By 2050, there are expected to be 25 to 35 summer days with temperatures exceeding 100ºF (Boesch, 2008; Najjar et al., 2010).

2. Climate change itself has progressed faster than previously observed. Average global land and ocean surface temperatures in 2010 tied 2005 as the warmest on record (NASA, 2011). The acceleration of atmospheric warming, changes in the frequency and severity of extreme weather events, and the rate of sea level rise, have all been faster than previously anticipated. In Maryland, precipitation events are likely to become more episodic and intense, both suggesting a higher risk of stream and river flooding, especially in winter and spring. In summer, droughts lasting several weeks will become more likely, due to the combination of more intermittent rainfall and increased evaporation with warmer temperatures (Boesch, 2008).

3. Frequently, the relationship between climate change and associated impacts is non-linear. Small increases in the rate at which the climate changes can have disproportionately large and far-reaching implications for the economy, society and environment. For example, as the rate of freshwater flow into the Chesapeake Bay increases, which is driven by precipitation events and snowmelt, the amount of erosion and thus sediment deposition in the Bay will increase at a faster and faster rate (Pyke et al., 2008). As an illustration, the first 1,000 cubic feet of water flow may result in 2 pounds of sediment added to the Bay; as water flow increases to 2,000 cubic feet, the sediment addition might be 6 pounds, more than a simple doubling.

4. A growing economy and population mean that ever more assets are at risk. Since in Maryland most of the growth in both economic activity and population has occurred along the coast and in urban areas – the places where climate impacts are most felt – the costs of inaction have risen. By the end of the century, an estimated 6.1 percent of Maryland's 3,190 miles of coastline will be vulnerable to inundation from a 3.3-foot increase in sea-level (US EPA, 1998; MCCC, 2008). With two feet of additional sea-level rise, 550 square miles of land could also be inundated at high tide, including the homes of over 60,000 people and 66 miles of roads (Wu et al., 2008). Maryland's coastal zone encompasses two-thirds of the state's land area and is home to almost 70 percent of its residents (MDNR, 2011).

5. Interdependencies among social, economic and environmental changes can ripple through the economy to magnify climate impacts. Since 1973, the amount of developed land area in Maryland has grown by 135 percent at the expense of other types of land use such as agriculture and forests (MDP, 2011b). The loss of agricultural and forestland can exacerbate the effect of climate change on water availability from aquifers because as the share of developed land area increases, storm water runoff increases and water is unable to enter and recharge aquifers. In contrast, permeable surfaces such as forest and farmland allow water to infiltrate the soil and recharge aquifers. As another example of ripple effects, increased urbanization can worsen extreme heat in cities, thus requiring more air conditioning during peak heat events, which further drives energy consumption and GHG emissions.

6. The absence of a globally binding climate accord and of national energy and climate legislation that reduces GHG emissions mean that the planet will continue to experience increases in emissions of GHGs, and thus increases in temperatures, sea level rise and in the frequency and severity of extreme weather events.

ES.2 Findings by Sector

This report highlights important new developments in climate science and the anticipated impact of climate change on the State of Maryland. These climate impacts serve to illustrate costs of inaction central to the welfare of Maryland’s citizenry in five sectors – (1) coastal land and ecosystems, (2) tourism, (3) agriculture, (4) public health and (5) energy.

1. Coastal Lands, Infrastructures and Ecosystems

Maryland’s coastal counties, including all of those adjacent to the Chesapeake Bay and the Atlantic Ocean, are home to a significant share of the state’s population. Many parts of its infrastructure – from roads, airports, ports, and water treatment facilities, to commercial and residential buildings – are located here as well. Sea level rise and more frequent and intense weather events will pose an increasing risk to ensuring reliable and sustained infrastructure services. For example, the trade, transportation, and utilities sector alone accounted for $42 billion, or 14 percent, of the gross domestic product in Maryland in 2010 (US BEA, 2011). Increasingly frequent and severe weather events will not only disrupt supply chains and jeopardize businesses, but also require expansion of emergency services and thus divert economic resources.

Existing storm water and transportation infrastructures are generally designed based on historic precipitation patterns and do not account for future climatic trends. As a result, key dimensions of major infrastructure investments, such as bridge height, pipe diameters, and storm water retention facilities, may be significantly under-designed for more precipitation, particularly for intermediate term peak events. One consequence of under-designed storm water infrastructure is that peak floods may be more frequent and severe than in the past.

The Maryland Commission on Climate Change's (MCCC) Scientific and Technical Working Group (STWG) projected 2.7-3.4 feet (.82 m to 1.04 m) of relative sea level rise by the end of the century (Boesch, 2008). Figure 8 in the body of the report shows that the southern half of the Eastern Shore (Dorchester and Somerset Counties) is rich in low-lying areas at-risk from sea level rise. These areas have many acres of ecologically diverse tidal wetlands, marshes, and farmland that could be swallowed by the waves. Already, 13 islands in the bay are submerged and 400,000 acres on the Eastern Shore are projected to join them (Begley, 2011).

Using geographic information system tools, this report evaluated the vulnerability of Maryland residential areas (U.S. Census Populated Places) to a relative sea level rise of 3.3 feet (1 m). Storm surge and high tide were not considered in the analysis. The analysis shows that 67.3 square miles of Maryland residential area would be inundated and Table ES1 gives the top twenty places affected by the percentage of their area that is at risk. These are shown by absolute area at risk and proportion of the place area at risk, respectively, from a 3.3-foot sea level rise.

2. Tourism

In 2009, tourism in Maryland generated roughly $13.7 billion in spending, which resulted in $1.6 billion in tax revenue, directly supported 134,677 full-time equivalency jobs and provided $3.8 billion in salaries and wages. Every year, 27-30 million visitors come to Maryland and each visitor stays an average of 1.6 days and spends $250 per trip (MOTD, 2011b).

Since much of Maryland's tourism is heavily dependent on short-term summer trips made by people from nearby destinations, and since such trips are not usually booked months in advance, the state's tourism industry is sensitive to extreme summer weather conditions. By mid-century, the number of days with temperatures exceeding 90ºF is expected to increase threefold. Heat waves will be more frequent and longer lasting (Boesch, 2008), making Baltimore and other Maryland cities less pleasant to visit. While summer revenues could be compensated by increased travel during the "off season," businesses will be adversely impacted by increasing volatility in tourism and an atmosphere of economic uncertainty driven by weather events. Assuming a linear relationship, if the tourist sector shrank by just 5 percent due to rising temperatures and more frequent and longer lasting heat waves, then this would translate to a loss of $685 million annually and approximately 6700 jobs.

In addition, tourism can be affected by threats to the physical environment. Increasing beach erosion as well as the frequency of major storms will most likely raise the cost of maintaining Maryland's shoreline or make it a less attractive tourist destination. It is estimated that beaches will move inland at a rate 50 to 100 times faster than the rate of sea level elevation and that the cost of replenishing the coastline after a 20-inch rise in sea level would be between $35 and $200 million (Zhang et al., 2004; USEPA, 1998). In addition, beach replenishment creates its own negative externalities including high ecological costs. Dredged material buries beach fauna and flora and is detrimental to the existing ecosystem because the material used to replenish beaches is often unsuitable for the reintroduction of the same species, or of any species (Stanton & Ackerman, 2007).

Table ES1. Top twenty Maryland places (U.S. Census Populated Places) by percentage area at risk from 3.3 ft (1 m) relative sea level rise.

	Area (square miles)	Sea level rise risk area [1] (square miles)	Percentage at risk
Frenchtown-Rumbly	4.18	3.88	92.73%
Dames Quarter	12.70	11.24	88.47%
Deal Island	3.29	2.32	70.53%
Smith Island	6.92	4.02	58.08%
Fairmount	15.33	8.53	55.66%
Church Creek	0.31	0.17	53.89%
Chance	1.77	0.83	47.16%
Crisfield	1.69	0.69	40.93%
Potomac Heights	1.37	0.48	35.38%
Kent Narrows	2.25	0.72	32.05%
Chesapeake City	0.61	0.19	30.74%
Highland Beach	0.08	0.02	30.47%
Golden Beach	3.44	1.03	29.99%
Oxford	0.72	0.21	29.65%
Ocean City	4.62	1.34	28.94%
Tilghman Island	2.85	0.82	28.65%
West Ocean City	4.32	1.11	25.76%
Mount Vernon	15.01	3.82	25.47%

Stevensville	6.17	1.44	23.28%
Deale	4.31	0.98	22.82%

[1] Elevation less than one meter

3. *Agriculture*

Roughly one-third of Maryland’s six million acres is farmland and agriculture plays a central role in the state’s economy. In 2007, the market value of agricultural products sold by Maryland farms was $1.8 billion. Of this value, $629 million (34 percent) was in the form of crop sales and $1,206 million (66 percent) in livestock. Of the latter, 75 percent ($903 million, 49 percent of the total) was for poultry and eggs alone (USDA, 2009).

It is because of the significance of Maryland’s agricultural sector to the economy as a whole that consideration of climate impacts is particularly important. Most segments of the Maryland agriculture industry face increasing costs from climate variability. As mentioned above, poultry production is responsible for a large portion of the industry’s revenue. This would not be such a concern were it not for the fact that the majority of production is located on the Eastern Shore, the area of the state most at risk of inundation from a rise in sea level. Also, rising summer temperatures and more frequent and longer-lasting heat waves could cause animals to grow more slowly or even die from heat stress. Chickens and turkeys are primarily raised in enclosures, so warmer temperatures will require more energy for building cooling and ventilation (CCSP, 2008). Finally, changing climatic conditions may increase the prevalence of pathogens that in turn increase the cost of disease prevention or decrease production.

The production of crops such as corn, soy and wheat will also face a variety of challenges. Those that seem most likely include increased irrigation needs, a higher risk of flooding, changes in crop yield due to rising temperatures, new pests and increased precipitation variability. Although a moderate rise in average temperatures and higher carbon dioxide levels can lengthen the growing season and stimulate crop growth, the negative impacts of climate change are expected to outweigh these benefits. Even where positive impacts are expected in the short term, optimal growing conditions will be surpassed towards the end of this century (CCSP, 2008).

Additionally, more frequent and intense rainfall can overwhelm nutrient runoff management systems and require investments by farmers and local communities to reduce the negative impacts to water systems caused by nutrient runoff. For example, farmers may need to more actively monitor soil nutrients and moisture to ensure optimal growing conditions. Furthermore, downstream impacts on streams, rivers and the Chesapeake Bay will be exacerbated by increased nutrient runoff. It may become increasingly difficult for Maryland localities and the state to comply with federal water quality regulations (e.g., Total Maximum Daily Loads), something that will require Maryland to adopt more aggressive and costly water protection measures to achieve and remain in compliance.

Increased climate variability means that farmers will have to be prepared for a wider range of climatic conditions. This could mean compromising crop yield with disease and weather resilience, or risk crop failure (CCSP, 2008). It also means more intense crop management with increasing equipment costs, which could be problematic for the many small-scale farmers in Maryland.

4. Public Health

Rising temperatures and an increase in precipitation variability is liable to influence air quality, heat stress and vector-borne diseases across Maryland. Additionally, the risk of water contamination (e.g., harmful algal blooms) will increase due to changes in temperature and precipitation patterns (CCSP, 2008). As summer days grow hotter due to the effects of climate change, Baltimore and other Maryland cities should be prepared to deal with higher rates of heat-related health effects. Furthermore, large changes in day-to-day temperatures can be expected to happen more frequently, which will have an adverse impact on mortality (Guo et al., 2011).

Impacts of climate change on human health will depend on a number of factors, including an individual’s sensitivity and exposure level to a given threat, as well as his or her capacity to cope and adapt. This, in turn, is partially a function of socioeconomic factors. Socially and economically disenfranchised individuals – such as the elderly, the disabled and the poor – are the most vulnerable. As a consequence, there may be considerable environmental justice implications to take into account (Harlan & Ruddell, 2011).

5. Energy

Climate changes will influence energy demand. Higher wintertime temperatures will reduce heating needs, and as a consequence, lower demand for heating fuels. However, summertime cooling requirements, typically met by electricity, will increase with more frequent and extreme heat events. Even if total annual electricity consumption in the state remains relatively constant, more extreme heat events are likely to lead to higher peak electricity demand during the summer months, thereby necessitating an increased investment in electricity generation capacity and transmission with those costs being transferred to customers.

Energy resource production and delivery systems along the Gulf Coast and the East Coast are vulnerable to sea level rise and extreme weather events. A hurricane landfall in the Gulf Coast region, where such storms occur more frequently than in the Mid-Atlantic, poses a substantial risk to Maryland due to the oil and gas interconnections between the two regions. Locally, snowstorms and hurricanes damage power lines and disrupt the delivery of fuel oil. Heating fuels are expected to be in less demand as winter temperatures increase. The net impact on natural gas, which serves as both a peak electricity fuel and a primary heating fuel, is uncertain. While less natural gas will be consumed to meet heating requirements, more natural gas is likely to be consumed to meet electricity demand during extreme heat events in the summer. Climate change will also impact renewable electricity sources such as bio-fuels, solar and wind. The warming of the planet is expected to mean greater variability in wind resources and direct solar radiation, which has substantial implications for the planning, siting, and financing of wind farms and solar power generators (CCSP, 2007).

1 Introduction

1.1 Climate change and the cost of inaction

Policy management of global climate change should be grounded in an effort to minimize health, economic and social costs. This pertains to both mitigation and adaptation efforts. However, the scope of global climate change, the range of valid response options, and financial and political constraints can create an atmosphere of indecision. Not only are there costs associated with mitigating and adapting to the impacts from climate change, but there can also be significant costs to taxpayers from inaction.

Policy makers are aware that the impacts of climate change are ongoing, and infrastructure and economic systems vital to our prosperity and wellbeing are at risk. Without the adoption of mitigation and adaptation measures, climate impacts will only worsen. Adaptation is essential because a significant amount of climate change has become inevitable. Interdependent physical, chemical and biological processes in the oceans, atmosphere and on land do not respond instantly to changes in atmospheric GHG concentrations, and GHGs reside in the atmosphere for decades or centuries. This inertia means that humanity has already triggered changes to our climate and the effects will be felt for many generations to come (Hansen & Sato, n.d.).

Reducing GHG emissions should be a primary goal of climate policy for at least the following two reasons. First, less mitigation today will mean that significantly larger efforts will be required over a long period of time to address the additional climate change caused by unmitigated emissions. Second, since the magnitude of human-caused climate perturbation is yet to be determined, investments in emissions reductions today can help to limit the uncertainty surrounding the future impacts to our society from climate change. Within a more certain idea of effects on our world, it will be easier to make the proper investments in our economy, society and environment.

Models of the earth's physical and ecological systems illustrate what may happen if we do not act now to effectively mitigate GHG emissions and if adaptation efforts are inadequate. Such earth system models, coupled with economic analyses, indicate that there are quantifiable benefits for protecting societal goods and services through early mitigation and regional adaptation policies. Performed at the sector and local levels, where costs are borne and benefits received, cost-of-inaction analyses are a powerful means for galvanizing climate change policy discourse, guiding investments and improving decision-making.

This report provides an update to the Maryland costs of inaction assessment first prepared by the University of Maryland Center for Integrative Environmental Research for the 2008 Maryland Climate Action Plan (Williamson et al., 2008). This report reinforces the findings of the earlier report. Specifically, that the impacts of climate change are already evident in Maryland, that they are widespread, and that the state will grow increasingly vulnerable in the absence of adaptation and mitigation measures. This report also adds new information related to the energy sector, provides the most current projections of physical impacts from climate change specific to Maryland and conducts a geographic analysis of sea level inundation in Maryland communities.

On its own, Maryland cannot ensure that the Earth moves toward rapid stabilization of atmospheric GHG concentrations. National policy and international cooperation to mitigate emissions need to provide the larger investment and policy-making context. Due to insufficient national policy dealing with climate change and the lack of a ratified international accord, Maryland has taken the lead in recognizing the urgency of the situation and moved forward.

Maryland's leadership is not an insignificant force of momentum toward concerted national and global actions to avert dangerous climate change. For example, Maryland's participation in the Regional Greenhouse Gas Initiative has established a valuable model policy tool for the U.S. and other nations from which to learn. Additionally, although mitigation and adaptation have often been perceived as fundamentally different, considerable overlap between climate change mitigation and adaptation exists (Pielke et al., 2007; Ruth et al., 2006). For example, expanding renewable electricity capacity reduces GHG emissions while simultaneously creating a more distributed energy system less susceptible to extreme events and cascading power outages (Mills, 2007). Also, climate action can promote broader goals of social, economic and environmental resilience in the face of a range of future challenges that is wider than just climate change. Maryland-led mitigation efforts are an important opportunity to capitalize on mitigation/adaptation synergies.

The consequences of global climate change will be unequally distributed and each locality must evaluate its vulnerability. Not only are less detrimental climate scenarios still under our influence, but also, opportunities to cost-effectively adapt to climate change today are abundant. For instance, everyday major investments are made in equipment and infrastructure (e.g., bridges, electricity transmission lines, buildings). These investments in physical capital and the associated technical specifications are locked-in for decades in advance. Maryland's vulnerability to climate impacts is in part a function of existing physical capital with the associated technical specifications, which may or may not be able to withstand the effects of climate change, including sea level rise and more frequent extreme heat events. Getting the relevant incentives and policies in place now is needed to provide guidance for making smart investment decisions that lead to more resilient energy, highway and building infrastructure.

1.2 Approach

In the next section we introduce the study methodology. Section 3 gives an overview of new developments in global climate change science since the 2008 Maryland Climate Action Plan, followed by a review of expected climate changes in Maryland in Section 4. Section 5 assesses how the regional climate projections play out along Maryland's urban and rural coastal zones, where vulnerability is expected to be especially high. Sections 6, 7, 8 and 9 focus on tourism, agriculture, public health and energy sectors, respectively. The report closes with a summary of the most important findings and lessons learned.

2 Methodology

The methods adopted for this study include a survey of existing studies from the scientific and policy literature, including the recent U.S. Climate Change Science Program's Scientific Assessments.[1] Importantly, we strive to be consistent with and build upon the work done by the Scientific and Technical Working Group (STWG) and the Adaptation and Response Working Group (ARWG) of the Maryland Commission on Climate Change (Boesch, 2008; Johnson, 2008; Boicourt & Johnson, 2010). Information resources from outside of Maryland (e.g., U.S. and local level studies and data) are also used in this report. Both public and private experiences function as valuable reference points against which Maryland is compared.

Some of the data and analyses used here have been derived from state-of-the-art computer models describing climate change and impacts. In some instances, historical experiences serve as benchmarks by which to assess potential future vulnerabilities and the costs of inaction. While we do not suggest past weather-related impacts in the state are unequivocally induced by anthropogenic climate change, observations of past impacts can help illustrate the kinds of challenges to be faced in the future, and the kinds of costs to be incurred, should Maryland not be adequately adapted to address the impacts of climate change.

By combining current economic data with Maryland-specific projections of climate change, as provided by the STWG, we illustrate the nature and magnitude of climate impacts that may lie ahead. This report identifies the key economic sectors in Maryland that will be affected by climate change and estimates the main impacts that will occur. Both direct and indirect economic impacts are considered; direct impacts occur as a primary result of climate processes (i.e., the loss of coastal property as a result of more frequent storm surges) while indirect impacts are a secondary result of climate processes (i.e., higher insurance rates in coastal areas as a result of more frequent storm surges). To the extent practical, we quantify the potential for financial impacts by extrapolating from historic Maryland trends or analogous cases in other locations. Discussion of impacts is primarily facilitated by qualitative analysis.

The estimated costs presented in this report may understate net impacts on the economy, the environment, and society to the extent that impacts can be readily captured in monetary terms. Additionally, there are significant information gaps and uncertainties regarding downscaled climate projections (i.e., Maryland-specific) and economic trends, which limits our characterization of impacts. The broader impacts to Maryland's social fabric, long-term economic competitiveness – both nationally and internationally – environmental quality, and quality of life, are largely outside the purview of this analysis. Furthermore, this report does not consider the benefits of concerted climate mitigation and adaptation action, including the potential creation of green, local jobs. Together, the monetary and non-monetary, direct, indirect and induced costs to society and the economy provide a strong basis on which to justify action to adapt.

[1] The complete suite of U.S. Climate Change Science Program scientific assessments can be accessed online at: http://www.globalchange.gov/publications/reports/scientific-assessments

3 What's new in global climate change research?

Since the release of the Intergovernmental Panel on Climate Change's Fourth Assessment Report in 2007 (IPCC 2007) and the 2008 Maryland Climate Action Plan, we have witnessed a continuation of global and local climate change trends. Recent scientific literature concludes that the climate is likely changing at an increasing rate, that it is becoming increasingly sensitive to GHGs, and that impacts will be more severe than previously predicted (PBL, 2009; Rahmstdorf, 2010; Rummukainen et al., 2010; Füssel, 2009). Average global land and ocean surface temperatures in 2010 tied 2005 as the warmest on record (NASA, 2011). June 2011 was the 316th consecutive month with a global temperature above the 20th century average (NOAA, 2011a).

Recently, the world has seen a host of natural disasters, which were possibly influenced by climate change. It is important to recognize that establishing causation between climate change and a particular event is extremely difficult and recent events may or may not have been partially influenced by climate change. Moreover, climate change may aggravate or mitigate a given weather event depending on any number of variables. Additional research is required to improve the methods for connecting specific weather events to climate change (Carey, 2011).

There is also abundant evidence suggesting the potential for an increase in global sea level of several feet by 2100. Gravity measurements by satellites reveal that the Greenland and Antarctic ice sheets are losing mass at an accelerating rate, more closely approximating a quadratic trend than a linear one (Rahmstdorf, 2010; Hansen & Sato, n.d.; PBL, 2009). The implication of this ice sheet finding is that global sea levels are projected to rise around 2.5-6.2 feet for the period 1990-2100. The projections reflect a shift from thermal expansion dominated sea-level rise to one dominated by the melting of polar ice sheets (Rahmstdorf, 2010; Overpeck & Weiss, 2009).[2] As recommended by the Maryland Commission on Climate Change, it is wise to assume that global sea-level rise could exceed three-feet by 2100 (Boesch, 2008; Johnson, 2008).

Additional findings of note since the release of the IPCC 2007 report include:

- Sea ice retreat and thinning in the Arctic are continuing at a pace much faster than reported in the 2007 report (Füssel, 2009);
- Amplification of global warming due to biological and geological carbon-cycle feedbacks may be stronger than originally expected (PBL, 2009);
- A 'mask' of aerosols in the atmosphere currently conceals a considerable amount of atmospheric warming ('global dimming'); health concerns related to aerosols could lead to aerosol reductions, triggering an acceleration in warming (Hansen et al., forthcoming);
- The increase in climate variability and extreme weather are likely greater than previously thought and the warming and acidification of the oceans likely pose early risks to marine ecosystems (Füssel, 2009);
- Some topics remain unresolved, such as past and future changes in tropical cyclone activity (Füssel, 2009); and

[2] Thermal expansion is the process of volumetric growth of the oceans as a result of increasing temperatures, which results in sea level rise (IPCC, 2007).

- The U.S. inventory of GHG emissions demonstrated the greatest single year-to-year reduction of approximately 6.1 percent between 2008 and 2009, which is largely the result of the global economic recession (US EPA, 2011a).

4 Climate change in Maryland

Climate change impacts are already being felt across Maryland. From the intensifying fight against the rising sea in Ocean City to the decline of maple syrup making in Garret County as vegetation zones shift pole-ward, it is clear that climatic changes span geographic differences in the state (Boesch, 2008).

4.1 Temperature

Despite Maryland's variety in climate regimes, average annual temperatures throughout the state have increased about 2°F over the past half century (NOAA, 2011e; Boesch, 2008), about twice the global average. The average temperature of the Chesapeake Bay has warmed by 2°F over the same time period, which is consistent with air temperatures (Boesch, 2008; Najjar et al., 2010). The greatest temperature increases have occurred during the winter months and all other seasons have increased slightly less (NOAA, 2011e). Climate models run by the STWG suggest that Maryland's warming will continue for a while, regardless of how global emissions unfold. An additional warming of 2ºF is expected by 2025. By mid-century, under a business-as-usual scenario, additional warming will surpass 3ºF, increasing further to 9ºF in summer and 7ºF in winter at the turn of the century (Boesch, 2008) (see Figure 1).

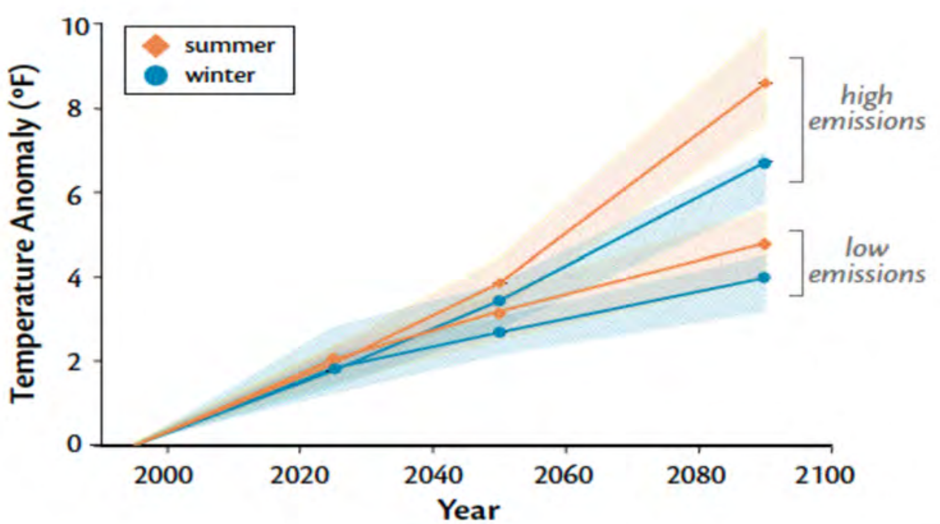

Figure 1. Temperature increase (ºF) for Maryland from 1990 to 2100. The shaded areas depict the 25th-75th percentile spread between all models (Source: Boesch, 2008).

A predicted outcome of climate change is that summer temperature extremes (e.g., 90+ºF) will become more frequent. Changing extremes will be more noticeable than gradual increases in average temperatures (IPCC, 2007). By 2050, under a business as usual global emissions scenario, the number of days with temperatures exceeding 90ºF is expected to triple to 90 days per year.

Further, by 2050, there are expected to be 25 to 35 summer days with temperatures exceeding 100ºF (Boesch, 2008). Figure 2 shows how the duration of heat waves is projected to change. These changes will likely have severe consequences on public health, agriculture, tourism and water and energy systems.

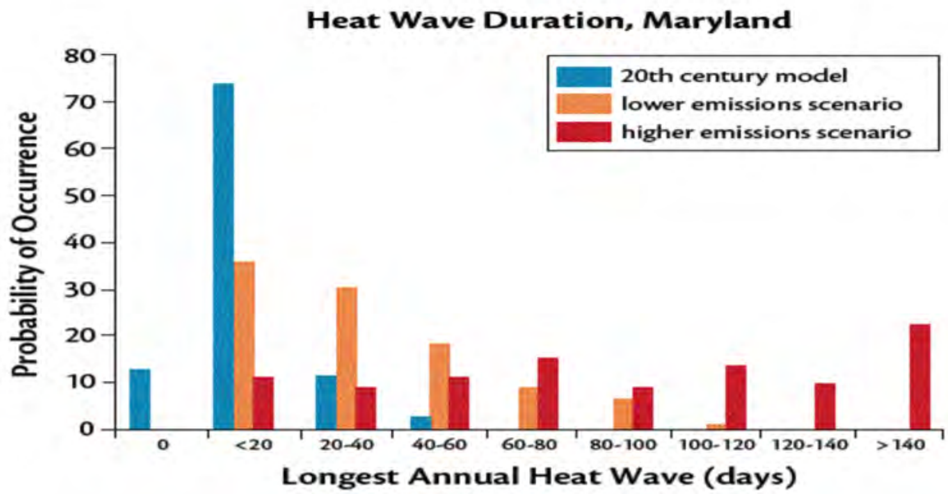

Figure 2. The chance that any given year will experience a heat wave of the indicated duration for present day and for the end of the century under low and high emissions scenarios (Source: Boesch, 2008).

4.2 Precipitation

The trend in annual precipitation is less clear in Maryland. According to climate and weather models, Maryland is situated at the boundary of two opposing atmospheric systems: a subtropical system, which would decrease precipitation, and a sub-polar system, which would increase precipitation (Najjar et al., 2010). Depending on which system dominates, Maryland could see an increase or decrease in annual precipitation. However, winter and springtime precipitation is likely to increase by about 10 percent by 2100. Though no season is expected to see a significant decrease in rainfall, year-to-year variability will be much greater (Boesch, 2008; Najjar et al., 2010; Pyke et al., 2008). Also, much less precipitation is expected to fall as snow. More importantly, precipitation events are likely to become more episodic and intense, suggesting a higher risk of stream and river flooding, especially in winter and spring. In summer, droughts lasting several weeks will become more likely, due to the combination of more intermittent rainfall and increased evaporation with warmer temperatures (Boesch, 2008).

4.3 Sea Level Rise

With over 3000 miles of coastline, sea level rise may well be the trend of most concern for Maryland. The sea level along the Maryland coastline has risen at a rate of 3-4 millimeters per year over the last decades (Figure 3, Table 1), nearly twice the global average of 1.8 millimeters per year (Oppenheimer et al., 2005; Pyke et al., 2008; Boon et al., 2010). The high rate of local sea level rise is exacerbated by natural subsidence of the land, which is the result of the post-glacial rebound effect.[3] Normal subsidence rates are expected to continue in the 21st century and will continue to add to high relative sea level increases in Maryland and heighten the risk of flooding from storm tides. Taking into account the combination of natural subsidence and rising seas due to thermal expansion and accelerated melting of polar ice sheets, Boesch (2008) estimates an additional sea level increase of 0.6 to 1.3 feet by 2050, and 2.7 to 3.4 feet by 2100 in a business-as-usual emissions scenario. Najjar et al. (2010) suggest that up to 5.3 feet of sea level rise by century's end is a real possibility for parts of the Chesapeake Bay coast.

Table 1. Recent historic linear trend in local sea level rise at four tide gauge stations in the Maryland portions of the Chesapeake Bay. About of half of sea level rise in Maryland is due to subsidence of land. (Source: Boon et al. 2010)

	Relative sea level rise [1] (1976-2007)	Subsidence [2]	Percentage [3]
Baltimore	3.09 ± 0.55 [mm per year]	1.29 [mm per year]	42
Annapolis	3.68 ± 0.58 [mm per year]	1.88 [mm per year]	51
Cambridge	3.44 ± 0.49 [mm per year]	1.64 [mm per year]	48
Solomon Island	3.61 ± 0.54 [mm per year]	1.81 [mm per year]	50

[1] Uncertainty expressed by a 95 percent confidence interval
[2] Absolute sea level rise - relative sea level rise
[3] Percentage of relative sea level rise attributed to subsidence

[3] The post-glacial rebound effect is the result of the retreat of polar ice at the end of the last ice age. The ice weighed heavily on the land underneath and caused bulging of the land immediately to its south (the Bay region); since the ice retreated, the land that was underneath has rebounded, while the land south of it has been subsiding (Boon et al., 2010).

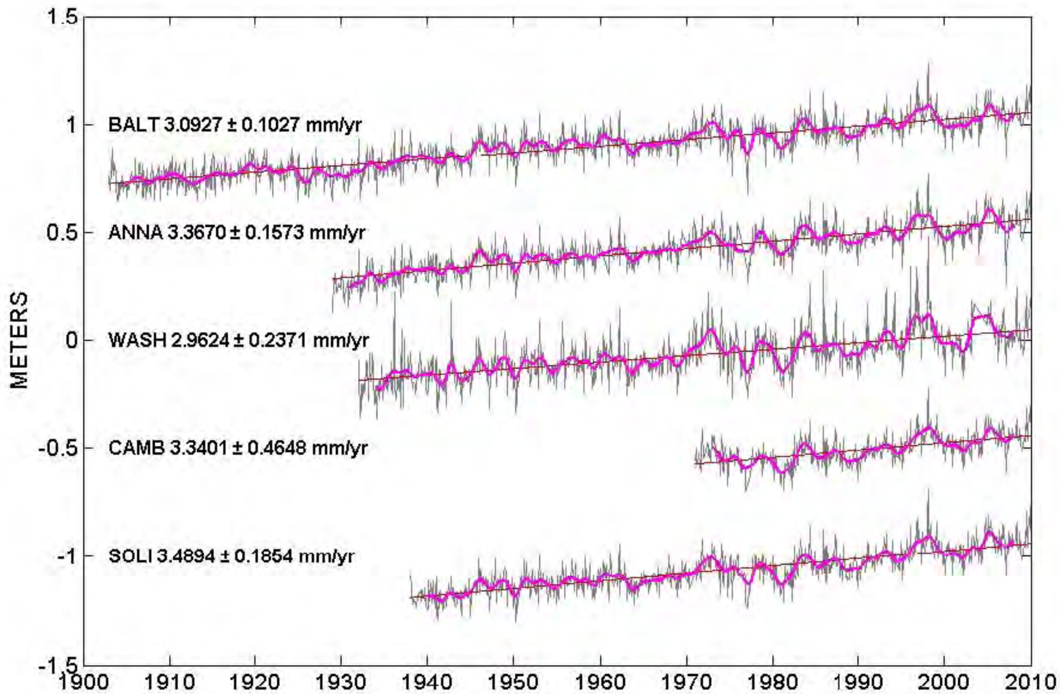

Figure 3. Sea level trends (straight-line) and decadal signals (magenta) at northern stations in the Chesapeake Bay (Source: Boon et al., 2010).

4.4 Extreme Events

Extreme high-temperature events such as heat waves are becoming more frequent and intense. Combined with increased precipitation variability, the likelihood of droughts and intense downpours is increasing as well. These events can severely impact the reliability of agriculture, energy and transportation systems, as well as public health and ecosystems. The most threatening prospect for Maryland, however, is more frequent and severe coastal storms, which in combination with sea level rise are liable to cause unprecedented storm surges and flooding along the coast of the Chesapeake Bay and its tidal rivers. Flooding in particular is devastating to property, as it does not spare property interiors. When wind directions are such that water is pushed up the Bay's main stem, as happened with hurricane Isabel, the storm surge can become seriously amplified in the narrowing tidal rivers. As a result of hurricane Isabel, Annapolis and Baltimore experienced water levels of 6-8 ft above normal and a nearly 8 ft rise was measured along the Potomac River in Washington, D.C. (Beven & Cobb, 2003).

In a review of past coastal storms, Zhang et al. (2000) found that sea level rise led to worse than expected storm damages, but no discernable long-term trend in the number and intensity of moderate and severe coastal storms during the 20th century. However, observations from the last decade in the North Atlantic show a 300-400 percent increase in the number of the most severe category (Category 5) of cyclones (Holland, 2009) (Figure 4). Model studies and theory project a 3-5 percent increase in wind-speed per 1 degree Celsius (1.8 degree Fahrenheit) increase of tropical sea surface temperatures (McBride et al., 2006). With a 2ºF rise in ocean temperature, the number of the most intense and destructive cyclones (Category 5) may roughly double while less intense cyclones would be less frequent (Richardson et al., 2009; Holland, 2009).

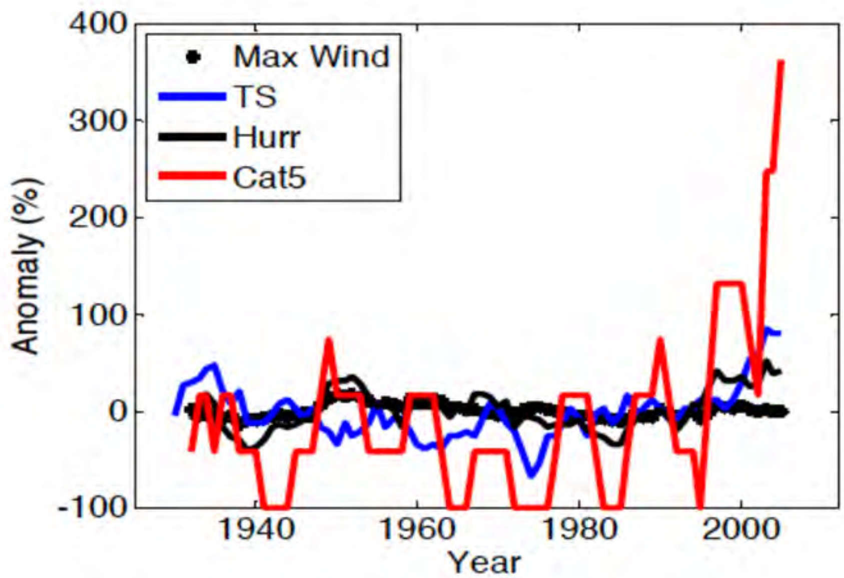

Figure 4. Annual anomalies in maximum wind and in numbers of: tropical storms (TS), hurricanes (Hurr), and category 5 hurricanes (Cat5). Anomalies are deviations (percentage) from the long-term annual average (Source: Holland, 2009).

The extent to which Maryland will be confronted with more frequent or powerful tropical storms and hurricanes depends heavily on storm tracks, which are difficult to predict in advance (Boesch, 2008; Landsea, 2007). Boesch notes that because storms intensify and will be able to travel farther north as a result of warmer ocean waters, it is likely that Maryland will experience more powerful hurricanes or tropical storms and more powerful and/or more frequent non-tropical storms than in the 20th century. However, the increase in number and intensity is still impossible to quantify.

5 *Major economic impacts: coastal*

5.1 *Introduction*

The largest economic impact of climate change for Maryland will be on its coastal infrastructure and developments. Coastal zones encompass two-thirds of Maryland's land area and are home to almost 70 percent of Maryland's residents (MDNR, 2011). By 2100, an estimated 6.1 percent of Maryland's 3,190 miles of coastline will be vulnerable to inundation as a result of an anticipated 3.4 foot sea-level rise (US EPA, 1998; MCCC, 2008). With two-feet of additional sea-level rise, 550 additional square miles of land could be inundated at high tide, including the property and homes of more than 60,000 people and 66 miles of roads (Wu et al., 2008). Further coastal impacts will come in the form of single events including more frequent and intense storms as well as flooding.

Three independent factors are expected to multiply damages and deaths resulting from future storms and hurricanes (Stanton & Ackerman, 2007):

1. Dense coastal development and population growth;
2. Sea levels rise will result in typical coastal storms creating significant harm as a result of storm surges, flooding, and erosion;
3. Coastal storm intensity may increase as sea-surface temperatures rise.

Current population and economic growth trends will likely place more people and infrastructure at risk to climate impacts in Maryland. The economic cost of coastal storm damages can be assumed to be proportional to the Gross State Product (Pielke & Landsea, 1998). Maryland's inflation-adjusted state gross domestic product increased nearly 42 percent between 1997-2010 (Figure 5) and average per capita real income increased 27 percent during the same time period (US BEA, 2011).

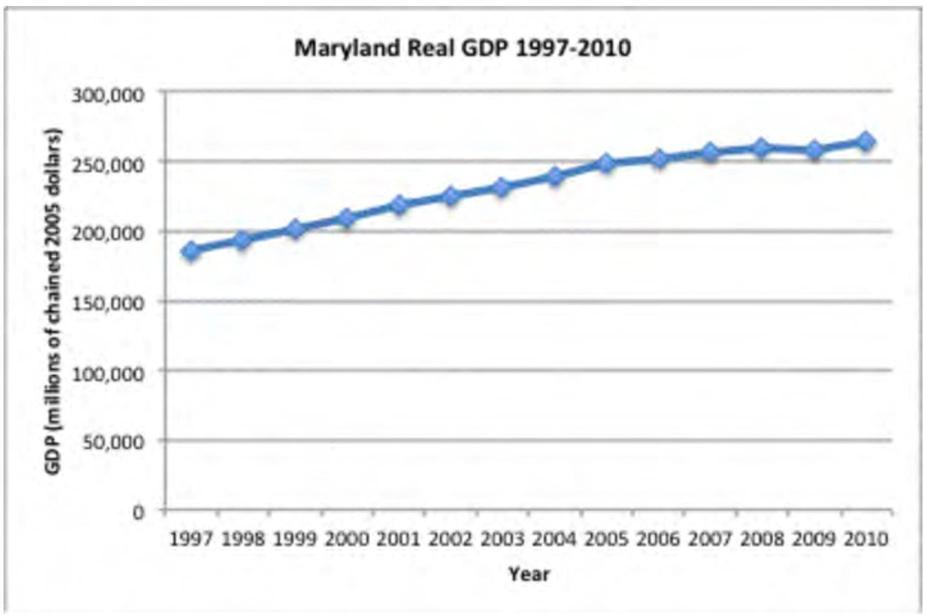

Figure 5. Maryland Gross State Product since 1997 (Source: US BEA, 2011).

Between 1980 and 2010 the population of Maryland grew by 37 percent, or over 1.5 million people. Besides this, the population density of Maryland's Eastern Shore, which is low-lying and particularly vulnerable to sea level rise, increased by 50 percent from 1980 to 2010. Although the rate of growth in the state has been decreasing since the 1980s, the Maryland Department of Planning projects another 20 percent increase in population between 2010 and 2040 for the entire state and a 36 percent increase for the Eastern Shore (MDP, 2011a) (Figure 6).

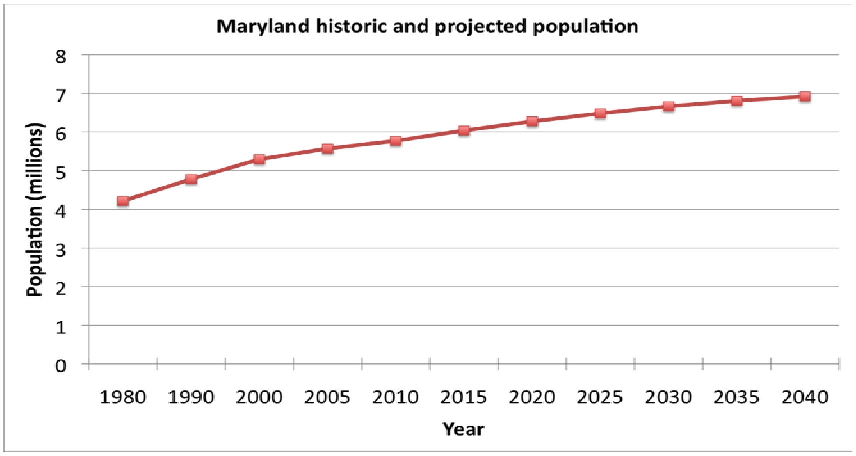

Figure 6. Maryland's population over time: historic and projected development (Source: MDP, 2011a).

Population growth requires commensurate increases in development of residential and commercial areas, utilities, roads, and public services, all of which increase the number of assets vulnerable to damage from climate change. Development patterns in Maryland indicate more developed acres per person, resulting in more urban land use (MDP, 2011b). As a corollary, increased development may lead to more impervious surfaces and nutrient runoff, which degrades both ground and surface water. To date, Maryland has developed 27 percent of its land area; total acreage of developed land in Maryland has grown by 135 percent since 1973, resulting in significant losses of agricultural and forest lands (MDP, 2011b). Decreases in household size and population growth are expected to continue and further expand the amount of developed land. Although smart growth policies can go a long way in limiting the expansion of developed land, it will not entirely offset development needs of a growing population (Laria, 2008; MDP, 2011b). Furthermore, it should be noted that development, including tall buildings and impervious surfaces, worsens the warming trend by inducing the urban heat island effect, which increases both daytime and nighttime temperatures, and compromises relief from daytime heat.

Currently, Maryland's coastal counties and Baltimore City are home to a significant share of the state's population in addition to hosting numerous tourist destinations, industrial sites, extensive commercial and residential development, and diverse ecosystems (MDP, 2011a; MDNR, 2011) (Figure 7). Because of the economic and geographic differences between Maryland's Baltimore-Washington corridor and its more rural and coastal regions, the effects of climate change will not be uniform across the state.[4] Altogether, sea level rise, flooding, and more frequent and intense storms will take an exacting toll on Maryland's multi-faceted and economically valuable coastal communities.

[4] We define the Baltimore-Washington corridor as Baltimore City, Baltimore County, Prince Georges, Anne Arundel, Montgomery, Howard, Harford, Charles and Calvert Counties.

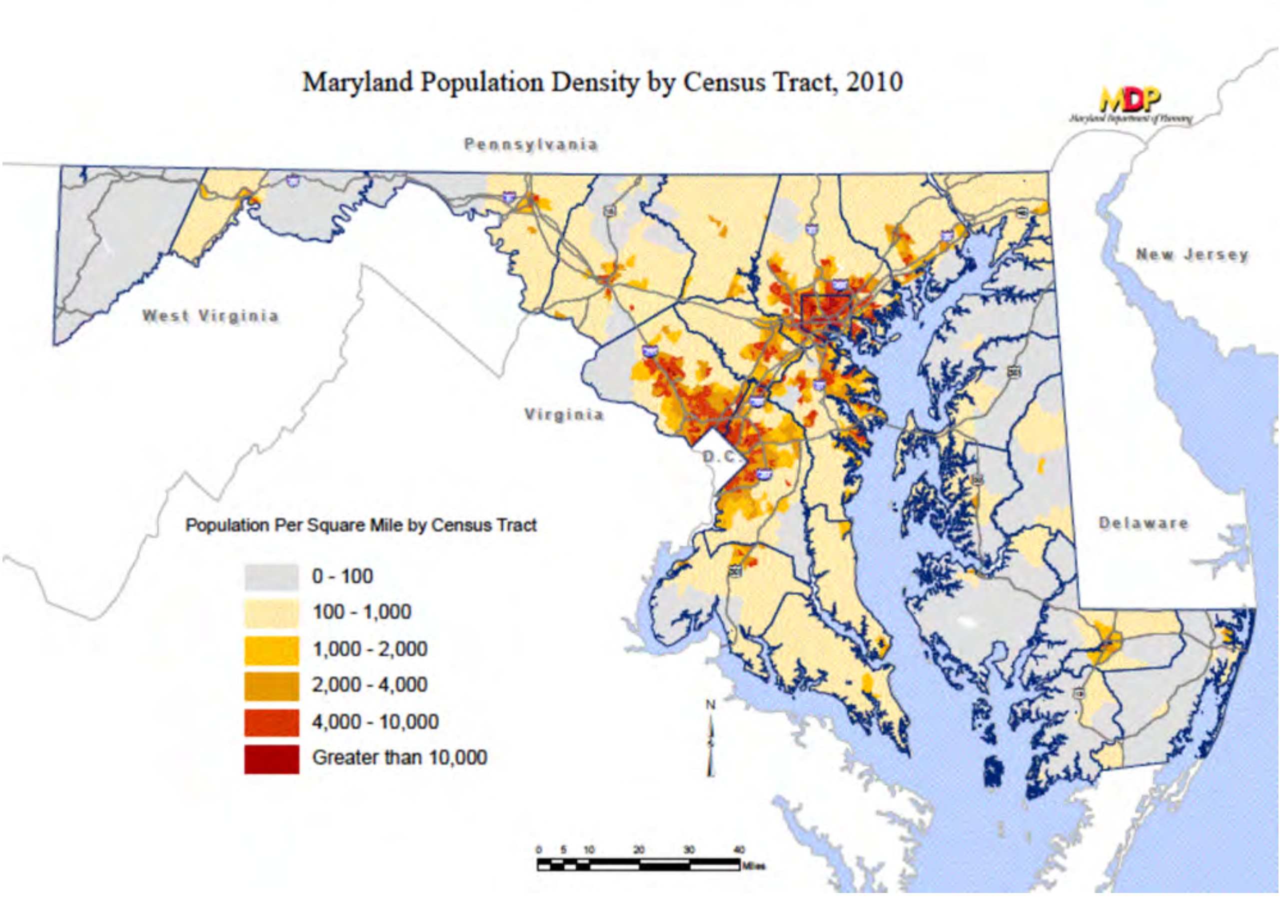

Figure 7. Maryland's population distribution, 2010; Baltimore-Washington corridor is most densely populated area (Source: MDP, 2011c via US Census Bureau).

Rising sea levels inundate wetlands and other low-lying lands, erode beaches, intensify flooding, and increase the salinity of rivers, bays and groundwater tables. Sea level rise also amplifies the damage done by storms. In the Chesapeake Bay region in particular, modeling shows that the kinds of cyclones or nor'easters that have not caused significant flooding in the past will begin to do so – and with greater frequency – as sea level continues to rise relative to the land (Boon et al., 2010). Coupling sea-level rise with storm surge is one of the most important considerations for assessing impacts of sea-level rise on infrastructure (CCSP, 2009). Controlling for other kinds of impacts, the Federal Emergency Management Agency estimates that existing development in the U.S. coastal zone would experience a 36-58 percent increase in average annual damages for a 1-foot rise in sea level, and a 102-200 percent increase for a 3-foot rise (US EPA, 2011b). Nordhaus (2006) estimates that for every meter of sea-level rise, economic damages from hurricanes double. In turn, we estimate that a storm similar to hurricane Isabel, which resulted in $485 million (2010$) in damages (Beven & Cobb, 2003), would result in at least twice the damage cost (i.e., close to $1 billion) in the context of a three-foot rise sea level. By accounting for population growth and development, this figure would be higher.

The warming of ocean waters in combination with warmer and moister air will increase the intensity of hurricanes, but the evidence is less clear for the effect of ocean warming on hurricane frequency (IPCC, 2007b). Nordhaus (2006) estimates the impact of increasing atmospheric carbon dioxide levels and sea-surface temperatures on storm intensity and economic damages. According to his calculations, every doubling of atmospheric carbon dioxide results in a doubling of hurricane damages — independent of the effects of sea-level rise. If this climate influence is again applied to the impacts of hurricane Isabel, the damage done by a hurricane striking at the end of the century would be amplified four times and reach damages of approximately $1.9 billion (2010$).

5.2 Industrial and commercial coastal impacts

Among all of the Baltimore-Washington corridor counties, only Calvert, Anne Arundel, Baltimore, Baltimore City, Harford, and Charles counties are coastal. However, because the Baltimore – Washington corridor is the most economically valuable region in Maryland with 89 percent of the wages (MDP, 2011c; MDP, 2011d) it is useful to consider the region in its entirety.

Much of the income generated in the corridor depends on reliable transportation. The trade, transportation, and utilities sectors accounted for $42 billion or 14 percent of Maryland's gross domestic product in 2010 (US BEA, 2011). These sectors provide an indispensable pillar to the state's economy. Sea-level rise, more frequent and intense storm events and extreme heat events pose a risk to these sectors by potentially inhibiting reliable and sustained transportation services. Development trends show the spreading of houses, offices, stores and businesses into suburban areas distant from city centers. As a consequence, daily long-distance commuting, frequently by personal occupancy vehicles, is a regular experience shared by many Marylanders. Recent (2009) data suggests that 87 percent of all work trips take place by automobile in the state (MDP, 2011b).

As dependence on cars and trucks increases, Maryland's economy is becoming more vulnerable to disruptions in the road transportation sector. Impacts from climate change, and more specifically the combination of sea level rise and extreme weather events, will significantly affect transportation and trade in the Baltimore-Washington corridor. With increasing frequency, roads (especially those located along coasts) and tunnels become flooded, airports need to interrupt services intermittently and ferries and bridges must close due to strong winds, floods or heavy snow. For instance, after Hurricane Isabel, the Baltimore Harbor Tunnel was closed for a period of time (Williamson et al., 2008). Although snow is projected to diminish on average, episodes of intense snowfall are expected to increase, making driving conditions difficult or roads impassable. Other consequences of extreme snow include disrupted supply chains, hindered emergency services and increased costs for snow removal. For example, in 2010, the blizzard "Snowmageddon" blanketed Maryland under a thigh-high layer of snow and brought practically all transportation to a standstill, causing billions of missed income for the retail sector throughout the Northeast (Dwyer, 2011). Moreover, Maryland's $26 million snow budget had already been depleted from cleaning up a December 2009 blizzard.

At the end of FY 2009, the Maryland Department of Transportation calculated it had $13.3 billion in total assets; among the capital assets are critical arteries for transportation including the Baltimore Harbor Tunnel, the Fort McHenry Tunnel, the Chesapeake Bay Bridges, and the Francis Scott Key Bridge (MDOT, 2009). Although inundation in Baltimore and Annapolis is expected to be small, the impacts of storm surges can be severe and the increasing rate of shoreline erosion resulting from sea level rise could weaken bridge support systems, limit access for maintenance, and deteriorate low-lying roads (Titus & Richman, 2001; Titus & Wang, 2008). 66 miles of Maryland roads would be inundated if sea level would rise 2.4 feet (Wu et al., 2011). The need for increased maintenance, impaired accessibility and protection of workers during extreme events will likely make construction and maintenance more difficult and costly.

The Baltimore-Washington corridor is a 15,000 square mile region with more than 8 million residents (including DC and Northern Virginia). The Maryland Department of Planning anticipates a 17 percent population increase in the Maryland part of this region in the next 30 years (MDP, 2011c). Such growth pressures introduce unavoidable stresses to water-sensitive sectors, even without climatic changes, but through more frequent and/or intense precipitation events climate change impacts could exacerbate the stress. The population-climate change tandem will impact the region via urban storm water runoff as well. Existing storm water and transportation infrastructure is technically specified and constructed based on historic precipitation records; future climatic trends are seldom "built-in" to infrastructure as this increases costs (Fankhauser et al., 1999). Thus key dimensions of major infrastructure investments, such as bridge openings, pipe diameters, and storm water detention facilities, may be significantly under-designed for more precipitation, particularly for intermediate term peak events. Thousands of septic systems are in flood zones. Under-designed water infrastructure coupled with impervious development increases the risk for flooding and nutrient loading. In addition to disrupting transportation and other human activities, runoff in urban areas also poses a serious threat to water quality (Begley, 2010; Wernstedt, 2010; Hejazi and Moglen, 2008).

In a more indirect, but not less important way, the transportation sector and the state economy could potentially suffer from a climate-induced disruption of its fuel supply chain. This could originate either within Maryland or outside the state. For instance, a major hurricane event along the Gulf Coast, where such events are frequent, could disrupt oil and gas extracting, refining and transmission thereby seriously constraining the supply and raising prices along the eastern U.S. After hurricane Katrina hit, gasoline prices in the Mid-Atlantic increased by 17 percent from $2.50 to $2.93 per gallon (Currie & Phung, 2007). In 2008, the arrival of Hurricanes Ike and Gustav on the Gulf Coast disrupted refinery operations and caused power outages, which ultimately shut down transportation pipelines and significantly reduced the supply of petroleum products in Maryland (e.g., gasoline, jet-fuel, heating oil, propane). Under a scenario of continued warming, the likelihood of a powerful hurricane hitting Maryland is increasing. Severe winter storms, such as nor'easters could increasingly inhibit shipments of petroleum via snow and ice blockage. Lack of gasoline and heating oil would create a dangerous winter situation for Marylanders.

The Port of Baltimore is an important economic hub in Maryland. The Port generates $3.2 billion in business revenue and $3.7 billion in wages and salaries annually. Over 50,000 jobs are directly or indirectly created by Port activity and the number of Maryland jobs linked to the Port is over 120,000. Its total economic impact was estimated to be $5.6 billion (Martin & Associates, 2008; MPA, 2010). According to the census, the value of the cargo moving through the Port of Baltimore reached $41.5 billion in 2010, a 37 percent rebound from the recession-racked 2009 (Dresser, 2011) (Value of shipments in 2008 was $45 billion (US BTS, 2011).

Shipping could be impaired by climate change in multiple ways. To keep shipping lanes open, the port regularly dredges the Chesapeake Bay's main shipping channels to remove excess sediment, which is generated by river runoff and bay currents. A surge in upstream flooding from spring and summer storms and more coastal erosion increase sediment deposits in turn raising the financial and environmental costs of dredging operations. Without dredging, ships may not be able to navigate to the port. In addition, if the frequency of dredging increases, it may become more difficult to find places to deposit the dredged materials, further increasing costs (Williamson et al., 2008; Boicourt & Johnson, 2010). Additionally, ships may be prohibited from docking more frequently due to inclement weather.

Low-lying access roads near ports are at risk of flooding and infrastructure adjustments will be necessary to establish a working land-sea interface. In 2009, Maryland's 2,800 commercial harvesters landed $76 million worth of crab and other fish in Maryland ports. And although the major employers of today no longer depend on bulky raw materials and large finished products that must be transported by rail or sea, manufacturing in 2009 still contributed $9.9 billion (2009) toward Maryland's gross domestic product. Both fisheries and manufacturing are dependent on reliable access to ports from both land and sea (MDP, 2011b; NOAA, 2011c; US BEA, 2011). Steadily rising sea levels as well as abrupt sea level increases could create economic hardships for Maryland's port-dependent shipping, fishing and manufacturing industries.

The Maryland Port Administration conducted a climate change vulnerability assessment of Maryland Port Administration-owned facilities in the port of Baltimore (JMT & MES, 2010). It concluded that although local sea level rise presented little risk of inundation, many of the facilities are at risk of flooding from a storm surge in combination with higher sea levels: *"Every marine terminal site modeled will likely experience substantial flooding during a Category III Hurricane when combined with up to 3 foot of sea level rise. Loading and unloading areas, cranes, buildings, and roadways are all at risk for potential damage from flooding and high winds"* (JMT & MES, 2010, pg 21*)*. More severe storms with higher wind speeds generate higher peak storm-water flows, which can extensively flood and damage the facilities.

5.3 Rural and residential coastal impacts

This section focuses on the rural portions of Maryland's Chesapeake Bay and Atlantic Ocean coasts, where vulnerability to soil erosion and naturally occurring land subsidence is expected to exacerbate the impacts of sea level rise. Costs of inactions include the cost of lost rural natural and artificial assets as a result of climate change. Also, this section will review the impacts to residential property and facilities along the coast as a result of climate change.

The STWG projected 2.7 to 3.4 feet of relative sea level rise by the end of the century (Boesch, 2008). The elevation map in Figure 8 shows that the southern half of Maryland's Eastern Shore (Dorchester and Somerset Counties) is rich in low-lying areas at risk from sea level rise. These areas have many acres of biologically diverse tidal wetlands, marshes and farmland. Currently, 13 islands in the Chesapeake Bay are submerged and 400,000 acres on the Eastern Shore are projected to join them over the course of the 21st century (Begley, 2011). Also, 2,500 historic and archeological sites face inundation (Begley, 2011). About two-thirds of Maryland's 428 square miles of tidal wetlands are in Dorchester and Somerset counties.

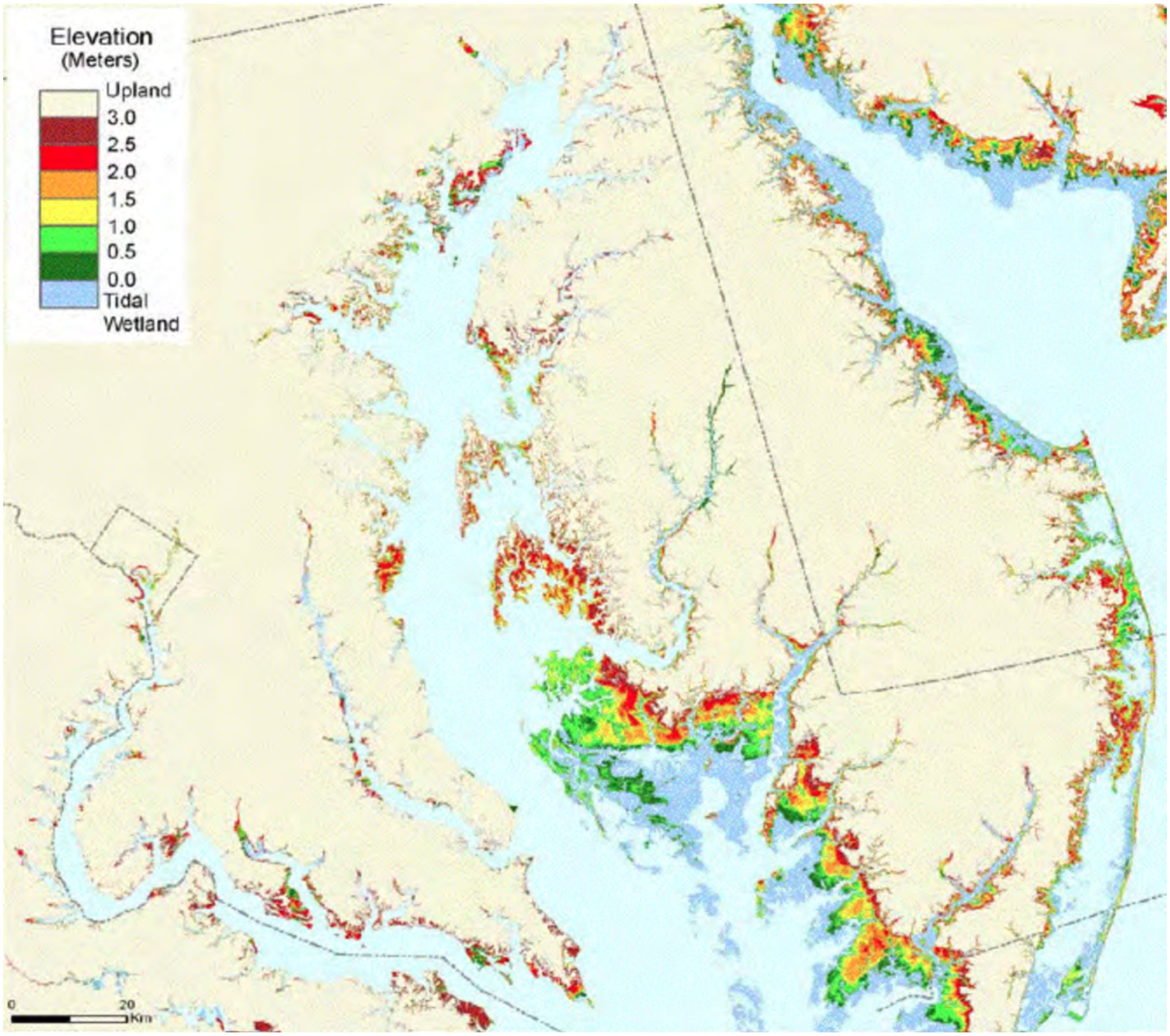

Figure 8. Elevation relative to spring high-water (Source: Titus & Wang, 2008).

5.4 Geographic analysis of Maryland coastal areas

We use GIS to identify residential areas (U.S. Census Populated Places) at risk from 3.3 feet (1 meter) relative sea level rise (storm surge and high tide have not been taken into account). The analysis shows that 67.3 square miles of residential area would be inundated. Table 2 gives the top twenty affected locations by percentage of their area at risk. Table 3 lists important facilities in Maryland that are partly or entirely within the 3.2 feet elevation zone. Appendix A presents a detailed table of most residential areas in Maryland and the amount of land at-risk from sea level rise. Additionally, Appendix A outlines the methods used to estimate the numbers presented in tables 2 and 3.

Table 2. Top twenty Maryland places (U.S. Census Populated Places) by percentage of their area that is at risk from 1 m (~3.3 ft) relative sea level rise.

	Area (square miles)	Sea level rise risk area [1] (square miles)	Percentage at risk
Frenchtown-Rumbly	4.18	3.88	92.73%
Dames Quarter	12.70	11.24	88.47%
Deal Island	3.29	2.32	70.53%
Smith Island	6.92	4.02	58.08%
Fairmount	15.33	8.53	55.66%
Church Creek	0.31	0.17	53.89%
Chance	1.77	0.83	47.16%
Crisfield	1.69	0.69	40.93%
Potomac Heights	1.37	0.48	35.38%
Kent Narrows	2.25	0.72	32.05%
Chesapeake City	0.61	0.19	30.74%
Highland Beach	0.08	0.02	30.47%
Golden Beach	3.44	1.03	29.99%
Oxford	0.72	0.21	29.65%
Ocean City	4.62	1.34	28.94%
Tilghman Island	2.85	0.82	28.65%
West Ocean City	4.32	1.11	25.76%
Mount Vernon	15.01	3.82	25.47%
Stevensville	6.17	1.44	23.28%
Deale	4.31	0.98	22.82%

[1] Elevation less than one meter

Table 3. Facilities that risk inundation from 1 m (3.3 ft) sea level rise.

Infrastructure type	Facility name
Airports	*Bay Bridge, Martin State and Ocean City Municipal*
Federal facilities	*Patuxent Naval Air Station, Naval Surface Warfare Center, Naval Electronics Systems Center, Naval Academy Complex and the Aberdeen Proving Grounds*
Education facilities	*Naval Academy*
Recreation facilities	*Country clubs, golf courses, shopping malls, stadiums, amusement parks*
Medical facilities	*Dorchester General, Harbor Hospital*

Sea level rise increases the vulnerability of coastal areas to flooding during storms. One effect is that the storm surge from a hurricane or nor'easter builds on top of a higher base of water. A three-foot sea level rise could more than double the impact of a hurricane or tropical storm. Experience from Florida shows that by failing to adequately take into account higher risks of property damage due to floods and winds, insurers may pull out of high-risk areas or default on claim coverage upon high-impact events. In turn, this shifts the burden of risk and damage to the taxpayer. For instance, after massive storms hit Florida in 2004 and 2005, many companies retreated from vulnerable parts of the state to limit their exposure. Average rates in Florida doubled and the state government is playing a growing role as an insurer of last resort for homeowners who cannot find private insurance (Stanton & Ackerman, 2007).

Shore erosion increases vulnerability to storms by removing the natural protection such as provided by beaches and dunes. In 2000, the Maryland Shore Erosion Task Force concluded that 31 percent of Maryland’s coastline was already experiencing some degree of erosion resulting in a loss of public and private property, historic and cultural sites, recreational beaches, productive farmland and forested areas (MDNR, 2000). While the range and magnitude of erosion varies, the problem affects all 16 coastal counties along the Chesapeake Bay and its watershed. Each year, erosion carries several million pounds of nutrients, and about 11 million cubic yards of sediment, into the Chesapeake Bay, significantly contributing to the Bay’s water quality problems and increasing dredging costs. The combination of sea level rise and development tend to exacerbate shore erosion problems (MDNR, 2000).

Box 1 - Planning for Sea-Level Rise in Baltimore

The U.S. Climate Change Science Program Assessment report on coastal impacts (CCSP 2009, p. 220) presents a case study on hurricane storm surge impact:

> *“Only 3.2 percent of the City of Baltimore’s 81 square miles [sq mi] of land is currently within the coastal floodplain. This land, however, includes popular tourist destinations such as Inner Harbor and the Fells Point Historic District, as well as industrial areas, some of which are being redeveloped into mixed-use developments with residential, commercial, and retail land uses. The map below depicts the areas that the city expects to be flooded by category 1, 2, 3, and 4 hurricanes, which roughly correspond to water levels of 6 ft, 10 ft, 14 ft and 18 ft above North American Vertical Datum (NAVD88). Approximately 250 homes are vulnerable to a category 1, while 700 homes could be flooded by a category 2 hurricane. As Hurricane Isabel passed in September 2003, water levels in Baltimore Harbor generally reached approximately 8 ft above NAVD, flooding streets and basements.”*(Flooded streets included Pratt and Light streets, *CIER*)

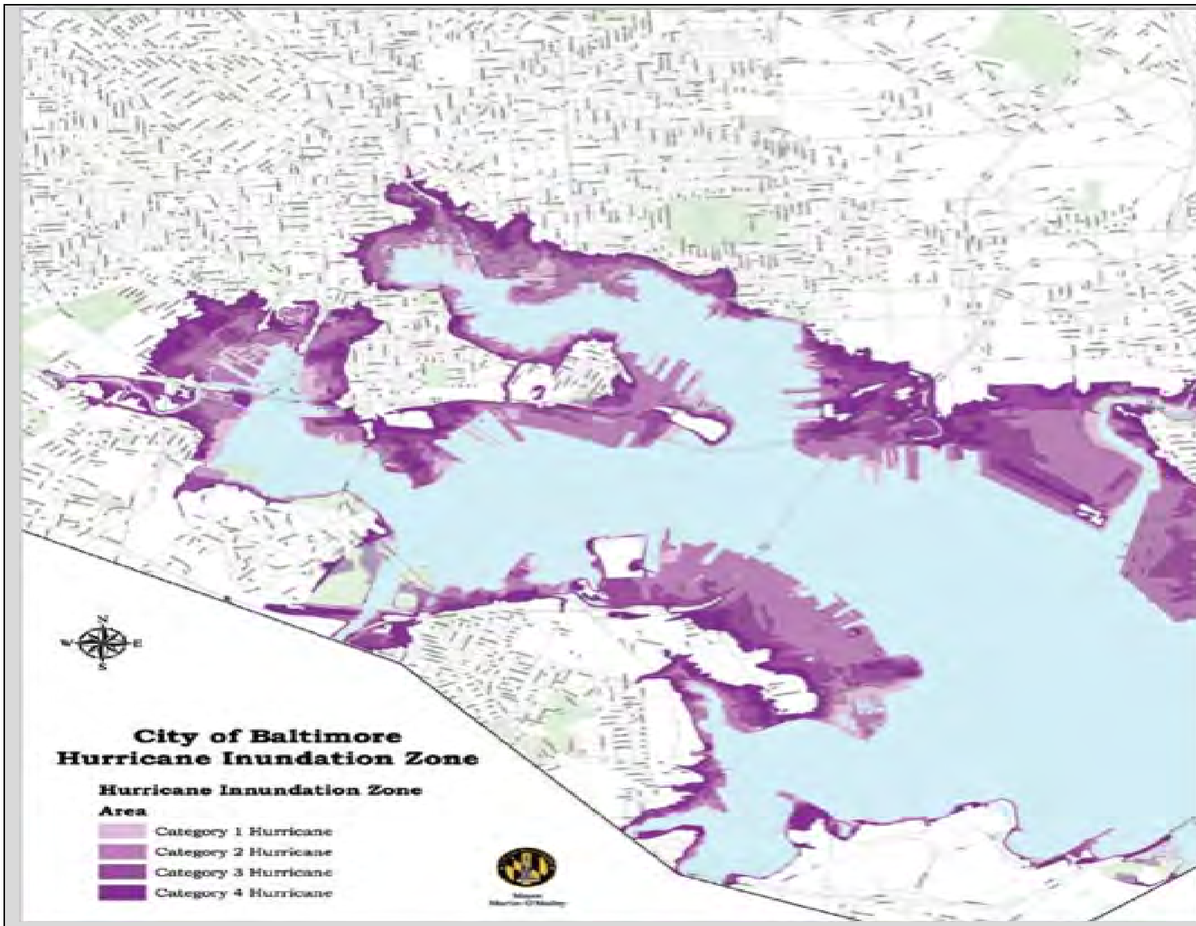

Figure 7. Inundation zone for Baltimore Harbor under category 1, 2, 3 and 4 hurricanes (Source: CCSP 2009).

"Property values are high, and there is a long-standing practice of armoring shores to facilitate port-related activities and more recently, protect waterfront structures from shore erosion. In most areas, there is not enough room between the harbor and waterfront buildings to fit a dike. Even where there is room, the loss of waterfront views would be unacceptable in tourist and residential areas. In addition, storm sewers, which drain by gravity into the harbor, would have to be fitted with pumping systems."

"Baltimore has two regional sewerage plants. One of them, the Patapsco Wastewater Treatment Plant, sits on ground that is less than 2 m (7 ft) above mean sea level and floods occasionally. The facility itself is elevated and currently drains by gravity into the Patapsco River. With a significant rise in sea level, however, pumping will be needed and possibly additional protections against storms. Numerous streets, with associated conduits and utility piping, are within the existing coastal floodplain and would potentially be affected by sea-level rise."

6 Tourism

In 2009, Maryland's tourism industry generated roughly $13.7 billion in visitor spending, which generated $1.6 billion in state and local tax revenue and directly supported 134,677 full-time equivalency jobs. Recent data suggests 27-30 million visitors come to Maryland each year and stay an average of 1.6 days while spending $250 per trip (MOTD, 2011b). Dining, shopping, entertainment and sightseeing are the top activities for Maryland visitors; beach and waterfront activities rank fifth. Visitors primarily spend money on transportation, food services and accommodations (Figure 10).

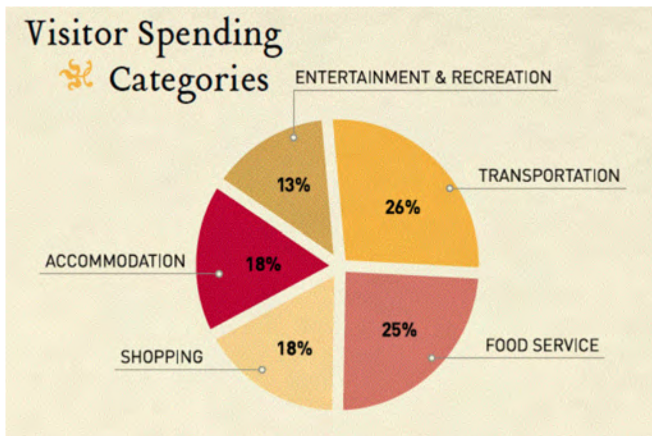

Figure 8. Maryland tourist expenditures, FY 2010 (Source: MOTD, 2011a).

Based on tourism-derived state tax revenue from each Maryland county, the top tourist destinations are as follows: the National Capital region (37 percent); the greater Baltimore-Annapolis region (35 percent); and Worcester County (7 percent), which includes the coastal hotspots Ocean City and Assateague Island. About one-third of Maryland visitors are Maryland citizens and another 19 percent visit from Virginia and 15 percent visit from Pennsylvania. About three-fourths of all visitors come for leisure with the remainder visiting for business (MOTD, 2011a; MOTD, 2011b). Monthly tourism sales tax revenue data show that tourist expenses peaks in the summer months and are lowest in the winter.

Maryland's tourism is heavily dependent on daylong summer trips made by people from nearby destinations. Such trips are not usually booked months in advance, which make them particularly sensitive to the weather situation. By 2100, there are expected to be 25-35 days in excess of 100ºF per year compared with only 2 days per year at the end of the 20th century. Days with temperatures exceeding 90ºF are expected to increase threefold during the same period and extended extreme heat (i.e., heat waves) will be more frequent and last longer (Boesch, 2008). We expect such extreme heat to take an economic toll on Maryland tourism. If we assume that all 100ºF days will fall in June, July and August (92 days) and that days with temperatures above 100ºF result in the cancelation of half of all trips, then annual tourist summer revenues could drop by as much as one-sixth. While summer revenues could be compensated by increased travel during the "off season," businesses will be adversely impacted by increasing volatility in tourism and an atmosphere of economic uncertainty as driven by weather events. If the tourist sector shrank by just 5 percent due to rising temperatures and more frequent and longer lasting heat waves, then this would translate to a loss of $685 million annually and approximately 6700 jobs.

Increasing beach erosion, major storms and public health threats (e.g., algal blooms) may render the Maryland coast a less attractive tourist destination. Ocean City underwent a $30 million beach replenishment project in the 1980s, but remains threatened by sea level rise. It is estimated that beaches will move inland at a rate 50 to 100 times faster than the rate of sea level elevation and that the cost of replenishing the coastline after a 20-inch rise in sea level would be between $35 and $200 million (Zhang et al., 2004; USEPA, 1998). As the cost of maintaining and protecting beaches from erosion increases, those costs will be passed along to residents and visitors. Also, beach replenishment has many unfortunate consequences including high ecological costs. Dredged material buries all beach fauna and flora and disrupts the existing ecosystem. The material used to replenish beaches is often unsuitable for the reintroduction of species (Stanton & Ackerman, 2007). As with coastal infrastructure and development, we expect extreme weather events to create a loss in economic activity in the tourism sector. Barrier islands and other tourist destinations around the Eastern Shore are often impacted by severe weather events.

Maryland is an ideal location for eco-tourism because of the ecologically diverse Chesapeake Bay. In 2006, in Maryland, more than $633 million was spent on wildlife watching (83 percent on equipment), $568 million was spent on recreational fishing ($300 million on saltwater fishing) and hunting expenditures amounted to $210 million ($54 million on migratory bird hunting) (USFWS & US Census, 2006). Maryland's 66 State Parks welcome more than 10 million visitors each year, who come "to hike, bike, camp, enjoy access to water and spend time with family and friends in scenic natural settings," creating an economic asset worth $650 million annually (Dougherty, 2011). These numbers combined make ecological and park tourism a roughly $2 billion business in Maryland.

An increase in the number of shoreline hardening and stabilization structures is a response to increased sea level, storm impacts and erosion These structures make it more difficult for wetlands and marshes to migrate in response to changes in sea level and could result in the loss of wetlands. Wu et al (2008) estimates that about 250,000 acres of land in the Mid-Atlantic region are below the 2.2 foot mean sea level rise contour, half of which is wetland (Pyke et al., 2009). A decrease in wetland area hinders shorebird nesting and fish nurseries in turn diminishing the quality of wildlife watching, waterfowl hunting and fishing (Najjar et al., 2000). A reduction of only a couple percent in hunting, fishing, wildlife-watching and other eco-activities would translate into $10 million-plus in lost income and hundreds of lost jobs.

7 Agriculture

One-third of Maryland's 6 million acres is farmland. Of Maryland's 2 million acres of farmland, 68.5 percent is cropland, 18.3 percent is woodland, 7.6 percent is pasture and the remaining 5.7 percent is for other uses (USDA, 2009). Agriculture plays a vital role in Maryland's economy. In 2007, the market value of agricultural products sold by Maryland farms was $1.8 billion, up almost 42 percent since 2002. Of this value, $629 million (34 percent) is for crop sales and

$1,206 million (66 percent) for livestock. Of the latter, 75 percent ($903 million, 49 percent of the total) is for poultry and eggs alone (USDA, 2009).

The Delmarva Peninsula, including Maryland's Eastern Shore, is well known for its chicken meat industry and ranks 7th in the nation in the number of broilers and other chickens. Grains are the second most-valuable product at $308 million, which are dominated by corn, soy and wheat (USDA, 2009). The STWG and the ARWG of the Maryland Commission on Climate Change identified the climate impacts for agricultural product categories (Table 4).

Table 4. Climate impacts on Maryland's top four agricultural categories (Source: Boicourt & Johnson, 2010).

Products	Climate Impacts
Poultry and eggs	Increased cooling costs; decreased production; changing disease presence
Grains, oilseeds, dry beans and peas	Water stress; increased irrigation use; winter flooding; changes in crop yields (both quantity and quality)
Nursery, greenhouse, floriculture and sod	Increased cooling costs; water stress
Milk and dairy	Decreased milk productivity; changing disease presence; low-quality pasture during drought

Rising summer temperatures and more frequent and longer-lasting heat waves could inhibit animal growth, dairy production or potentially lead to heat-related deaths. Poultry farmers will suffer production losses or be required to spend more on cooling. Chickens and turkeys are primarily raised in housed operations and extreme heat will influence building energy requirements (CCSP, 2008), for example by raising summer electricity costs for cooling. During heat waves, stocking density may need to be reduced, meaning increased operations and housing costs. Also, higher humidity levels will increase the need for ventilation increasing the cost of emissions control to prevent an increase in air and water pollution. On the other hand, higher winter temperatures will reduce the need for space heating and partially offset increased summer electricity cost. Furthermore, with changing climatic conditions, the types and number of pathogens may increase leading to more disease and potentially increasing the cost of antibiotics or causing production losses.

Furthermore, more frequent and intense heavy downpours can overwhelm nutrient runoff management systems and require additional investments. On top of that, nutrient runoff requirements may become stricter if natural filter systems in the Chesapeake Bay, such as the extensive wetlands of Dorchester County and oyster banks, continue to shrink, leading to an increase in the Chesapeake Bay's sensitivity to nutrient emissions from air and water.

The effects of climate change will increase the costs of production as more labor is needed to monitor crops and livestock and as equipment modifications are required to respond to new heat and precipitation patterns. In turn, these higher costs of doing business will influence the price of agricultural products. A 2009 report of the International Food Policy Research Institute (Nelson et al., 2009) estimates world food price increases in 2050 under the Intergovernmental Panel on Climate Change A2 climate scenario (consistent with the climate scenario used by the Maryland Commission on Climate Change). In a world absent of climate change, poultry meat, which cost $1,203 per metric ton in 2000, will increase 34.7 percent to $1,621 per metric ton in 2050. With climate change, the price increase is 63.6 percent, resulting in $1,968 per metric ton in 2050, a difference of $347 per metric ton compared to the no-climate change situation. The climate-induced price impacts on wheat and corn are even more dramatic (see Table 5).

Table 5. Projected global market prices for poultry and Maryland's top three crops for 2050 (Source: Nelson et al. 2009).

	2000	2050 *No Climate Change*	2050 *Climate Change*
Poultry	1,203 [USD per metric tons]	1,621 [USD per metric tons]	1,968 [USD per metric tons]
percent change from 2000		*34.7 [percent]*	*63.6 [percent]*
Corn	95 [USD per metric tons]	155 [USD per metric tons]	237 [USD per metric tons]
percent change from 2000		*63.2 [percent]*	*149.5 [percent]*
Soybeans	206 [USD per metric tons]	354 [USD per metric tons]	399 [USD per metric tons]
percent change from 2000		*71.8 [percent]*	*93.7 [percent]*
Wheat	113 [USD per metric tons]	158 [USD per metric tons]	320 [USD per metric tons]
percent change from 2000		*39.8 [percent]*	*183.2 [percent]*

Maryland's poultry production consumes the majority of the state's corn and soybean. Increasing grain and bean prices due to increasing global demand can stress meat markets, but for soy-fed poultry, under a climate change scenario, the value of the product could increase more than soybeans, potentially increasing profitability of poultry production .

Increased climate variability means that farmers will have to be prepared for a wider range of climatic conditions, which necessitates more intense farm management and escalating equipment costs, or the risk of crop failure will rise. This will be especially problematic for Maryland's small farmers with limited time and financial capital. At present, 90 percent of Maryland crops are rain-fed, but this could decrease with less predicable precipitation patterns and extreme summer heat. The production of corn, soy and wheat will likely face increased irrigation needs as heat increases evaporation rates. Also, farmers will see more exposure to flooding as precipitation events become more frequent and intense.

Additionally, pest patterns are liable to shift along with changes in seasonal temperatures. Maryland farmers spent $50.8 million on pesticides in 2007, up 30 percent from the amount spent in 2002 (USDA, 2009). As a share of total production costs, chemical costs increased 10 percent from 3.0 to 3.3 percent between 2002 and 2007. That trend, however small, is expected to continue, but the cost of using more pesticides includes environmental degradation, as well. Runoff from pesticides contributes to degrading freshwater and coastal ecosystems (Rogers & McCarthy, 2000).

In low-lying coastal areas, like the Eastern Shore, the combination of sea level rise and increased water withdrawal (due to higher temperatures) could cause saltwater intrusion, making soils more saline and less valuable (Boicourt & Johnson, 2010; CCSP, 2008; Stanton & Ackerman, 2007). This would be especially detrimental to corn and soybeans, Maryland's top-two crops, which are easily stressed by very low amounts of salt (Mosset al., 2002). Also, groundwater aquifers, which supply most potable water on the Eastern Shore, might not be suitable without investments in desalination technology, which would raise the cost of water by about 50 percent (Kranhold, 2008). Alternatively, farmers may be able to drill deeper wells, which is still a significant investment.

While a moderate rise in average temperatures and higher carbon dioxide concentrations could be beneficial for Maryland farmers, the overall impact of climate change is expected to create costs (see Figure 11). An increase in carbon dioxide concentrations could increase yields as it naturally fertilizes plants. Soybeans thrive under higher carbon dioxide levels, but corn, the largest crop in terms of market value, is already so efficient at absorbing carbon dioxide that it would not benefit much from higher concentrations. Furthermore, higher carbon dioxide levels stimulate weed growth making herbicides less effective. Finally, higher temperatures lead to elevated ozone concentrations, which has a poisonous effect on plant growth (CCSP, 2008; Boicourt & Johnson, 2010; Ackerman & Santon, 2008).

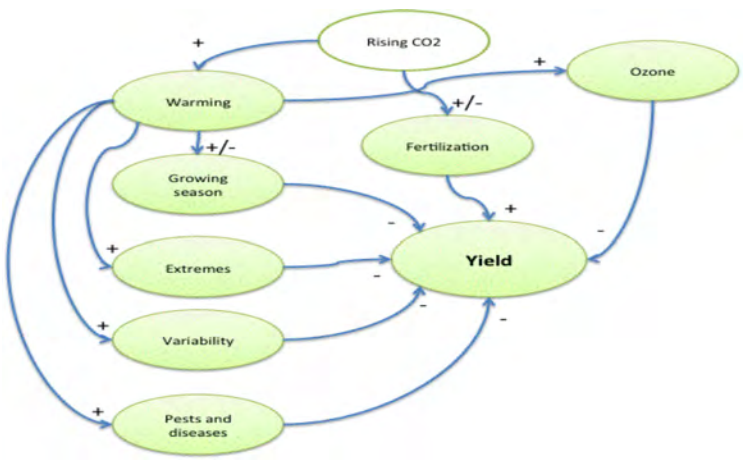

Figure 11. Overview of impacts of rising carbon dioxide concentrations on climate drivers and ultimately yield.

The U.S. Climate Change Science Program's assessment of the effects of climate change on agriculture reviewed the science on how changing climate parameters affect the yields for America's most important cash crops (CCSP, 2008). The assessment evaluates crop yield sensitivity to a modest temperature rise of 2ºF and an increase of carbon dioxide concentrations (see Table 6).

Average growing season temperatures in Maryland (July, August, September) are around 73ºF and closely resemble the Midwest, as opposed to Southern states (Maryland State Climatologist Office, 2011). An average summer temperature rise of 9ºF by 2100 would bring Maryland temperatures above current southern state averages. Temperatures are already above optimal for corn and wheat, whereas soybeans are grown below optimum in the Midwest and above optimum in the South. Here we project future yield effects for Maryland's top three crops based on only temperature and carbon dioxide effects. Assuming a linear response and neglecting impacts from pests, precipitation and carbon dioxide fertilization, we find that for every 1ºF temperature rise in summer averages, corn yield will decline by two percent and wheat yield will decline by 3.8 percent.

Table 6. Percent grain yield responses to increased temperature (2ºF), increased carbon dioxide (380 to 440 ppm and 350 to 700 ppm), and the net effects of temperature plus increased carbon dioxide, assuming additivity. Current mean air temperature during reproductive growth is shown in parentheses for each crop/region to give starting references, although yield of all the cereal crops declines with a temperature slope that originates below current mean air temperatures during grain filling (Source: CCSP, 2008).

	Grain Yield (percent change)		
Crop	Temperature (2ºF)	CO_2 (380 to 440 ppm)	Temp/CO_2 Combined
Corn – Midwest (72.5ºF)	-4.0	+1.0	-3.0
Corn – South (80.1ºF)	-4.0	+1.0	-3.0
Soybean – Midwest (72.5ºF)	+2.5	+7.4	+9.9
Soybean – South (80.1ºF)	-3.5	+7.4	+3.9
Wheat – Plains (67.1ºF)	-6.7	+6.8	+0.1

Based on the above assumptions and current commodity prices, which would be expected to change along with supply, we estimate that by 2030, annual corn production losses would total $5.4 million, while soybean and wheat production would gain $6.5 million annually and $53 thousand annually, respectively (2010$). This calculation neglects the influence of disease, extreme events, ozone and other climatic changes, all of which compromise the projected gains and exacerbate losses. Beyond 2030, as the benefits of carbon dioxide fertilization level off and temperatures climb beyond the optimal range, yield outlook will not be as productive (CCSP, 2008).

On a global scale, Maryland agriculture may benefit in the first few decades of this century as climate change adversely impacts agriculture in other parts of the world, especially south Asia. Combined with elevated global food demand, these supply constraints would raise prices for the world's most important staples including rice, wheat, corn and soybeans (Nelson et al., 2009). While agricultural production may benefit from increased yields and higher crop prices, Maryland consumers would not be sheltered from increases in global food prices.

There has always been a strong link between the agricultural sector and Chesapeake Bay water quality. Crop and animal farming are responsible for roughly forty percent of nitrogen deposition in the Chesapeake Bay and, despite the efforts being made to mitigate nutrient loading into the Bay's air- and watersheds, climate change can complicate the interactions between agriculture and nutrient loading (O'Brien, n.d.).

Rising sea levels, warmer water and overfishing threaten the water filtering services provided by coastal wetlands and oyster banks. As a result, the Chesapeake Bay's water quality could become more sensitive to nutrient deposition, requiring more stringent (and costly) nutrient control measures upstream. Storms and heavy downpours can wash large amounts of fertilizers, pesticides and animal manure into surface waters. When such events become more frequent and more intense, they overwhelm municipal sewer and septic systems, which are seldom designed with future climate conditions in mind. Extreme precipitation events may lead farmers to switch from the spreading of manure to use of commercial fertilizers because the latter is more versatile (though more expensive) and can be quickly applied to compensate for lost nutrients.

Abler et al. (2002) found that Chesapeake Bay water quality will be affected by how corn farmers respond to climate change. However, the magnitude and direction of impact are very sensitive to how the global commodity prices changes. The Chesapeake Bay region is a marginal producer of corn meaning farmers tend to grow corn only when commodity or yield outlooks are very optimistic. If more corn is grown, as Reilly et al. (2003) suggest, then achieving current environmental goals (i.e., Total Maximum Daily Load goals) will be made more difficult. These results suggest environmental targets related to the Chesapeake Bay and the current mechanisms in place to meet the targets would be significantly complicated by climate change.

8 Public Health

The Maryland Commission on Climate Change has documented a comprehensive assessment of potential climate change impacts on public health (Boicourt & Johnson, 2010). Climate drivers, such as temperature and precipitation, influence many pathogens and human physiology. Among the health concerns are harmful algal blooms, which prevent swimming and fishing. Rising temperatures and increases in precipitation variability are likely to influence air quality (e.g., ozone), heat stress and vector-borne diseases. Mental health can also be impaired by extreme storm events and flooding. The impacts of climate change on human health will vary and depend on, among other factors, an individual's sensitivity and exposure to a given threat and capacity to adapt. Within Maryland, the overall impacts of climate change on human health during this century are expected to be relatively small compared to the current major causes of mortality including heart disease, cancer, stroke, and lung disease.

Increased flooding from sea level elevation and intense downpours has the potential to introduce harmful bacteria, chemicals and salt water into fresh drinking water sources (Frumhoff et al., 2007). In 1992, for example, salt water seeped into the Potomac-Raritan-Magothy aquifer, which is a primary source of drinking water in the New Jersey coastal plain. The chloride concentrations increased from 10 milligrams per liter to 70 milligrams per liter; a higher than ideal amount of chloride in drinking water (Oppenheimer et al., 2005). Also, more runoff events following extreme precipitation can increase particulate and chemical concentrations in drinking water reserves. Runoff can damage water and sewage treatment plants and cause septic tanks to fail[5], all of which increases the risk of drinking water contamination and the costs of managing water resources (Neff et al., 2000).

Higher temperatures can have acute and chronic respiratory health effects, especially in cities where heat islands develop and concentrations of ground level ozone are elevated (Moss et al. 2002). A study by the Johns Hopkins School of Public Health correlated daily mortality rates and temperatures for eleven east coast U.S. cities from 1973-1994 and found that there is a minimum mortality temperature above which heat-related deaths increase steadily. The study found that Baltimore ranks first among east coast cities for the rate of increased mortality at temperatures above the minimum mortality temperature (Curriero et al., 2002), with a 6.56 percent increase in heat-related mortality per 1.8 ºF increase.

As summer days grow hotter due to the effects of climate change, Baltimore and other Maryland cities should be prepared to deal with higher rates of heat-related health effects. Of course, there is also the potential for fewer cold-related deaths. Considering that maximum temperatures have been rising faster than average temperatures (Boesch, 2008), this may be construed as a conservative estimate. In addition, large temperature swings from day-to-day, which is expected to occur more frequently, has an adverse impact on mortality (Guo et al., 2011). Health risks are not distributed equally; urban residents who are physiologically susceptible, socioeconomically disadvantaged and live in the most degraded environments are disproportionally at risk (Harlan & Ruddell, 2011). The aging of Maryland's population makes it more vulnerable to heat waves, adding to health costs. By 2030, 20 percent of all Marylanders are forecasted to be over 65, up from 13 percent in 2010 (MDP, 2011b).

Institutional and physical adaptation and preparedness can go a very long way in mitigating heat-related mortality. For instance, a 1995 heat wave in Chicago killed 700 people, mostly vulnerable elderly residents. Since then, Chicago authorities have implemented many adaptive measures such as setting up cooling centers around the city and having city workers check on the frail and elderly anytime the temperature rises above 90 ºF (Huber, 2011). Mitigation and adaptation strategies as a component of city management plans may produce health co-benefits by reducing emissions and cooling temperatures through changes in the built environment (Harlan & Ruddell, 2011; Ruth, 2010).

9 Energy sector

Maryland's energy infrastructure including fuel and coal distribution systems, electricity generating capacity and electricity transmission and distribution networks are at risk from the effects of climate change. In 2009, Maryland had 35 power generators with over 100 MW in nameplate capacity (EIA, 2010). Maryland's large power generators are concentrated on the northern part of the Western Shore, close to Baltimore and Washington with several others along the rivers in the South and toward Western Maryland. As Figure 12 shows, transmission power lines are concentrated in the densely populated Baltimore-Washington corridor. There is one

[5] Stormwater runoff water from roofs, roads, or paved areas may end up on a septic system drainfield. The soil could become saturated to the point that it can no longer absorb additional water. Sewage then backs up into the house or on top of the ground. If storm water enters the septic tank, the septic system can become overloaded.

nuclear power plant at Calvert Cliffs. Petroleum arrives by barge in the Port of Baltimore and by pipeline from the Gulf Coast refineries. Most natural gas is piped in from the Gulf Coast area; liquefied natural gas arrives via the Cove Point facility. Maryland predominately relies on outside sources for primary energy (i.e., gas, oil, coal) although a small amount of coal is extracted in the state. Natural gas extraction from Marcellus shale deposits in Western Maryland may become an additional source of in-state energy (EIA, 2010).

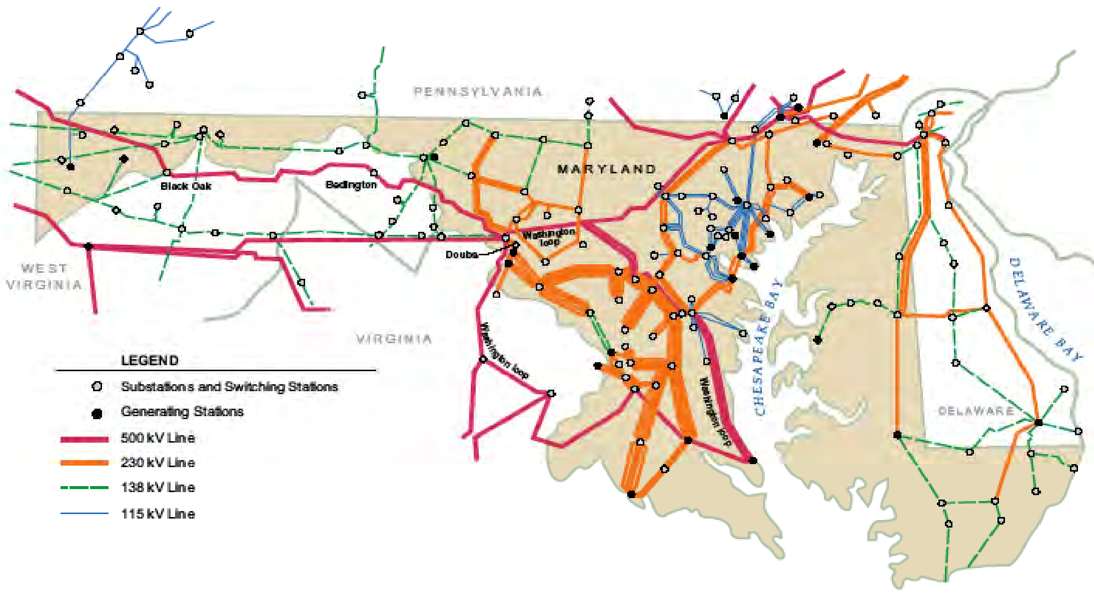

Figure 12. High-voltage (>115 kV) transmission lines in Maryland (Source: PPRP, 2009).

Maryland energy consumers, including citizens, private companies and public entities, spent $24 billion on energy in 2008, up from roughly $10 billion at the turn of the century. As segregated by energy type, $8.2 billion was spent on electricity; $13.5 billion went to petroleum, about two-thirds of which for gasoline and 23 percent for heating oil; and $2.7 billion was spent on natural gas (EIA, 2011). Utilities added $6.5 billion or 2.2 percent to Maryland's gross domestic product in 2010 (US BEA, 2011).

Historically, energy consumption has progressed along with economic and population growth. By 2040, Maryland's population is expected to grow by 20 percent relative to today (MDP, 2011a). Economic growth over the past decade varied between 1.7 and 4.3 percent, if the recession-affected years 2008 and 2009 are excluded (US BEA, 2011). With the combination of these growth trends, Maryland can expect future increases in total energy demand. The regional electricity transmission organization, Pennsylvania-New Jersey-Maryland Interconnection (PJM), projects electricity consumption in Maryland to increase by 1.2-1.8 percent per year depending on the location (PSC, 2011). Per capita energy and electricity consumption are forecasted to decrease with assistance from utility-operated EmPower Maryland programs (PSC, 2011).

Climate change induced temperature variability will influence the demand side of the energy system. Higher summer temperatures will increase cooling requirements while higher winter temperatures will decrease heating requirements; cooling is dependent on electricity while heating is primarily dependent on fuels (e.g., natural gas and heating oil). This will affect households and business energy costs as well as energy suppliers. Summer electricity expenditures will be impacted in two distinct ways: (1) as more electricity is consumed for cooling, more kilowatt-hours of electricity will be required; and (2) as consumers demand more electricity, wholesale electricity markets will respond through higher unit prices. While rate impacts may not emerge in the short-term due to Maryland Public Service Commission rate controls, the costs of operating, and potentially building, more capacity will be reflected in electricity rates in the long-term. A decrease in consumption for energy end-uses such as residential, commercial and industrial water heating is expected, while energy consumption for refrigeration and industrial process cooling will rise. Other electricity end-uses relevant to climate change include water pumping and desalination, which may be necessary to meet agricultural and public water demand. In the context of variable precipitation patterns and sea level rise, Maryland may increasingly rely on electricity to meet water demand.

Ruth & Lin (2006) analyzed the expected impacts of climate change on energy demand in Maryland. They used a regional warming projection of 3-4ºF by 2100, which is less than half the projections of the STWG (Boesch, 2008) for the business-as-usual scenario and translates into very modest amounts of warming by 2025. Ruth & Lin found that the modest level of warming only minimally influenced energy consumption. Table 7 shows the changes in energy consumption for heating and cooling purposes that are attributable to climate change. Energy prices and population change are anticipated to have a much greater impact on Maryland's energy use in the near-term. However, the impact of climate change on energy consumption increases rapidly as extreme and average temperatures rise. Under the STWG high-emissions scenario, climate induced shifts in energy consumption are likely to be particularly pronounced during the summer.

Table 7. Change in energy consumption for space heating and cooling in Maryland by 2025 relative to 1977-2000 average; climate trend: +3-4 ºF warming by 2100 (Sources: Boesch, 2008; Ruth & Lin 2006).

Sector	Change in energy consumption
Residential space heating	2.5% reduction in natural gas consumption
	2.7% reduction in heating oil consumption
Commercial space heating	2.7% reduction in natural gas consumption
Residential space cooling	2.5% increase in May-September high energy prices
	24% increase in low energy prices
Commercial space cooling	10% increase per employee April through October

The supply side of the energy system will be impacted by climate change as well. The average warming will change the distribution of energy sources, shifting consumption away from heating fuels such as natural gas and heating oil and towards electricity for cooling. Moreover, the quantity and quality of fuels used to generate electricity will be impacted. Baseload electricity is provided by high capacity coal and nuclear plants, which are always in operation. As demand for electricity spikes on a daily and seasonal pattern, natural gas (and sometimes oil) powered plants, are quickly dispatched so that supply is able to meet demand. Due to economic and technical constraints, only natural gas and oil are suitable for meeting peak electricity demand. In turn, with more extreme heat events, which trigger cooling demand, there will be increased reliance on peaking plants and natural gas. Another relevant dynamic in the electricity market is growing capacity from renewable sources, which may be used during base and peak periods, but are generally constrained by intermittence or an inability to generate electricity on a moment's notice. Climate change has the potential to impact renewable electricity sources because it is expected to mean greater variability in wind resources and direct solar radiation. This has substantial implications for the planning, siting and financing of wind farms and solar power generators in the future (CCSP, 2007).

Extreme heat can make power generation much more costly. Higher environmental temperatures decrease efficiency in overall thermoelectric power generation. In other words, less electricity is generated (output) per unit of fuel energy (input) as environmental temperatures increase. The natural gas electricity generation capacity dispatched to meet peak demand during hot summer days is typically less efficient and has higher fuel costs relative to base capacity. As a result, natural gas capacity is typically uncompetitive when only base demand needs to be met. As demand rises, however, and less expensive base capacity supplies become exhausted, more expensive natural gas capacity is called upon to generate electricity. The costs associated with operating more natural gas fueled electricity capacity will be reflected in electricity rates.

Electricity transmission is also of concern in the context of climate change. Over the last few years, transmission congestion and constraints in the PJM region have put upward pressure on electricity prices and created concerns about the reliability of the electricity delivery system in Maryland (MEA, 2010). With increasingly severe storms, power outages will occur more often in the absence of modifications to the existing electricity transmission and distribution system. Additionally, heat increases the resistance of transmission lines, rendering the electricity supply less efficient. During heat waves, transmission losses can amount to nearly a third of the generated electricity, compared to about 8-12 percent during normal operations (CCSP, 2007; Ackerman & Stanton, 2008). As a result of heat driven increases in electricity demand and supply-side constraints (i.e., transmission losses), demand for carbon-intensive fuels to provide power is expected to grow. In turn, a feedback loop emerges whereby the rate of GHG emissions from power generation increases as a response to climate change induced extreme heat.

Changes in the distribution of water availability in the U.S. will affect power plants, especially when droughts coincide with heat waves. Power generators almost always require water for cooling. During extreme heat, when increased demand for cooling combines with decreased generation efficiency, the need for cooling water rises. However, if heat waves coincide with a prolonged drought, which it very well may with summer precipitation expected to decrease, water may become limited or unavailable. Moreover, if water becomes a scarce resource, the cost to electricity generators of obtaining cooling water will increase and carry over to the ratepayer. Ecological constraints can further limit the availability of water for cooling. For example, as water temperatures increase via the heat transfer from the power plant, the amount of dissolved oxygen decreases and inhibits aquatic life. Such situations may become reality for decision-makers as they are forced to acknowledge difficult trade-offs between several important services.

Increases in storm intensity could threaten further disruptions in power generation and distribution. Much of Maryland's electricity generation capacity, transmission network and areas of demand lie in the Baltimore-Washington corridor. This area is also coastal and susceptible to sea level rise and severe storms. As a result, much of Maryland's electricity infrastructure is exposed to storm damage. For example, hurricane Isabel cut power to 1.2 million Marylanders, largely caused by trees hitting overhead distribution lines. In the future, storm surges in low-lying areas may also lead to flooding and inhibit power restoration efforts (BGE 2003). Last, nuclear power plants' procedures require them to shut down prior to any predicted hurricane force winds on site (NRC, 2011).

Energy resource production and delivery systems along the Gulf Coast and the East Coast are vulnerable to the effects of sea level rise and extreme weather events. A hurricane landfall in the Gulf Coast region, where such storms occur more frequently than in the Mid-Atlantic, poses a risk to Maryland due to the oil and gas interconnections between the two regions. Any major hurricane event along the Gulf Coast will likely disrupt oil and gas extraction, refining and transmission, and place constraints on supply and price. Hurricanes Katrina and Rita shut down large natural gas production facilities in the Gulf region, which led to an increase in prices from under $10 to over $14 per million British Thermal Unit. Also, damage to gas processing facilities disabled petroleum treatment operations and further extended the delay of gas delivery (EIA 2005). Supply shortages from production losses in the Gulf Coast could not be mitigated by increased supply from production areas in the Western U.S. because of inadequate east to west pipeline capacity (Energy and Environmental Analysis, Inc.. 2005). Following Hurricane Katrina, it became clear that Maryland's energy supply is vulnerable because most of it is processed in one geographic location. Climate change impacts could exacerbate that vulnerability (MEA, 2010).

One study of energy and climate change concluded that most climate induced effects are likely to be modest except for regional extreme weather events and water shortages, of which the latter is less a concern for Maryland than for more drought-prone states in the south and southwest U.S. (CCSP, 2007). Nonetheless, with Maryland's densely populated Baltimore-Washington corridor and the vulnerabilities of its energy infrastructure, the consequences of extreme heat and storm events must not be discounted. Overall, Maryland is expected to consume more electricity, which must be met with adequate generation capacity and reliable transmission networks. Even if total annual electricity consumption in the state remains relatively constant, more extreme heat events are likely to lead to higher peak electricity demand, which will necessitates increased investment in generation capacity and transmission with those costs carrying over to ratepayers. Heating fuels are expected to be in less demand as winter temperatures increase. The net impact on natural gas, which serves as both a peak electricity fuel and a heating fuel, is uncertain. While less natural gas will be consumed to meet heating requirements, more natural gas is likely to be consumed to meet electricity demand during extreme heat events.

10 Conclusions

10.1 Recap of climate change impacts and costs of inaction

The economic impacts of climate change on Maryland will depend on the exact physical changes that manifest themselves over the coming decades. Although there is uncertainty about the exact physical changes, there is broad scientific consensus that, by 2100, global annual average temperatures will increase by 4-9°F. As a consequence, there will be more frequent and intense storms, and sea levels will rise by 2.7-3.4 feet. New research since the 2007 Intergovernmental Panel on Climate Change assessment report has shown that the conclusions are robust, but that the climate is probably more sensitive to carbon dioxide concentrations than previously thought. Some of the recent research suggests that even greater estimates cannot be ruled out.

The physical changes and altered weather patterns that develop from the impacts of climate change will significantly influence Maryland’s coastline, agricultural productivity, ecosystems, energy systems and overall economy. Two critical factors dictating the economic impacts of climate change in the state are population growth and land development. Should Maryland’s population grow the expected 20 percent between now and 2040 and should the state’s gross domestic product resume its pre-recession growth trajectory, the potential for economic losses from climate change can be expected to increase considerably. By becoming a more populated, developed, and economically interconnected state, there will be more avenues for the direct and indirect effects of climate change to impact Maryland.

10.2 Missing information and data gaps

As the policy and investment communities have begun to embrace the need for addressing impacts associated with climate change, much attention has been paid to the costs associated with mitigating GHG emissions. Since significant changes to virtually all aspects of modern life are needed – from food production to energy to transportation and beyond – the costs of mitigation may seem dauntingly high. However, rational investment and policy decisions require full-cost accounting including an assessment of the potential costs of inaction. These are much more difficult to quantify, especially if quantification entails expressing costs in monetary terms, because these costs are more diffuse and include costs associated with declining infrastructure performance, compromised public health and impacts on ecosystems.

Additionally, quantifying the local costs of inaction is challenging because climate impacts are global. To make accurate forecasts that inform local action, accurate global model projections need to be brought in synch with complex regional drivers. Since the early 1990s, and especially during the 21st century, significant progress has been made in understanding the impacts of climate change at national, regional, and local scales. Much effort is currently put into “downscaling” global climate models to refine the spatial and temporal resolution for the region of interest and incorporate regionally significant land-water-air interactions. These ongoing efforts will likely allow for more accurate projections in the future of how climate change will impact Maryland. We expect those predictions to also become more valued by local decision makers. To get the most out of the downscaled climate projections, there is a need to (1) improve the presentation in a way that resonates with the users of the information and (2) better understand which information attributes (e.g., accuracy, completeness, availability, etc.) are most valued and lead to effective action.

Further, data gaps exist between the effects of climate change in one particular sector and the ripple effects that manifest in interconnected sectors. Analysis of this sort would be useful to policy-makers and businesses at all levels and sizes. Additionally, much of the literature on the topic of economic costs of climate inaction succeeds in only partially characterizing impacts and frequently lacks robust quantifications.

10.3 Take-aways

A number of lessons can be taken away from this report that are of particular importance for Maryland's forthcoming adaptation and mitigation efforts. Four key take-aways include:

1. Maryland's greatest challenge is adapting to climate change along its expansive coast and in the Baltimore-Washington urban corridor as this is where significant human, physical and financial capital lie. The state's economy is particularly vulnerable to more intense coastal storms because of the scale of development along the coast, stressed infrastructure and the high rate of coastal erosion and relative sea level rise.
2. The costs of inaction will be spread throughout the state, will affect multiple economic sectors and are anticipated to increase through time if adaptation measures remain inadequate. For example, electricity is a common necessity in modern economies and all businesses internalize electricity in their cost of doing business. With more severe and more frequent extreme heat events creating more cooling demand, the region will need to grow electricity generation capacity and transmission networks in accordance. The ecological and economic costs of this expansion will be the responsibility of Maryland ratepayers.
3. The costs of climate change will not be evenly distributed and some Marylanders will be worse off than others. For instance, Maryland's crop and poultry farmers face rising costs due to the need for investments in new equipment, facilities and intensified management processes to keep-up with alternative heat and precipitation regimes, which will impact profitability, especially for small-scale farmers with limited financial capital.
4. There are important regional and global connections that will influence Maryland's cost of inaction. If, for example, more intense storms strike the energy production and processing infrastructure of the Gulf region, then Maryland's energy reliability becomes a serious concern. The costs of not anticipating and preparing for events that arise from global economic dependence are likely to be significant and should not be discounted.

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Appendix A – Areas at risk from a 1 m sea level rise

The table in this appendix lists the results of the analysis of residential acreage (i.e., U.S. Census Populated Place Areas) in Maryland at risk of inundation if the sea level in Maryland were to rise 1 meter or 3.3 feet. This table (Table A-1) lists all at-risk Maryland residential areas whereas Table 2 in the text lists only the most at-risk places. U.S. Populated Place Areas represent populated place areas within the United States that include census-designated places, consolidated cities, and incorporated places as identified by the U.S. Census Bureau.

For this analysis we used GIS to combine a map of U.S. Populated Place Areas with elevation data from the U.S. Geological Survey.[6] We used 2009 TeleAtlas maps.[7]

Table A-1. All Maryland places (U.S. Census Populated Places) by percentage area at risk from 3.3 ft (1 m) relative sea level rise.

	Area (square miles)	Sea level rise risk area [1] (square miles)	Percentage
Aberdeen	6.39	0.0206	0.32%
Aberdeen Proving Ground	11.42	0.8262	7.24%
Accokeek	23.54	1.3801	5.86%
Algonquin	3.18	0.0172	0.54%
Annapolis	7.44	0.1020	1.37%
Arbutus	6.53	0.0015	0.02%
Arden-on-the-Severn	1.65	0.0049	0.30%
Arnold	13.45	0.0935	0.69%
Baltimore	92.08	1.9225	2.09%
Berlin	2.27	0.0038	0.17%
Betterton	0.88	0.0045	0.52%
Bladensburg	1.02	0.0343	3.36%
Bowleys Quarters	5.01	0.2431	4.85%
Brooklyn Park	2.97	0.0199	0.67%

[6] Earth Resources Observation and Science Center. 2010. Shuttle Radar Topology Mission (SRTM) Data. Sioux Falls, SD: United States Geological Survey. The Shuttle Radar Topography Mission (SRTM) is a partnership between NASA and the National Geospatial-Intelligence Agency (NGA). Flown aboard the NASA Space Shuttle Endeavour (11-22 February 2000), SRTM fulfilled its mission to map the world in three dimensions. The USGS is under agreement with NGA and NASA's Jet Propulsion Laboratory to distribute the C-band data. SRTM utilized dual Spaceborne Imaging Radar (SIR-C) and dual X-band Synthetic Aperture Radar (X-SAR) configured as a baseline interferometer to successfully collect data over 80 per cent of the Earth's land surface, everything between 60 degrees North and 56 degrees South latitude. SRTM data is being used to generate a digital topographic map of the Earth's land surface with data points spaced every 1 arc second for the United States of latitude and longitude (approximately 30 meters). The SRTM "finished" data meet the absolute horizontal and vertical accuracies of 20 meters (circular error at 90% confidence) and 16 meters (linear error at 90% confidence), respectively, as specified for the mission.

[7] Tele Atlas. 2009. Tele Atlas StreetMap Premium for ArcGIS - North America, 11.1. Lebanon, New Hampshire: Tele Atlas North America, Inc.

Brookview	0.04	0.0010	2.59%
Bryans Road	8.29	0.0870	1.05%
California	14.73	1.6927	11.49%
Calvert Beach-Long Beach	2.56	0.0443	1.73%
Cambridge	9.06	0.2997	3.31%
Cape St. Claire	2.41	0.0854	3.54%
Centreville	2.12	0.0509	2.40%
Chance	1.77	0.8347	47.16%
Charlestown	1.30	0.0293	2.25%
Chesapeake Beach	2.82	0.4359	15.46%
Chesapeake City	0.61	0.1875	30.74%
Chesapeake Ranch Estates-Drum Point	6.36	0.1071	1.68%
Chester	6.36	0.9962	15.66%
Chestertown	2.80	0.2324	8.30%
Chillum	3.98	0.0002	0.00%
Church Creek	0.31	0.1670	53.89%
Church Hill	0.52	0.0003	0.05%
Cockeysville	11.44	0.0410	0.36%
Colmar Manor	0.53	0.0323	6.10%
Cottage City	0.25	0.0065	2.61%
Crisfield	1.69	0.6917	40.93%
Crownsville	5.54	0.0352	0.63%
Dames Quarter	12.70	11.2351	88.47%
Deal Island	3.29	2.3204	70.53%
Deale	4.31	0.9836	22.82%
Denton	2.54	0.1193	4.70%
Dundalk	17.56	0.5559	3.17%
Dunkirk	7.27	0.9734	13.39%
Eagle Harbor	0.12	0.0097	8.08%
Easton	10.33	0.1401	1.36%
Eden	5.65	0.0035	0.06%
Edgemere	17.56	0.7319	4.17%
Edgewood	17.96	0.6606	3.68%
Edmonston	0.39	0.0061	1.56%
Eldorado	0.08	0.0039	4.94%
Elkton	8.07	0.4633	5.74%
Essex	11.88	0.1672	1.41%
Fairmount	15.33	8.5333	55.66%
Federalsburg	1.97	0.0968	4.91%
Ferndale	4.04	0.0027	0.07%
Forest Heights	0.49	0.0007	0.15%
Fort Washington	14.01	0.7250	5.17%

Frenchtown-Rumbly	4.18	3.8763	92.73%
Galestown	0.23	0.0117	5.08%
Glen Burnie	12.89	0.2570	1.99%
Golden Beach	3.44	1.0315	29.99%
Grasonville	5.37	0.3311	6.17%
Greater Upper Marlboro	37.57	1.4613	3.89%
Green Haven	3.37	0.0079	0.23%
Greensboro	0.67	0.0155	2.32%
Havre de Grace	4.57	0.7408	16.21%
Herald Harbor	2.29	0.0205	0.89%
Highland Beach	0.08	0.0244	30.47%
Hillsboro	0.15	0.0018	1.20%
Hillsmere Shores	1.88	0.0513	2.73%
Huntingtown	8.31	0.0043	0.05%
Hyattsville	2.14	0.0071	0.33%
Indian Head	1.17	0.0151	1.29%
Joppatowne	7.36	0.3238	4.40%
Kent Narrows	2.25	0.7211	32.05%
Kingstown	2.56	0.3195	12.48%
Lake Shore	14.34	0.1536	1.07%
Lansdowne-Baltimore Highlands	4.22	0.2022	4.79%
Leonardtown	3.17	0.0541	1.71%
Lexington Park	8.10	0.0102	0.13%
Londontowne	3.80	0.1265	3.33%
Lusby	3.66	0.1078	2.94%
Mardela Springs	0.38	0.0143	3.77%
Mayo	3.30	0.1986	6.02%
Middle River	8.39	0.2256	2.69%
Millington	0.33	0.0086	2.60%
Mount Vernon	15.01	3.8225	25.47%
Naval Academy	0.86	0.0804	9.35%
North Beach	0.35	0.0494	14.13%
North Brentwood	0.12	0.0007	0.59%
North East	1.53	0.0582	3.80%
Ocean City	4.62	1.3369	28.94%
Ocean Pines	8.50	0.4212	4.96%
Oxford	0.72	0.2134	29.65%
Parole	11.85	0.0563	0.48%
Pasadena	7.68	0.0222	0.29%
Perryman	5.53	0.0632	1.14%
Perryville	2.47	0.0072	0.29%
Pikesville	12.33	0.0021	0.02%
Pocomoke City	3.27	0.2579	7.89%

Port Deposit	1.66	0.0030	0.18%
Port Tobacco Village	0.17	0.0140	8.26%
Potomac Heights	1.37	0.4847	35.38%
Princess Anne	1.26	0.1009	8.01%
Pumphrey	2.53	0.1627	6.43%
Queen Anne	0.12	0.0055	4.59%
Queenstown	0.40	0.0152	3.79%
Riva	2.91	0.0727	2.50%
Riverdale Park	1.59	0.0010	0.06%
Riverside	2.42	0.0209	0.86%
Riviera Beach	3.32	0.0920	2.77%
Rock Hall	1.42	0.2816	19.83%
Rosedale	7.12	0.0479	0.67%
Salisbury	11.27	0.4474	3.97%
Secretary	0.24	0.0305	12.72%
Selby-on-the-Bay	4.60	0.1833	3.98%
Severna Park	15.59	0.1108	0.71%
Shady Side	7.80	1.7080	21.90%
Sharptown	0.46	0.0638	13.86%
Smith Island	6.92	4.0193	58.08%
Snow Hill	1.31	0.0180	1.38%
Solomons	2.14	0.3429	16.02%
St. Leonard	3.20	0.0058	0.18%
St. Michaels	0.90	0.1465	16.28%
Stevensville	6.17	1.4363	23.28%
Stockton	1.72	0.0334	1.94%
Tilghman Island	2.85	0.8165	28.65%
Upper Marlboro	0.43	0.0073	1.69%
Vienna	0.18	0.0107	5.96%
West Ocean City	4.32	1.1130	25.76%
West Pocomoke	9.65	0.3128	3.24%
White Marsh	5.29	0.0008	0.01%