DRAFT

Summary of Potential Climate Change Impacts, Vulnerabilities, and Adaptation Strategies in the Metropolitan Washington Region:

A synopsis of lessons learned from the Metropolitan Washington Council of Governments' climate adaptation planning initiatives from 2010 – 2012.

METROPOLITAN WASHINGTON COUNCIL OF GOVERNMENTS (COG)

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For resources and information about COG's Climate Impacts and Adaptation Initiatives:
http://www.mwcog.org/environment/climate/adaptation.asp

COG CLIMATE ADAPTATION INITIATIVES

The *2008 National Capital Region Climate Change Report* established regional greenhouse gas (GHG) reduction goals and recommended over 100 actions, including adaptation measures. In 2009, the COG Board created the Climate, Energy and Environment Policy Committee (CEEPC) to provide leadership on environmental issues and to help support area governments as they work together to meet the goals outlined in the *2008 National Capital Region Climate Change Report*. In January 2010, CEEPC adopted the 2010-2012 Regional Climate & Energy Workplan which includes measures to mitigate GHG emissions and adapt to climate impacts.

EPA Office of Sustainable Communities has been working with Metropolitan Washington Council of Governments (COG) and its stakeholders since October 2010 to develop an EPA guidebook on approaches to smart growth and climate adaptation. The project with EPA has provided COG an opportunity to begin exploring how the region can adapt to the unavoidable impacts of climate change. The final EPA guidebook has not yet been published.

COG has hosted several events in order to meet the CEEPC Workplan goals and advance the EPA project. The National Oceanic and Atmospheric Administration (NOAA) came to COG in March 2011 to train local officials on how to conduct a vulnerability assessment in their communities. In September 2011, COG held several adaptation stakeholder meetings to engage experts from a variety of sectors, including transportation, land use, buildings and water. National and local best practices were presented, climate impacts and vulnerabilities for the region were reviewed, and information was gathered from stakeholders to help with the development of the guidebook. The draft guidebook was discussed at a stakeholder meeting in March 2012. Stakeholders expressed interest in more detailed information on climate impacts and implications for local decision-makers. To that end, COG held a Climate Impacts Symposium on May 21, 2012.

This document is a summary of key information that has been learned throughout the process of working with EPA, stakeholders and climate experts on the development of the guidebook. Much of the climate impacts in this document reflect information presented by the climate experts at the Climate Impacts Symposium.

GLOBAL CLIMATE MODELS

Global climate models have become more sophisticated and have improved resolution overtime. Between the 1970s and 2000s, global climate models have become much more sophisticated, beginning with weather models, and later incorporating ocean circulation, clouds, land cover, aerosols, and other physical elements (Figure 1). Global climate models have improved resolution from 500 km^2 (311 mi^2) in 1990 to 110 km^2 (68 mi^2) in 2007 (see Figure 2) but are not yet to the point that they can be considered accurate at the regional scale. Next generation climate models are being designed to incorporate land use, infrastructure, econometrics, and natural processes at 52 km^2 (20 mi^2) resolution[i].

Figure 1: Evolution of Global Climate Model Complexity

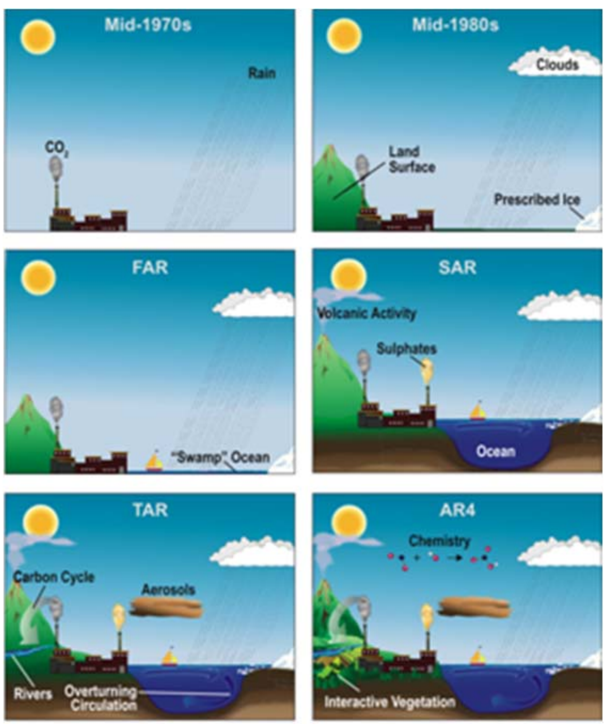
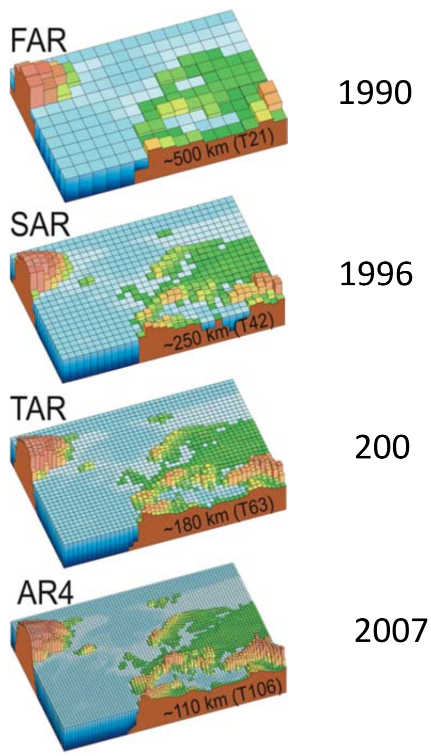


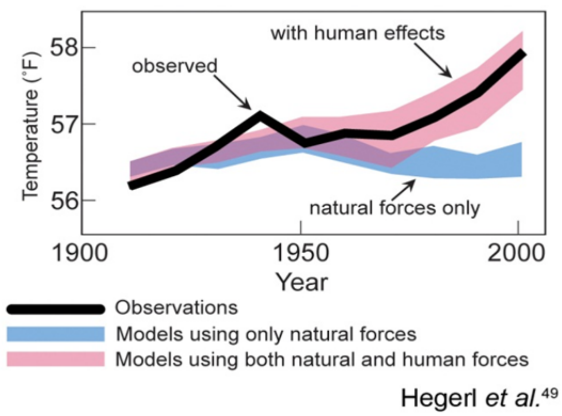
Figure 2: Evolution of Geographic Resolution in Global Climate Models



TEMPERATURE

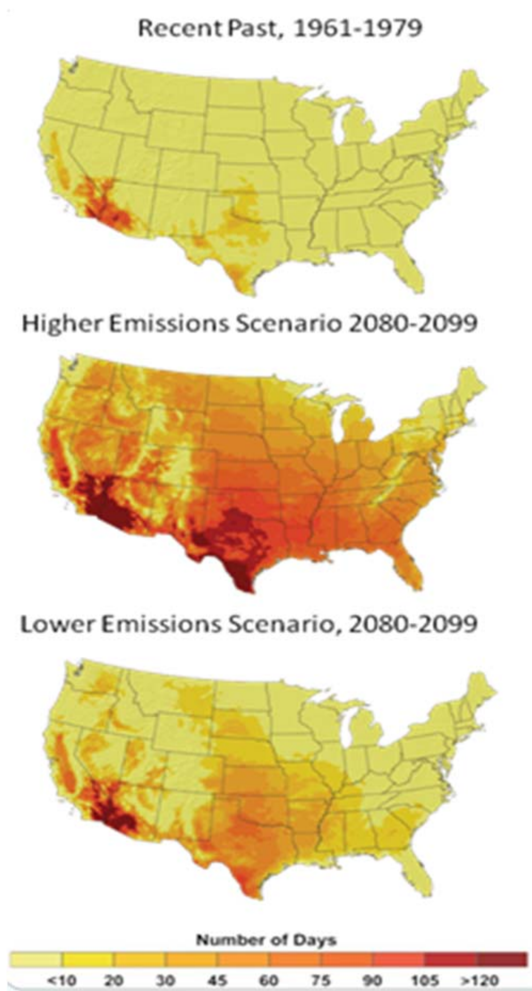
Climate change is occurring and is caused largely by human activities[ii]. Without human influences, temperature over the past century would actually have first warmed and then cooled slightly over recent decades. Modeling results show the increase in average global temperatures since the 1970s cannot be explained by natural forces alone (Figure 3)[iii].

Figure 3: Temperature and Human Influences



A key factor that raises the range of predicted mean temperature change in the long-term is the level of greenhouse gases emitted, although some degree of climate change effects will continue to occur for a time due to lifespan of greenhouse gases in the atmosphere. Figure 4 shows the number of days over 100°F in the recent past and towards the end of the century under higher and lower emissions scenarios[iv]. Over the next century, the region will experience increasingly milder winters and much hotter summers[v].

Figure 4: Temperature Trends and Predictions: Average Number of Yearly Days over 100°F



PRECIPITATION

Precipitation trends are harder to pin down: precipitation patterns are more complex, global models are less consistent in predicting precipitation, and the COG region is in a transition zone between a predicted drier south and wetter northeast. The region has experienced a slight increase in average annual precipitation from 1950-2008 (Figure 5). The region is projected to have less precipitation in the summer and more in the fall by 2080-2099 (Figure 6). There is evidence of trends toward heavier downpours: the US has seen a 20% increase in the amount of rain falling in the heaviest downpours in the last century[vi].

Figure 5: Observed Annual Precipitation Change 1950-2008

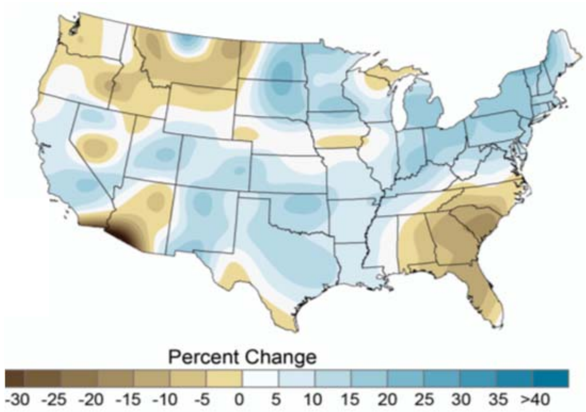
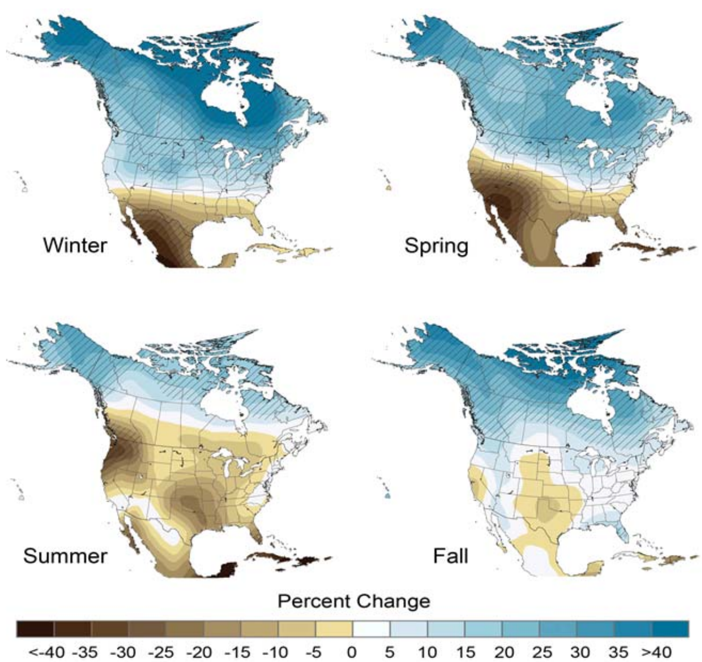


Figure 6: Projected Precipitation Change by 2080-2099 (under Higher Emissions scenario)



SEA LEVEL RISE

The Chesapeake Bay has experienced 1 foot of sea level rise over the last century (Figure 7) and could experience another 1-3 feet of sea level rise by 2100.This includes local geological land subsidence. Sea level in the Chesapeake Bay rose roughly an additional half foot per century than global sea level; therefore, subsidence accounts for about half of the rise in sea level in the Chesapeake Bay in the 20th century. The local land subsidence trend is expected to continue. Future sea level rise in the Chesapeake Bay will depend on increases in future emissions and the rate at which ice melts globally (Figure 8)[vii].

Figure 7: Mean Sea Level Rise at Baltimore Tide Gauge, 1903 - 2006

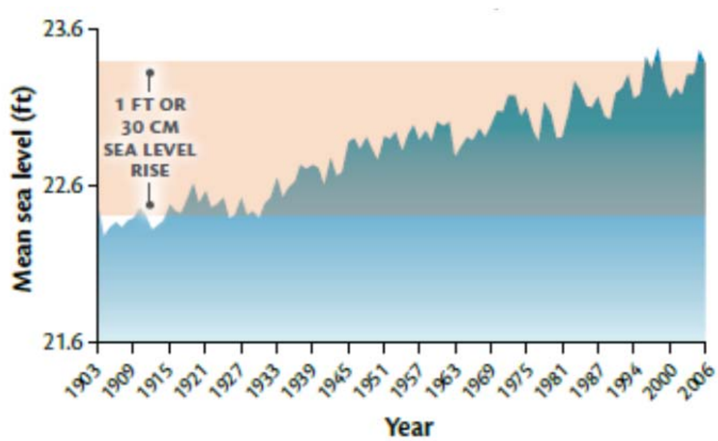
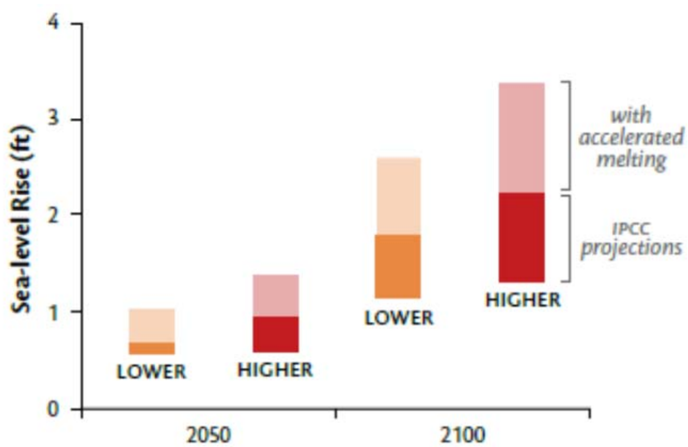


Figure 8: 21st Century Projected Sea Level Rise in Maryland Under Lower and Higher Emission Scenarios



Sea level rise, especially when combined with storm surge (see next section) could impact about six of the 22 COG jurisdictions that border tidal water bodies (the Potomac and Anacostia). These areas include valuable real estate, infrastructure, residences and employment centers located in the heart of the region. Some areas are not threatened by sea level rise—the region straddles the hilly piedmont and the relatively flat coastal plain zones. The Potomac and Anacostia Rivers are connected to the Chesapeake Bay, but the region is about 100 miles from the open ocean.

FLOOD RISKS

Flooding will become increasingly problematic if precipitation continues to fall in heavier events, sea level rises, and storms intensify under climate change[viii]. Flooding is also heavily influenced by the amount and type of development, shore protection measures, site and building design, stormwater drainage infrastructure, and other flood mitigation measures[ix].

There are three main types of flood risk in the National Capital Region, including:

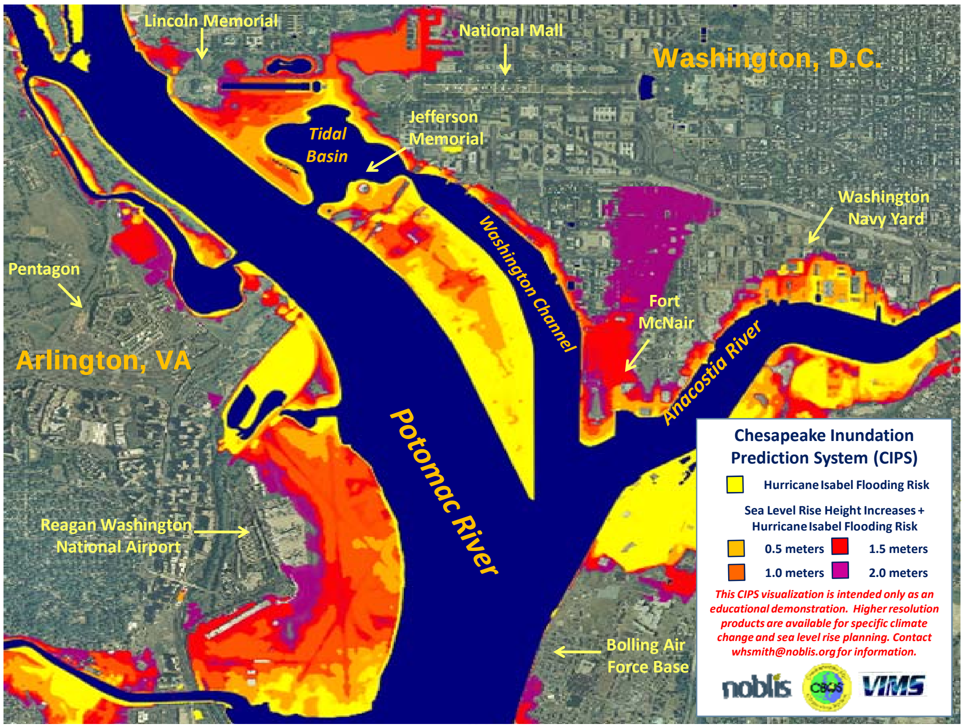
1. Overbank flooding, which is river caused
2. Tidal flooding, caused by storm surge
3. Urban drainage flooding, caused by limited sewer capacity[x]

Potomac River overbank flooding, originating from precipitation in the Potomac River Basin is a potentially bigger, more immediate threat than storm surge, which is caused by coastal storm dynamics. The most frequent and most significant flooding is caused by overbank flooding. For instance, the USGS Potomac River gauge at Wisconsin Avenue in Georgetown has a record tide height of 17.7 feet from the 1942 Potomac River Basin flood (Figure 9). The worst storm surge on record at this gauge is from Hurricane Isabel in 2003 where the tide height only reached about 11 feet.

Figure 9: 1942 Potomac River Flood

Storm surge floods will become a significant threat in the long term with added subsidence and sea level rise (Figure 10). Due to sea level rise, areas that experience frequent tidal/storm surge flooding now are expected to be within the daily tidal inundation zones toward the end of the century unless protected[xi].

Figure 10: Scenarios for an Isabel-type storm surge with sea level rise



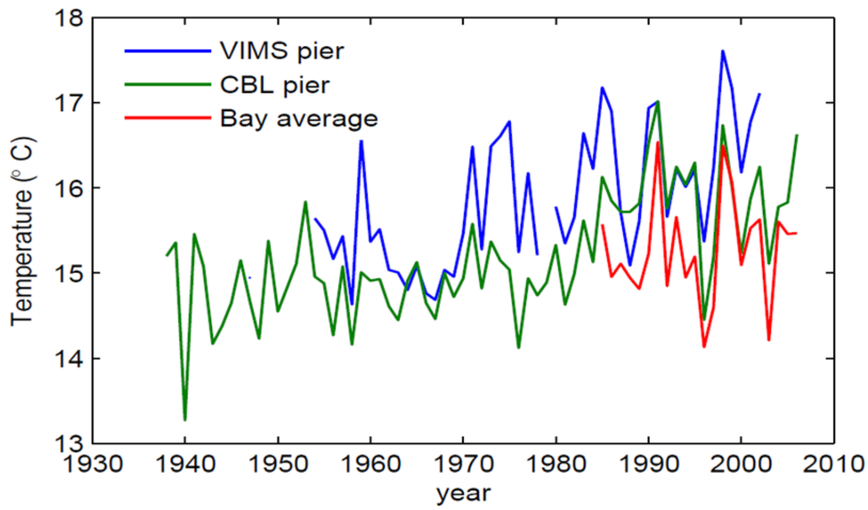
Floodplain increase: According to the NY Times blog ClimateWire, a report commissioned by FEMA on the impacts of climate change and growth on floodplains found that flood-prone land is likely to increase by 40 to 45% over the next 90 years[xii]. The report estimated that climate change is responsible for 70% of the flood plain increase. The remaining 30% stems from increased development.

Urban drainage (or interior drainage) flooding impacts homes and businesses located outside of floodplains. In some areas of the District of Columbia and Alexandria, heavy precipitation load in storm drains causes sewage to enter local waterways (termed combined sewer overflows), and sometimes even back up into basements. Localized interior drainage events are not generally tracked. Interior flooding may become more problematic with heavier downpours, as well as increased development.

CHESAPEAKE BAY WARMING

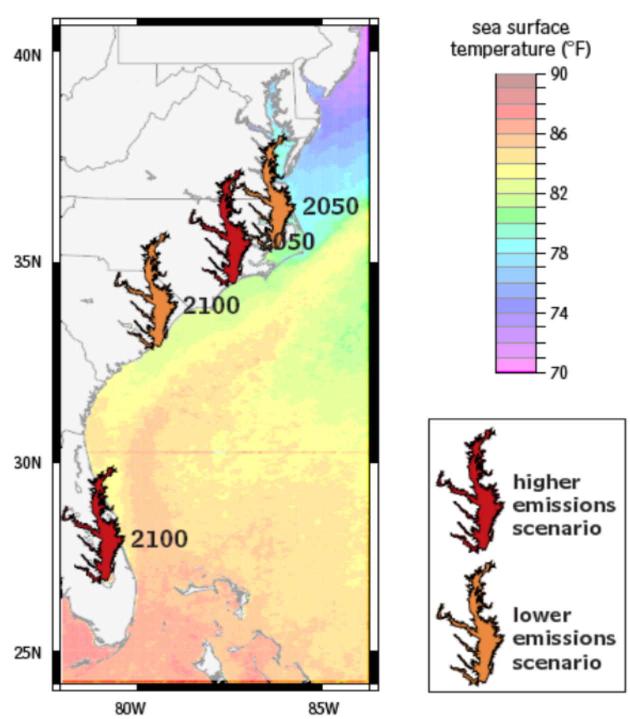
The Chesapeake Bay has been experiencing a warming trend (Figure 11)[xiii].

Figure 11: Chesapeake Bay Water Temperature Trend



By 2050 the summer water temperature of the Bay is likely to be similar to water temperatures of North Carolina sounds, or in a high emissions scenario similar to South Florida (Figure 12)[xiv]. Three key indicators of Chesapeake Bay health are dissolved oxygen, submerged aquatic vegetation, and oysters - all of which will be effected negatively by the projected climate impacts in the Bay. Higher spring flows, higher temperatures and higher CO_2 lead to decreases in bottom-water oxygen and affect submerged aquatic vegetation. Oyster disease has spread in response to winter warming, and larvae shell calcification decreases in the presence of higher concentrations of CO_2 due to increased ocean acidity[xv].

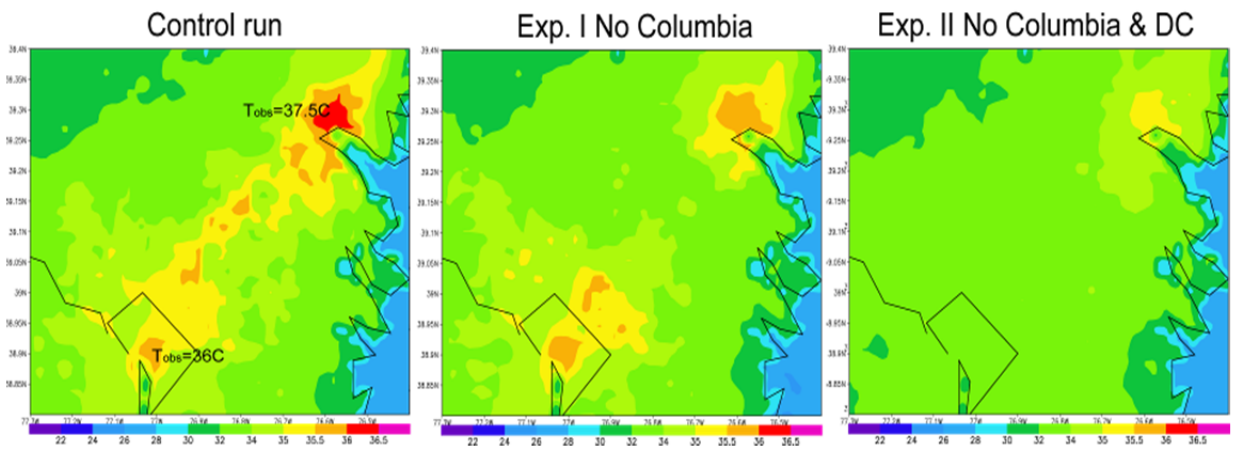
Figure 12: Chesapeake Bay Water Temperature Scenarios



URBAN HEAT ISLAND

Urban heat island accounts for about one-third of the decadal rise in temperatures in cities in the past 50 years. In growing cities, urban heat island accounts for half of the rise in temperatures. The remainder is attributed to global warming[xvi]. One University of Maryland model was used to explore the hypothesis that Baltimore is often warmer and has higher ozone concentrations than Washington, DC primarily from upstream urban heat island effects originating from D.C. and Columbia, MD (Figure 13)[xvii].

Figure 13: Simulated Surface Temperatures



Heat is the number one cause of weather-related injuries and fatalities in the region. Although impacts from heat may go underreported, deaths and injuries (1 death/year, 10 injuries/year) are small compared to other causes of injuries and deaths (see Appendix 1). Still, average temperatures have been rising, and minimum temperatures rising faster than maximums. Along with a predicted greater number of days over 90 degrees Fahrenheit, these facts indicate higher risks from heat waves in the future. Extreme heat is a concern since it will certainly increase not only with climate change, but also with increasing urban heat island effects from expanding development.

ADDITIONAL CLIMATE IMPACTS

Hurricanes and Severe Storms

A number of factors like wind shear, the North Atlantic Oscillation, drying from higher temperatures, convection, the jet stream and so forth interact in complex ways and make predicting damage from hurricanes, thunderstorms, lightning, hail, wind, and tornados difficult. Combined, these events cost the region over $14 million in damage annually (see Appendix 1). Climate change research points to towards possibly fewer hurricanes and severe storms overall, but more of the strongest storms. Sea level rise increases the threat from coastal storms. Threat analysis depends on the number of people and value of assets exposed to storm impacts, which will increase regardless due to growth and development[xviii]. The most widespread impact of severe storms is often power outages. Prolonged outages reduces productivity, can cause food spoilage costs for businesses and homeowners, and can compromise health for susceptible populations during a heat wave or for those needing the support of electronic medical equipment.

Drought

Although drought accounts for only a small percentage of hazard events in the region it accounts for the fifth highest natural hazards losses from, from damage to crops. Drought areas are expected to expand in the Southeast US due to climate change, but increased precipitation is expected in the Northeast. Since drought is affected by the number of precipitation-free days and warmer temperatures, which in turn cause greater evaporation and evapotranspiration. One study found that drought will likely increase in the Mid-Atlantic region due to climate change[xix].

Wildfires

Wildfires are a concern, but not a serious threat to the region. Although wildfires are frequent, they are quickly contained and suppressed. In Northern Virginia, 86 wildfire events burned 339 acres, causing $176,000 in property damage between 1995 and 2001[xx]. Increases in numbers of very hot days in the Southeast are expected to increase wildfires[xxi]. If there are longer stretches of days without precipitation, especially in the late summer or fall, climate change could slightly increase the wildfire threat in the region.

Winter Weather

Winter weather may cause increased costs if heavy precipitation falls on a day when the temperature is below freezing. Winter weather impacts are expected to be reduced in the long term if winter low temperatures continue to rise.

CURRENT ISSUES IN THE COG REGION

Current challenges in the COG region that climate change may exacerbate:

- ❑ Water quality and the Potomac River, Anacostia River, and Chesapeake Bay
- ❑ Stormwater management
- ❑ Inland drainage problems (i.e. basement flooding)
- ❑ Urban heat island
- ❑ Population and development growth (more people, buildings and infrastructure exposed; more impervious surfaces)
- ❑ Air quality
- ❑ Localized poverty
- ❑ Transportation disruptions
- ❑ Power disruptions
- ❑ Aging building stock in some areas
- ❑ Aging transportation and utility infrastructure

VULNERABILITY ASSESSMENTS

COG staff conducted a preliminary vulnerability assessment to identify possible impacts of climate change to transportation, land use, buildings, and water sectors. Transportation includes roadways, transit, bicycle and pedestrian modes. Land use includes buildings and developed, agricultural and natural areas. Water includes water quality and watershed management, water supply, and wastewater/stormwater/potable water-related infrastructure planning. The list below in Figure 14 is based on historic climate data, a regional climate change literature review, spatial data, and a regional application of issues identified in other climate adaptation plans. Regional conditions, issues and priorities helped shape the impacts highlighted here. Pertinent plans in the region that informed the assessment include the Virginia Governor's Commission on Climate Change Final Report, the Northern Virginia Regional Commission's Hazard Mitigation Plan, the State of Maryland's Climate Action Plan, and the National Capital Planning Commission's Report on Flooding and Stormwater in Washington, DC. Many of these regional plans also studied human and health costs and environmental impacts.

The vulnerabilities listed have implications for maintenance and operations, capital investments, planning, environment and society. Future actions, local priorities, emissions scenarios, and the characteristics of future growth and development will influence the extent of the impacts.

Figure 14: National Capital Region Vulnerabilities by Sector

		Climate Drivers			
	IMPACT	Heat	Precip. Intensity	Severe Storms	Sea Level Rise
Transportation	a. More frequent travel disruptions (ex. downed trees, power outages)	X	X	X	X
	b. Change in infrastructure maintenance needs	X	X	X	X

	c. Possible increased road surface damage	X	X	X	X
	d. Increase in erosion around bridge footings and roads		X	X	X
	e. Increased rail delays (commute and delivery of goods)	X	X	X	X
	f. Increase in rail infrastructure deterioration from buckling and expansion	X			
	g. Change in replacement and maintenance needs for vehicle fleets	X	X	X	
	h. Increase in poor outdoor air quality days	X			
	i. More frequent street tree replacement and maintenance needs				
Land Use/ Buildings	j. Increased threat of drought, wildfires, invasive species, disease, and storm damage to natural and landscaped areas	X	X	X	
	k. Increased stress on urban tree canopy	X	X	X	
	l. Increase in ozone damage to crops	X			
	m. Possible increased irrigation needs and crop loss	X			
	n. Possible changes in lifetime and maintenance of roofs, facades, parking lots, sidewalks	X	X	X	
	o. Increase in short-term power disruptions and resulting economic losses	X	X	X	
	p. Increase in cooling costs; small decrease in heating costs	X			
Water	q. Increased strain on and need for infrastructure maintenance	X	X	X	X
	r. Potential for more combined sewer overflows		X	X	
	s. Possible increased flood risks to infrastructure in flood-prone areas		X	X	X
	t. Increased runoff volume, erosion, and sedimentation		X	X	
	u. Loss of wetlands due to sea level rise and erosion		X	X	X
	v. Change in water quality (temperature, sediments, salinity, nutrients, dissolved oxygen) in streams, rivers and bays	X	X	X	X
	w. Increased demand for water supply	X	X		
All Sectors	x. Energy: Seasonal changes in demand; increased short-term disruptions	X		X	
	y. EMS: Increased demand for emergency management response to extreme weather events	X	X	X	X
	z. Increased damage to property from severe weather events	X	X	X	X
	aa. Expansion of flood-prone areas; increase in flood frequency (inland drainage, riverine, and coastal)		X	X	X
	bb. Increased health impacts due to heat, vector-borne diseases, severe events, and flooding	X	X	X	X

CLIMATE ADAPTATION MEASURES BY SECTOR

This section lists several climate adaptation and risk reduction options for the Transportation, Land Use, Buildings, and Water sectors that aim to address potential vulnerabilities to climate change impacts. Pertinent measures were drawn from regional and national best practices, with a focus on planning rather than response. Measures are labeled with a checkmark symbol that have potential to reduce overall greenhouse gas emissions, since reducing global greenhouse gases can help reduce the risks of the worst climate impacts in the long term. Measures are also labeled with a checkmark symbol if they are considered 'no regrets'—in other words, the measure provides benefits under current climate conditions regardless of the exact changes in future climate. Cost of each measure is estimated in the final column.

Figure 15: Rhode Island Avenue inland drainage flooding

Source: http://www.washingtonpost.com/local/weather/rain-severely-floods-streets-and-metro-just-north-of-downtown-dc/2012/09/02/a6cf9d86-f55a-11e1-a126-fc5f423715b5_story.html

	Potential to Reduce Overall Greenhouse Gas Emissions	No-regrets Measures	Cost Level
Transportation Approaches:			
1. Assess vulnerability of critical assets		✓	$$
2. Improve real-time response to severe events through training, interagency coordination, and contingency planning		✓	$
3. Maintain state of good repair for infrastructure and fleets and keep street tree and brush maintenance up to date	✓	✓	$$
4. Update maintenance and staff schedules to better accommodate heat waves and storm events		✓	$$$
5. Strengthen long term air quality planning and implement short term measures such as discouraging engine idling and incentives to reduce emissions from mobile sources during heat waves	✓	✓	$-$$$
6. Coordinate capital projects with stormwater management, land use, and utility upgrades	✓	✓	$
7. Site new facilities in less vulnerable locations; consider re-locating, hardening, or elevating facilities in vulnerable locations			$
8. Enhance redundancy: foster transit oriented development, increase street connectivity and enhance multi-modal options	✓	✓	$$$
9. Implement complete streets and green streets practices	✓	✓	$$$
10. Consider updating standards/materials/design to account for expected changes			$-$$$
11. Consider low-cost protective actions such as covering air vent shafts, cleaning culverts, or placing sandbags in strategic locations before a known major precipitation event		✓	$

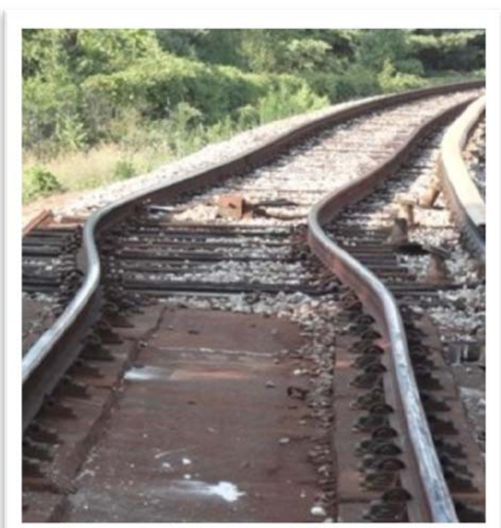


Figure 16: Buckling caused by heat wave in the Metro's Green Line.

Source: Washingtonpost.com
http://www.washingtonpost.com/local/metro-hopes-to-repair-damaged-green-line-for-monday-rush-official-says/2012/07/08/gJQA0oWpWW_story.html

	Potential to Reduce Overall Greenhouse Gas Emissions	No-regrets Measures	Cost Level
Land use Approaches:			
1. Incorporate language on climate impacts and natural hazard risk mitigation in comprehensive plans	✓	✓	$
2. Promote and incentivize compact, mixed use, walkable, transit-oriented, and infill development in appropriate, non-vulnerable areas	✓	✓	$$
3. Limit or disincentivize new development in the most vulnerable areas			$$
4. Coordinate with other jurisdictions in the Potomac watershed to construct or strengthen hard-engineered structures to provide flood and stormwater volume control when necessary			$$$
5. Protect agricultural lands and forests through present use value tax status, forest mitigation bank programs, or transfer of development rights	✓	✓	$$
6. Prioritize existing properties vulnerable to flooding and SLR for buyout programs and conservation easements		✓	$$$
7. Protect, maintain, and enhance tree canopy; strategically plant trees to reduce urban heat island, absorb stormwater, and buffer wind (without interfering with other infrastructure performance); conduct outreach to homeowners regarding right tree, right place and proper maintenance	✓	✓	$
8. Prioritize areas with high ecosystem services and habitat value for restoration and protection such as stream buffers, wetlands, and forest; work towards networking these areas through a green infrastructure plan to foster resilience	✓	✓	$$
9. Consider recent changes in temperature and precipitation patterns when managing livestock, choosing crops, and choosing landscape plants		✓	$

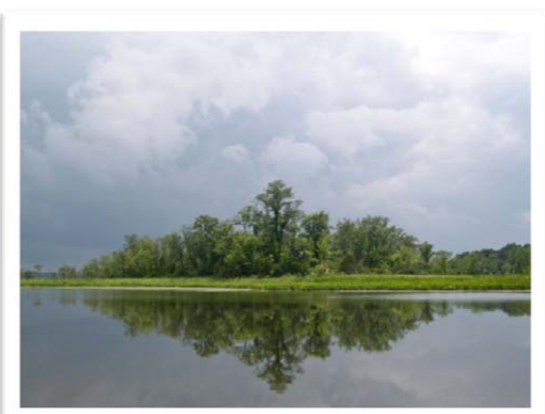


Figure 17: Chicamuxen Creek, Charles County, MD

Source: Photography-in-place
http://photography-in-place.blogspot.com/2010_07_01_archive.html

	Potential to Reduce Overall Greenhouse Gas Emissions	No-regrets Measures	Cost Level
Building Approaches:			
1. Require green building standards, low impact development (LID), environmental site design (ESD) for new development	✓	✓	$$
2. Promote energy efficiency, stormwater retrofits, and flood-proofing retrofits for existing buildings where appropriate	✓	✓	$$
3. Implement heat island reduction strategies: green roofs, cool roofs, cool pavements	✓	✓	$-$$
4. Incorporate passive survivability principles into new and existing projects, allowing buildings to retain critical functions during utility failures	✓	✓	$$
5. Promote emergency preparedness for all sites--residential, commercial, industrial, institutional, government, recreational, etc.		✓	$
6. Encourage purchase of property insurance and flood insurance especially in flood-prone areas (whether located within the 100-year or 500-year floodplain or not)			$$
7. Strategically locate cooling centers and publish public health advisories during heat/poor air quality events		✓	$
8. Implement appropriate site-scale flood protection measures such as proper grading, french drains, flood walls, water dams, sand bags and temporary rainwater-holding facilities			$-$$$

Figure 18: A 1,711 square foot green roof was installed on the area of roof that connects Potomac Yard One and Two in Arlington, Virginia.

Source: http://www.epa.gov/oaintrnt/stormwater/actions.htm

	Potential to Reduce Overall Greenhouse Gas Emissions	No-regrets Measures	Cost Level
Water Sector Approaches:			
1. Evaluate climate impacts to drinking water, wastewater, and stormwater infrastructure, planning, and operations			$$
2. Monitor changes to water quality and implement additional measures to reduce algal blooms, erosion and sedimentation, and nutrient pollution if necessary			$-$$$
3. Evaluate climate impacts to water supply needs, especially consumptive water users such as power plants			$$
4. Monitor changes in groundwater levels for possible impacts to septic fields, wells, pollutant conveyance, and inflow/infiltration to wastewater infrastructure		✓	$$
5. Increase drought preparedness and water storage if necessary			$-$$$
6. Design infrastructure upgrades with an extra margin of safety for climate change impacts if necessary			$$$
7. Bolster facility protection against floods if necessary (especially wastewater)			$$$
8. Investigate and implement effective stormwater management technologies such as ESD/LID and gray infrastructure where appropriate		✓	$$
9. Keep system maintenance up to date		✓	$$
10. Protect and restore ecosystems such as forested watersheds, vegetation strips, and wetlands to buffer against sediment and nutrient flows into source waterways	✓	✓	$$$
11. Promote water-efficient fixtures and appliances, rainwater capture and re-use, and low-maintenance landscaping	✓	✓	$$
12. Establish alternative power supplies, potentially through on-site generation, especially biogas, combined heat and power, and other renewable energy sources, to reduce reliance on the power grid and support operations in case of loss of power.	✓	✓	$$
13. Ensure that water/wastewater operations are prioritized in local emergency management procedures		✓	$

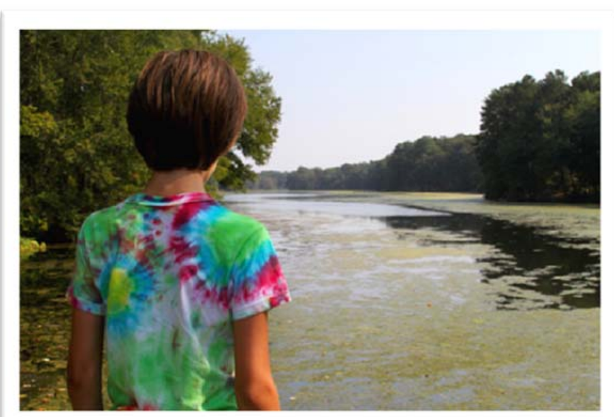


Figure 19: June 2012 algal bloom in the Chesapeake Bay

Source: http://www.wypr.org/podcast/6-20-12-record-warmth-triggers-early-algal-blooms-chesapeake-bay

	Potential to Reduce Overall Greenhouse Gas Emissions	No-regrets Measures	Cost Level
Across Sectors:			
1. Incorporate renewable energy (i.e. solar, wind, hydro, biogas, green power purchase) and energy efficiency (i.e. air sealing/insulation, combined heat and power, district energy) wherever feasible	✓	✓	$$
2. Improve power grid resilience and reliability; shorten restoration time		✓	$-$$$
3. Energy assurance: install energy/water storage or backup sources where necessary to maintain critical infrastructure during power failures		✓	$$
4. Evaluate climate impacts on public health and vulnerable populations			$$
5. Continue to engage climate scientist/researchers, local governments and other stakeholders to identify actionable climate information needed on regional scales			$$$

LIMITATIONS

This preliminary assessment does not prioritize or quantitatively assess relative risk to and exposure of infrastructure, community assets, human health and well-being, and the environment. It does not identify priority hazard areas, such as flood plains and storm surge zones, and their relationship to community assets. Analysis of future costs of impacts and equity considerations are not included. Further expert analysis is needed to determine the full spectrum of potential local risks. This also does not consider global economic or social impacts that may end up influencing the region such as social migration. Future actions, emissions scenarios, and the characteristics of future growth and development will influence the extent of the impacts.

REGIONAL CHALLENGES TO IMPLEMENTING ADAPTATION APPROACHES

At the stakeholder meetings in August 2011, participants identified the following challenges:

1. Data needs: sector-specific information on projected climate changes
2. Administration needs: Interagency coordination and data sharing; overcoming regulatory and permitting hurdles.
3. Education and messaging to policymakers and the public
4. Funding sources
5. Research on the best practices, costs/benefits, and low-cost, no-regrets measures to reduce climate risks, and the costs of inaction.

DISCUSSION AND NEXT STEPS

The certainty of projected climate change in the Chesapeake Bay region is as follows:

- Virtually certain (>99%): Higher atmospheric CO_2 (Carbon Dioxide) and higher sea level
- Very likely (90-99%): Warmer, higher winter & spring precipitation
- Likely (66-90%): More intense precipitation, flashier streamflow, increased winter streamflow, increased storm intensity[xxii]

There are uncertainties associated with climate projections and impacts. Key uncertainties include levels of future greenhouse gas concentrations, sensitivity of the climate system to greenhouse gas concentrations, climate variability, and changes in local physical processes not captured by global climate models. Although there are uncertainties, especially with precise local scale projections, climate observations and projections can assist with identifying and managing climate risks and opportunities[xxiii].

Next steps include working on a local level to engage community stakeholders in order to identify and prioritize existing problems that could be exacerbated by climate change. Any strategy should be considered within the context of local conditions and challenges. A number of information sources and tools are available to assist communities in adaptation planning, including:

- NOAA's Roadmap to Adapting to Coastal Risks provides an overview of the roadmap's approach, available trainings, resources, and example community assessment and strategies.
- Chicago Area Climate Change Quick Guide discusses a risk assessment methodology and adaptation tactics for municipalities.
- ICLEI Climate Adaptation Guidebook for reviews a process, risk assessment methodology, and how to develop a preparedness plan for local, regional and state governments.
- Georgetown Climate Center Adaptation Clearinghouse was developed to assist communities in adapting to climate change and features a variety of public sector vulnerability assessments and adaptation plans.

In addition, there will be a couple key resources on climate science and impacts available in 2013/2014, including:

- The Intergovernmental Panel on Climate Change (IPCC) reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide. Updated information will be provided in the Fifth Assessment Report (AR5), which will consist of three Work Group Reports (available between fall 2013 and spring 2014) and a Synthesis Report (available fall of 2014).
- The U.S. Global Change Research Program (GCRP) National Climate Assessment synthesizes and communicates climate change science and impacts in the United States across sectors and regions. The draft 2013 National Climate Assessment is currently available on GCRP's website.

APPENDIX 1

Spatial Hazard Events and Losses Database for the United States (SHELDUS) Loss Estimates[xxiv]

SHELDUS Annualized Natural Event Losses from 1960-2009			
	Annualized monetary damages	Annualized fatalities	Annualized injuries
Flooding	$4,784,757	0.4	0.3
Severe/Thunder Storm	$4,540,208	0.4	1.1
Wind	$4,176,713	0.5	2.8
Tornado	$3,821,886	0.1	3.1
Drought	$3,416,913	0.0	0.0
Winter Weather	$1,420,859	1.2	7.2
Hail	$944,121	0.0	0.2
Coastal	$894,650	0.0	0.0
Lightning	$531,198	0.4	2.4
Hurricane/Tropical Storm	$411,544	0.0	0.1
Heat	$6,766	1.2	10.0
Wildfire	$1,733	0.0	0.0

Northern Virginia Regional Commission (NVRC) Hazard Mitigation Plan Annualized Loss Estimates[xxv]

Table 6.35
Annualized Loss Estimates

Hazard	Annualized Loss
Hurricanes and Tropical Storms	**$33,723,000**
Flood	**$3,912,000**
Drought	**$2,207,000**
Severe Thunderstorms	**$1,110,000**
Tornadoes	**$731,000**
Earthquakes	**$341,000**
Winter Storms	**$109,000**
Wildfire	**$25,000**
Extreme Temperatures	**Negligible**
Erosion	**Negligible**
Sinkholes	**Negligible**
Landslides	**Negligible**
Dam Failure	**Negligible**

[i] Le Treut, H., Somerville, R., Cubasch, U., Ding, Y., Mauritzen, C., Mokssit, A., Peterson T., and Prather, M. (2007). Historical Overview of Climate Change. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Retrieved from http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter1.pdf

[ii] America's Climate Choices: Panel of Advancing the Science of Climate Change. (2010). *Advancing the Science of Climate Change*. The National Academies Press. Retrieved from http://nas-sites.org/americasclimatechoices/sample-page/panel-reports/87-2/

[iii] Hegerl, G.C., Zwiers, F. W., Braconnot, P., Gillett, N. P., Luo, Y., Marengo Orsini, J. A., Nicholls, N., Penner J.E., and Stott, P. A. (2007). Understanding and Attributing Climate Change. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Retrieved from http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter9.pdf

[iv] Karl, T. R., Melillo, J. M., and Peterson, T. C. (eds.). (2009). *Global Climate Change Impacts in the United States*. Cambridge University Press. Retrieved from http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf

[v] Boesch, D.F (ed). (2008). *Global Warming and the Free State: Comprehensive Assessment of Climate Change Impacts in Maryland.* Retrieved from http://www.umces.edu/sites/default/files/pdfs/global_warming_free_state_report.pdf

[vi] Karl, T. R., Melillo, J. M., and Peterson, T. C. (eds.). (2009). *Global Climate Change Impacts in the United States.* Cambridge University Press. Retrieved from http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf

[vii] Boesch, D. F. (ed). (2008). *Global Warming and the Free State: Comprehensive Assessment of Climate Change Impacts in Maryland.* Retrieved from http://www.umces.edu/sites/default/files/pdfs/global_warming_free_state_report.pdf

[viii] US Global Change Research Program. (2009). *Global Climate Change Impacts in the United States.* Retrieved from http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf

[ix] Federal Emergency Management Agency (FEMA). (2013). *Flooding & Flood Risks*. Retrieved from http://www.floodsmart.gov/floodsmart/pages/flooding_flood_risks/ffr_overview.jsp

[x] Koster, Julia. (2012). *Stormy Weather: NCPC's Climate Adaptation Initiatives [Power Point Slides].* Presented at the Metropolitan Washington Council of Governments Climate Impacts Symposium. Retrieved from http://www.mwcog.org/environment/climate/adaptation/Presentations/6-%20Koster_Online.pdf

[xi] Smith, Wade. (2012). *Sea Level Rise and Flooding in the Washington, DC Metropolitan Region [Power Point Slides].* Presented at the Metropolitan Washington Council of Governments Climate Impacts

Symposium. Retrieved from http://www.mwcog.org/environment/climate/adaptation/Presentations/5-%20Smith.pdf

[xii] Lehmann, Evan. (2011, July 22). Flood-Prone Land Likely to Increase by 45%--a Major Challenge to Federal Insurance Program. The New York Times. Retrieved from http://www.nytimes.com/cwire/2011/07/22/22climatewire-flood-prone-land-likely-to-increase-by-45-a-19117.html?pagewanted=all

[xiii] Najjar, R. G., Pyke, C. R., Adams, M. B., Breitburg, D., Hershner, C., Kemp, M., Howarth, R., Mulholland, M. R., Paolisso, M., Secor, D., Sellner, K., Wardrop, D., and Wood, R. (2010). Potential climate-change impacts on the Chesapeake Bay. *Estuarine, Coastal and Shelf Science*, Volume 86, Issue 1, 1, Pages 1-20. Retrieved from http://www.nrs.fs.fed.us/pubs/jrnl/2010/nrs_2010_najjar_001.pdf

[xiv] Boesch, D.F (ed). (2008). *Global Warming and the Free State: Comprehensive Assessment of Climate Change Impacts in Maryland.* Retrieved from http://www.umces.edu/sites/default/files/pdfs/global_warming_free_state_report.pdf

[xv] Najjar, Raymond G. (2012). *Cleaning Up the Bay in a Warmer World [Power Point Slides]*. Presented at Metropolitan Washington Council of Governments Climate Impacts Symposium, Washington D.C. Retrieved from http://www.mwcog.org/environment/climate/adaptation/Presentations/4-%20Najjar%20[Compatibility%20Mode].pdf

[xvi] Stone, Brian. (2012). *Urban Heat Islands and Climate Change: Planning for Extreme Heat for Cities [Power Point Slides].* Retrieved from http://www.epa.gov/heatisland/resources/pdf/8_aug_2012-2_BrianStone.pdf

[xvii] Zhang, D-L., Shou, Y-X., and Dickerson, R. R. (2009).Upstream Urbanization Exacerbates Urban Heat Island Effects. *Journal of Geophysical Research Letters*, VOL. 36, L24401. doi:10.1029/2009GL041082.

Adapted and presented in: Busalacchi, Antonio J. (2012). *State of the Science of Climate Modeling from Global to Regional Scales [Power Point Slides]*. Presented at Metropolitan Washington Council of Governments Climate Impacts Symposium, Washington D.C. Retrieved from http://www.mwcog.org/environment/climate/adaptation/Presentations/3-%20Busalacchi.pdf

[xviii] Del Genio, Anthony. (2011). Will the World be Stormier? NASA Goddard Institute for Space Studies. New York, NY. Retrieved from http://www.earthzine.org/2011/04/16/will-a-warmer-world-be-stormier/

[xix] Mid-Atlantic Regional Assessment Team, Pennsylvania State University. (2000). *Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change*. Retrieved from http://www.cara.psu.edu/mara.pdf

[xx] Northern Virginia Regional Planning Commission. (2006). *Northern Virginia Regional Hazard Mitigation Plan.* Retrieved from http://www.novaregion.org/index.aspx?NID=661

[xxi] US Global Change Research Program. (2009). *Global Climate Change Impacts in the United States.* Retrieved from http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf

[xxii] Najjar, Raymond G. (2012). *Cleaning Up the Bay in a Warmer World [Power Point Slides]*. Presented at Metropolitan Washington Council of Governments Climate Impacts Symposium, Washington D.C. Retrieved from http://www.mwcog.org/environment/climate/adaptation/Presentations/4-%20Najjar%20[Compatibility%20Mode].pdf Based on information from:

- Boesch, D.F (ed). (2008). *Global Warming and the Free State: Comprehensive Assessment of Climate Change Impacts in Maryland.* Retrieved from http://www.umces.edu/sites/default/files/pdfs/global_warming_free_state_report.pdf

and

- Najjar, R. G., Pyke, C. R., Adams, M. B., Breitburg, D., Hershner, C., Kemp, M., Howarth, R., Mulholland, M. R., Paolisso, M., Secor, D., Sellner, K., Wardrop, D., and Wood, R. (2010). Potential climate-change impacts on the Chesapeake Bay. *Estuarine, Coastal and Shelf Science*, Volume 86, Issue 1, 1, Pages 1-20. Retrieved from http://www.nrs.fs.fed.us/pubs/jrnl/2010/nrs_2010_najjar_001.pdf

[xxiii] National Aeronautics and Space Administration. (2012). Adapting to Climate Change: Federal Agencies in the Washington DC Metro Area Fact Sheet.

[xxiv] Hazards & Vulnerability Research Institute, University of South Carolina. (2010). *Spatial Hazard Events and Losses Database for the United States--COG Regional Data*. SHELDUS™ Version 8.0. Retrieved from www.sheldus.org

[xxv] Northern Virginia Regional Planning Commission. (2006). *Northern Virginia Regional Hazard Mitigation Plan.* Retrieved from http://www.novaregion.org/index.aspx?NID=661