Chapter 4

Vulnerability and Risk Assessments

A risk assessment is a multi-faceted, 'stepped' process. When conducting a risk assessment, the first step is the completion of a thorough hazard identification analysis, as was provided in Chapter 3. This hazard identification process reviewed cases of historical hazards in Baltimore — including current threats as well as any predicted threats due to climate change — and considered the severity of each hazard. Understanding the full extent to which Baltimore may be affected in the future by the hazards identified and profiled in this document provides the foundation for a comprehensive vulnerability assessment.

Damage from Hurricane Agnes

Source: Baltimore Sun

The vulnerability assessment, the second step of the risk assessment, is the process of evaluating the potential losses associated with a given hazard and estimating the degree to which property damage, economic loss, physical injury, or death are likely to occur. In this chapter, the risk assessment is expanded beyond identifying relevant hazards to fully understand how and why Baltimore is at risk, and where a risk may be greatest in Baltimore City.

Vulnerability, specifically, refers to the *susceptibility* of people, properties, and resources to the impacts associated with such hazard events. For example, a range of community assets — including residential or public structures and infrastructure — may be deemed vulnerable to various hazard risks. The level of vulnerability depends on a number of factors, including location, construction, property contents, and the economic value of the function(s) being provided by an individual, facility, or system. Vulnerability may be intensified due to a lack of resources or information. Additionally, certain geographic areas or social dynamics may contribute to the circumstances that can make one population more sensitive to hazards than others. When vulnerability is greater for particular social groups or individuals, it becomes a matter of environmental justice. The vulnerability assessment investigates the exposure (lack of defense), sensitivity (degree to which a system is affected), and Adaptive Capacity (ability to recover[1]) of an individual or asset in regards to a particular hazard.

Observing conditions in Baltimore City as a whole, the vulnerability assessment identifies what key community assets and critical facilities exist across all of Baltimore in order to understand where special consideration may be required (see Assessing General Hazard Vulnerabilities for the City of Baltimore). Later in the chapter, vulnerability is assessed for each of the specific hazards identified in Chapter 3 and, again, identifies which community assets and critical facilities are vulnerable to the specific hazard. These focused inventories will, when possible, provide descriptions to note why certain structures, critical facilities, or vulnerable populations are most susceptible.

While "impact" had been considered in the previous stages of the risk analysis (the hazard identification process considered what, in the past, had been impacted during a hazard event in terms of extent and severity; while the vulnerability analysis reviewed assets and systems that are most likely to be impacted during a hazard event based on their exposure, sensitivity, and adaptive capacity), the formal impact assessment offers a better understanding of the types and costs of injury or damage that a hazard event may cause in Baltimore. As a result, the impact assessment builds upon the earlier risk assessment stages through an evaluation of the asset inventory — highlighting particular assets that are likely to be impacted and summarizing estimated potential losses sustained as the result of a particular hazard.

By doing so, the vulnerability and impact assessment findings discussed below, when combined with the information revealed in the previous hazard identification process, will lay the foundation for effective adaptation and mitigation strategies.

Chapter 4 provides the following information:

1. Self-Assessments of the City of Baltimore vulnerabilities;
2. Description of HAZUS-MH assessment tool;
3. General inventory of assets and critical facilities;
4. Specific vulnerability assessments by hazard including:
5. Identification of the range of vulnerabilities to community assets;
6. Identification of the range of vulnerabilities to critical facilities;
7. Estimated economic impacts
8. Initial selections of key vulnerabilities; and
9. An explanation of adaptive capacity.

Throughout this process, the City utilized self-assessment tools as well as the Hazards U.S.–Multi-Hazard, or HAZUS-MH, software offered by the Federal Emergency Management Agency (FEMA). Self-assessments were conducted with Agency Directors, the DP3 Advisory Committee, and members of the public. To further inform the assessment, FEMA's HAZUS-MH software was utilized for estimating potential losses to natural disasters which is the national standardized methodology used across the country.

Vulnerability Assessment Tools Utilized

This plan recognizes that a number of tools for understanding natural hazard and climate impacts already exist. Perhaps most notable among these existing resources is NOAA's Coastal Services Center (CSC) Roadmap for Adapting to Coastal Risk, which includes a Risk and Vulnerability Assessment Tool (RVAT) and a Community Vulnerability Assessment Tool (CVAT). These existing tools and resources helped to establish a thorough framework for guiding the risk and vulnerability process of this plan. Learning from such tools, DP3 created an approach that was most appropriate for issues specific to Baltimore.

NOAA's Coastal Services Roadmap Approach

Getting Started: Define community goals, build the team, identify priority issues, and prepare for the assessment

Hazards Profile: Explore relevant hazards, climate trends, and potential impacts as a starting point in assessing community vulnerabilities

Societal Profile: Evaluate strengths and vulnerabilities of the local population

Infrastructure Profile: Identify the strengths and vulnerabilities of the built environment

Ecosystem Profile: Consider the strengths and vulnerabilities of important natural resources

Risk-Wise Strategies: Explore opportunities for risk reduction through education, planning, and regulatory processes

Self-Assessment Tools and Methodology

To supplement the technical and quantitative methods used to analyze potential natural hazards in Baltimore, the DP3 process consulted a number of community stakeholders and constituents, as well as the expert input from members of the Advisory Committee, for a self-assessment of risk and vulnerability. This process guided early development of the DP3 plan by identifying priority actions for addressing the key issues which confront the City of Baltimore.

Self-Assessment by Agency Directors

Assessing risk required input from the City of Baltimore DP3 Advisory Committee; this self-assessment utilized two different methods. First, the process employed a Disaster Preparedness and Planning Project Vulnerability Assessment Tool. This tool, which asked members to rank the probability and severity of various hazards (both natural hazards and man-made incidents were considered), revealed the percentage of relative threat (risk) for each hazard.

The Vulnerability Assessment Tool determined that extreme heat and severe storms were considered high concerns, in regards to both their relative threat and potential severity. Events which would either have small implications (e.g. drought or erosion of the coastline), as well as those hazards which have had little effect in the past or are unlikely to impact the City in the future, were of less concern. (A detailed summary of this assessment may be found in Appendix D: Advisory Committee).

In a second self-assessment, the Advisory Committee was asked to interpret potential impacts from three different scenarios by providing their qualitative input regarding the potential impact to economic, environmental, personal, and systems-related aspects of urban living. In each category, a number of factors were considered.

This assessment focused on specific vulnerabilities. In general, the responses indicate that the committee members were most concerned about the impact of hazards on Baltimore's operational systems, primarily on energy systems (demand and capacity), and any associated increases in costs required for maintaining continuous service. Additionally, throughout all scenarios, health, healthcare, and individual wellness and productivity were commonly cited as potentially being impacted.

Main economic matters that were discussed included business viability, business owner hardship, workforce capacity, and other issues related to meeting commercial and service demands. Even outside of questions specifically about economic implications, financial impact was a major concern of all scenarios. Systems interpretations of each scenario were focused on infrastructure, particularly related to transportation and utilities, communication, and water and wastewater systems. Additional concern was expressed for the resiliency of city services, including trash collection.

Overall, Committee members were concerned with resident health and for the capacity of Baltimore's infrastructure and economic systems to withstand hazard impacts. A detailed summary of this self-assessment, included each committee member's survey, may be found in Appendix D: Advisory Committee.

BALTIMORE SELF ASSESSMENT

The questions listed below were asked of the Advisory Committee members when interpreting the scenarios impacts.

Personal

- How would this scenario impact your personal life?
- How would it impact your immediate family?
- How would it impact the people you work with?
- What impact would it have to your home?

Economic

- How would this scenario impact business in your neighborhood?
- How would it impact the city at large?

Environmental

- How would this scenario impact your local environment?

Systems

- How would this scenario impact the systems in which you work?
- How would it impact the daily systems upon which you rely?

Self-Assessment by Members of the Community

Members of the community were also asked to provide their input through various outlets and tools. First, community members received brief surveys during attendance of the two Town Hall events. At the second Town Hall, residents and attendees were also asked to participate in two activities through which they could recommend directed actions.

During the April 30th Town Hall event, surveys indicated that most residents perceived an increase in the frequency of extreme weather events, particularly storms accompanied by high wind and heavy rain. Most respondents felt that individuals in their immediate households were moderately vulnerable to extreme weather events. Approximately half of the respondents expressed concern for both public sewer systems and human health. While the Advisory Committee self-assessments indicated that few representatives saw erosion or coastline damage to be a major issue, about half of the community participants selected coastlines as a resource that may be harmed by climate change.

Although most respondents indicated the presence of a hospital and strong community groups in their areas, there was a general lack of additional critical facilities or assets within the communities of the survey participants. While this may be true, it could, however, indicate a lack of awareness where those facilities and assets do indeed exist. These same surveys were distributed at a second Town Hall on July 30th.

During the July 30th Town Hall, attendees were asked to participate in two activates. As they arrived, attendees were given $500 in "DP3 Dollars" to allocate, with this limited budget, where Baltimore should spend money to create a more resilient City. Their options included stormwater infrastructure, resilient energy systems, transportation infrastructure, human health programs, trees and greening, and building codes. The funds were distributed relatively evenly; in total, 22 percent of the money had been "invested" in stormwater infrastructure, with 21 percent going towards resilient energy systems. The remaining money was allocated, in order of importance, to transportation infrastructure (19 percent), human health programs (15 percent), trees and greening (12 percent), and building codes (10 percent).

As attendees arrived, they were also provided with six blue sticker dots and were asked to place stickers

Photo from the July 30th Town Hall

next to strategies they felt would be most important. A total of nine strategies received ten or more stickers; four from infrastructure, two from natural systems, two from public services, and one from buildings. In general, the attendees were concerned with strengthening the resiliency of systems upon which residents depend on a daily basis. Water quality was a major concern, and strategies which protected distribution systems for drinking supplies (IN-14, 16 votes) and improved stormwater management techniques — including reductions in impervious surfaces (IN-17, 12 votes) and the enhanced environmental health of Baltimore's watersheds (NS-3, 11 votes) — were supported. Environmental health efforts were also valued, illustrated by the number of attendees supporting a strategy that would enhance the resilience of Baltimore's urban forest (NS-2, 12 votes).

The preferred strategies also tended to ensure adequate integration of hazard mitigation planning with City and community plans (PS-4, 11 votes), as well as with existing private and State systems, operations, and maintenance efforts (IN-21, 10 votes). Similarly, attendees were interested in empowering community members to be involved and assist with the DP3 process (PS-3, 10 votes). Finally, attendees supported the increased resiliency of electricity systems (IN-1, 10 votes) and a revision of building codes to reflect anticipated climate changes (BL-3, 10 votes). (Detailed descriptions of these strategies can be found in the following Chapter, Strategies and Actions, or in the Implementation, Maintenance and Evaluation segment of Chapter 6)

HAZUS-MH

The City of Baltimore has utilized the Hazards U.S.–Multi-Hazard, or "HAZUS-MH," software offered by FEMA. HAZUS-MH is a nationally standardized methodology that provides a framework for estimating potential losses from natural hazard events—specifically, earthquakes, floods, and hurricanes. HAZUS-MH uses Geographic Information Systems (GIS) technology to map and estimate the potential physical, economic, and social impacts of these natural disasters. Providing an essential function of pre-disaster planning, the mapping processes can illustrate the coverage of identified high-risk areas, allowing users to visualize the spatial relationships between these specific hazards and Baltimore's many populations, assets, and resources.

HAZUS-MH is used for both mitigation and recovery efforts, as well as for preparedness and emergency response activities. Government agencies, GIS specialists, and emergency planners use HAZUS-MH, reviewing estimated losses to determine the most beneficial mitigation approaches for minimizing impacts. As a part of DP3's risk assessment, products of HAZUS-MH analyses help to identify critical vulnerabilities and significant impacts, and to inform long-term strategies and actions for preventing damage, effectively aiding in recovery and reconstruction efforts. Additionally, the maps generated by HAZUS-MH software are being used to supplement the information discussed in this report, as well as to grow general hazard awareness across the City.

HURREVAC

HURREVAC (short for Hurricane Evacuation) is a storm tracking and decision support tool. The program combines live feeds of tropical cyclone forecast information with data from various state Hurricane Evacuation Studies (HES) to assist the local emergency manager in determining the most prudent evacuation decision time and the potential for significant storm effects such as wind and storm surge. Many Emergency Operations Centers use HURREVAC as a situational awareness and briefing tool. Program access is restricted to officials in government emergency management. Maryland is an active user of HURREVAC.

Hurrevac user interface during Hurricane Sandy *Source: www.hurrevac.com*

Assessing General Hazard Vulnerabilities for the City of Baltimore

General Inventory of Community Asset in Baltimore City

Baltimore City has a rich history and boasts many diverse, vibrant communities. Community assets are all of the people, places, and activities which shape everyday life. A Community Asset Inventory (CAI) considers both physical structures and social environment. The CAI considers highly vulnerable populations, historic and cultural resources, economic elements, natural resources and recreation areas, and other important services.

While the CAI reviewed a number of facilities that contribute to the City's emergency response to hazards (see the General Inventory of Critical Facilities in Baltimore City segment below), there are also many community assets that — while not directly affecting the City's capacity for emergency response — will have a devastating impact should they not be aware of the vulnerability and take appropriate steps to mitigate and prepare. Next steps of the continuing DP3 effort will include outreach to the responsible parties identified in the CAI by communicating risks of hazards; offering assistance in vulnerability assessments; and to generally assist parties responsible for these assets in the own risk assessments. Outcome of this effort will be a partnership to identify common-interest mitigation measures.

Societal Impact Analysis

As stated, the CAI reviews an asset in terms of its hazard risk and vulnerability. The assessment below considers the various conditions that may make one person, place, or activity more vulnerable than others. In all instances of hazard events, vulnerability of the human population is based on the availability, reception and understanding of early warnings of hazard events (i.e., Hurricane Watches and Warnings issued by the NWS; Tornado Warning issued by the NWS) as well as access to substantial shelter and a means and desire to evacuate if so ordered. In some cases, despite having access to technology (computer, radio, television, outdoor sirens, etc.) that allows for the reception of a warning, language differences are sometimes a barrier to individuals understanding them. Certain populations — including children, elderly residents (Figure 4–1, right), and non-English speaking residents— may face greater challenges when overcoming the impacts of a hazard.

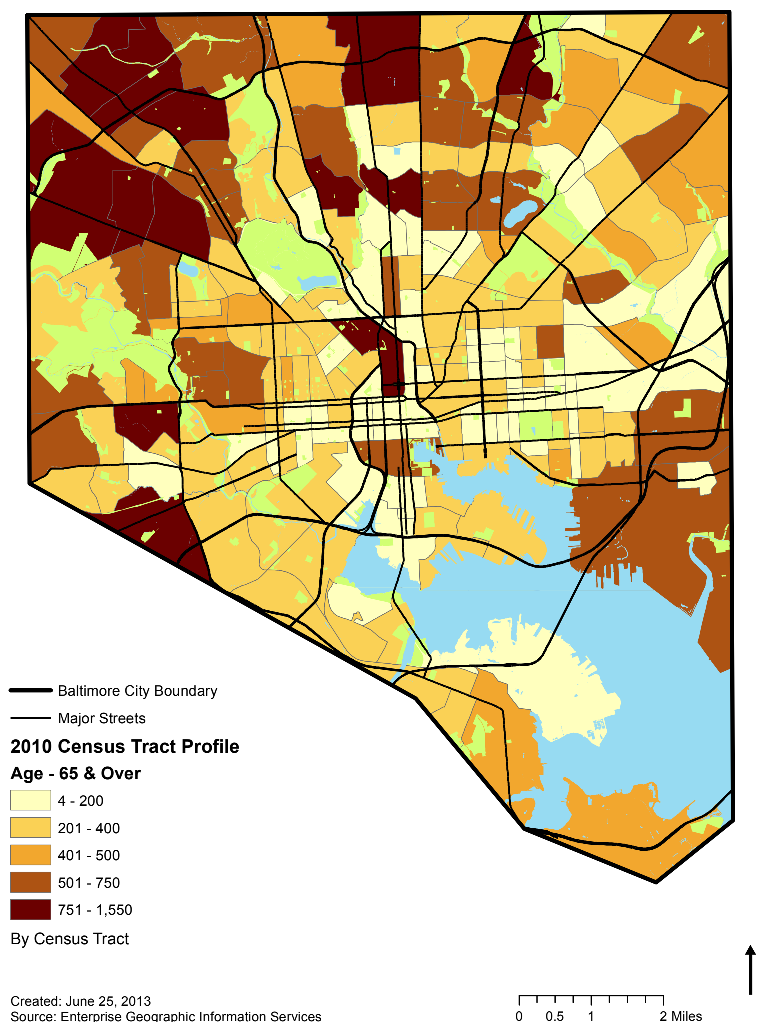


Figure 4–1 Concentrations of Baltimore City Elderly Residents

Health Impact Assessment (HIA)

According to the National Research Council, HIA is a systematic process that uses an array of data sources and analytic methods, and considers input from stakeholders to determine the potential effects of a proposed policy, plan, program, or project on the health of a population and the distribution of those effects within the population. HIA provides recommendations on monitoring and managing those effects.

The Baltimore Office of Sustainability (BoS) worked with the Baltimore City Health Department (BCHD) to integrate a preliminary Health Impact Assessment (HIA) into the Disaster Preparedness and Planning Project (DP3). The HIA focused on one strategy and two specific actions of the plan:

Strategy NS-2: Increase and enhance the resilience and health of Baltimore's urban forest

Action 3: Establish a comprehensive maintenance program that includes pruning for sound structure and the removal of hazardous limbs and trees. First focus on vulnerable infrastructure nearby such as essential facilities and roads

Action 5: Increase the urban tree canopy and target areas with urban heat island impacts.

The BCHD HIA team conducted preliminary research to gather evidence around the potential health outcomes related to NS-2. In order to better understand the impact on health outcomes of the proposed actions, community stakeholders were gathered to provide feedback and guidance. This meeting was held on July 31st, 2013. The stakeholder group was recruited through the Citizen's Planning and Housing Association to represent vulnerable stakeholders including residents, non-profits, City agencies, and community organizations. The stakeholders, in collaboration with the City agency representatives, prioritized their health concerns and indicated the magnitude of the potential health outcomes, keeping equity in mind.

The HIA team refined the literature and data search based on stakeholder input, thoroughly exploring areas prioritized by the community in addition to other significant areas identified through the preliminary research. Additionally, the team gathered data on local air temperature, crime, and Baltimore's tree canopy. On September 5th, 2013 the stakeholders reconvened to discuss new information and data. The stakeholder group reviewed the data and developed draft recommendations focused on equity and maximizing positive health outcomes.

The HIA team is currently in the process of developing formal recommendations concerning the types of trees, the locations of trees, the number of trees, and incentives for stakeholder engagement around tree maintenance. Additional information about this process can be found in Appendix J.

Health Impact Assessment stakeholder meeting, July 31, 2013 *Source: Kristin Baja*

Economic Impact Analysis

This risk and vulnerability analysis has also reviewed information regarding some of Baltimore's major employers. These facilities and businesses play a significant role in Baltimore's economy. Furthermore, due to the number of residents who may be employed by, or benefit from, these businesses, consideration must be given to their integrity to reduce and prevent the severity and scope of any possible impact as a result of a natural hazard. The map below (Figure 4–2) shows the location of major employers in Baltimore.

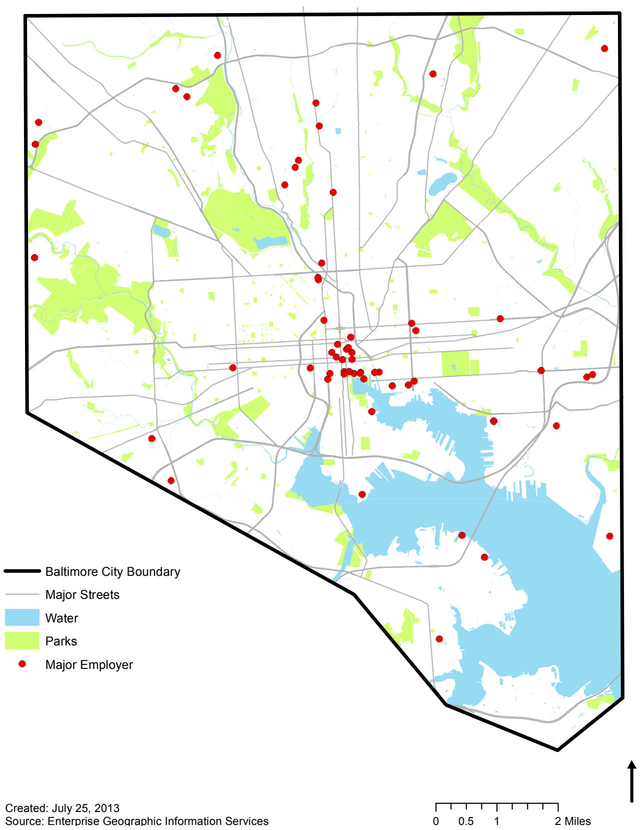


Figure 4–2 Major Employers in Baltimore City

Environmental Impact Analysis

Baltimore City has a number of natural features, open spaces, and parks and recreational facilities which should also be considered in the hazard mitigation and climate adaptation process. Natural features provide valuable ecosystem services, and may be vulnerable to the impacts of hazards. At the same time, parks and recreational areas offer unique value to the City and its communities, and may be susceptible to hazard events. On the other hand, natural systems often play a role in mitigating impacts from climate change and hazard events, and can be seen as a resource.

Historical and Cultural Impact Analysis

Historic and cultural resources are also considered as they make a significant contribution to local history and culture, and often have strong emotional ties with the community. Baltimore has a rich historic fabric, and the City prides itself on being a national leader in historic preservation. In fact, Baltimore has 34 local and 67 national historic preservation districts, which include 196 landmarks. Designated Historic structures represent approximately one-third of Baltimore's built environment. Baltimore has one of the highest percentages of designated historic structures of any major city in the United States.

Historic structures may be at an even greater risk as these buildings were constructed prior to the adoption of appropriate building standards (e.g. floodplain development code, electrical code). FEMA has produced a guideline for Integrating Historic Property and Cultural Resource Considerations Into Hazard Mitigation Planning. It is important to recognize that these assets may require special considerations, or specific technical and financial assistance.

Finally, other assets and facilities deserve attention as they can have immediate or lasting impact on people and everyday services. In the event of a no-warning hazard, densely populated facilities, for instance, would be of more concern due to the number of people that might potentially be within. This list includes hotels, malls, theaters and auditoriums, and churches, among other things. Some of Baltimore's larger scale facilities include the convention center, stadiums and arenas, and major tourist destinations like the National Aquarium in Baltimore and the Science Center. High-density residential and commercial developments could likewise result in high injury or fatality rates if damaged. Other assets, still, provide vital services which ensure the continuity of everyday activities. These facilities include grocery stores, banks, government buildings, gas stations, and agricultural areas, to name a few.

Some assets may be more vulnerable than others depending on their age, location, or other characteristics. Additionally, facilities are impacted differently depending on the type of hazard experienced. A more detailed impact on Baltimore assets accompanies the assessment of each hazard type below.

General Inventory of Critical Facilities in Baltimore City

According to FEMA, a Critical Facility is a structure or other improvement that — because of its function, size, service area, or uniqueness — has the potential to contribute to serious bodily harm, extensive property damage, or to the disruption of vital socio-economic activities if that facility is either destroyed or damaged, or if functionality is impaired. Critical facilities include essential operations, such as health facilities, including hospitals, critical care facilities, outpatient clinics — and any other facility that would be able to provide immediate emergency relief and care following a hazard event. Emergency response stations and evacuation centers are considered to be critical facilities, as well as fire stations, police stations, government buildings, buildings that store critical records, and other similar facilities that might manage essential activities. Each of these facilities plays a vital role in disaster response and recovery and must therefore remain fully operational and accessible before, during, and after a hazard event.

Table 4–1 Critical Facilities Located in Baltimore City

Critical Facility	Number
Hospitals	15
Police Stations	10
Fire Stations	41
Schools (Public and Private)	235
Colleges	15
Government Facilities	374
Banks	54
Grocery Stores	48
Hardware Stores	37
Gas Stations	238
Water Pumps	15
Electrical Cooperatives	-
Wastewater Treatment Facilities	3
Sewage Treatment Facilities	12
Drinking Water Treatment Facilities	11
Critical Roadways	61
311 and 911 Operation Centers	-
Hazardous Waste Facilities	-
Total	**1169**

Source: Baltimore City Enterprise Geographic Information Services and HAZUS

Back River Wastewater Treatment Plant *Source: ccjm.com*

Table 4–2 List of Critical Emergency Facilities

Facility Type	Facility Name	Neighborhood
Fire Station	E-45 T-27 M-14	Mount Washington
Fire Station	E-46	Woodmere
Fire Station	E-40 T-12 BC-5	Dorchester
Fire Station	E-29 M-17	Central Park Heights
Fire Station	E-44 T-25	Roland Park
Fire Station	E-21 M-11	Hampden
Fire Station	E-31 M-3	Better Waverly
Fire Station	E-43 M-18, BC-4	Glen Oaks
Fire Station	E-4 T-29	New Northwood
Fire Station	E-56	Westfield
Fire Station	E-42 M-6, M-13	Lauraville
Fire Station	E-33 M-16 T-5	East Baltimore Midway
Fire Station	E-27 T-26	Parkside
Fire Station	E-20 T-18 M-8	Walbrook
Fire Station	E-30 T-8 M-12	Carroll-South Hilton
Fire Station	E-47	Morrell Park
Fire Station	E-14	Booth-Boyd
Fire Station	E-36	Midtown-Edmondson
Fire Station	E-52	Parkview/ Woodbrook
Fire Station	E-8 T-10 M-15 BC-3	Harlem Park
Fire Station	E-13 T-16 M-4	Madison Park
Fire Station	E-23 T-2 M-1 BC-6 R-1 AF-1	Downtown
Fire Station	Headquarters	Downtown
Fire Station	Communications	Downtown
Fire Station	E-6 T-1 M-7 BC-2 AF-2 Sh.Cmd	Oldtown
Fire Station	T-15	Broadway East
Fire Station	E-5 T-3 M-10	Upper Fells Point
Fire Station	E-51	Ellwood Park/ Monument
Fire Station	E-41 BC-1	Canton
Fire Station	E-50 M-2	Broening Manor
Fire Station	E-55 T-23	Washington Village
Fire Station	E-2	Federal Hill
Fire Station	T-6	Federal Hill
Fire Station	E-26 M-5	Riverside
Fire Station	FB-1 FRB-1	Locust Point Industrial Area
Fire Station	E-58	Westport
Fire Station	E-35 T-21 M-9 BC-6 Hazmat-1	Brooklyn
Fire Station	E-57	Curtis Bay
Fire Station	E-124 T-20	Hopkins Bayview
Fire Station	E-54 T-30	Cedmont
Fire Station	E-53	Hunting Ridge
Headquarters	Headquarters	Downtown
Police Station	Central	Downtown
Police Station	Northern	Woodberry
Police Station	Northeastern	Morgan State University
Police Station	Northwestern	Woodmere
Police Station	Eastern	Berea
Police Station	Southern	Middle Branch/ Reedbird Parks
Police Station	Southeastern	Hopkins Bayview
Police Station	Southwestern	Gwynns Falls
Police Station	Western	Sandtown-Winchester
Salt Dome	Pulaski Industrial Area Salt Dome	Pulaski Industrial Area

Salt Dome	Brewers Hill Salt Dome	Brewers Hill
Salt Dome	Dolfield Salt Dome	Dolfield
Salt Dome	Spring Garden Industrial Area Salt Dome	Spring Garden Industrial Area
Salt Dome	Guilford Salt Dome Salt Dome	Guilford
Salt Dome	Lakeland Salt Dome	Lakeland
Salt Dome	Jones Falls Area Salt Dome	Jones Falls Area
Emergency	American Rescue Workers	SBIC
Emergency	Aunt CC's Harbor House	Oldtown
Emergency	Baltimore Rescue Mission	Jonestown
Emergency	Christ Lutheran Place	Otterbein
Emergency (temporary)	Code Blue J, H & R	Jonestown
Emergency	Collington Square	Broadway East
Emergency	Helping Up	Jonestown
Emergency	House of Ruth ES	
Emergency	Interfaith ES	Sandtown-Winchester
Emergency	Karis House	Jonestown
Emergency	MCVET ES	Jonestown
Emergency	Prisoners AID ES	Charles Village
Emergency	Project PLASE ES	Greenmount West
Emergency	Salvation Army/Booth House	Mid-Town Belvedere
City Building	City Hall	Downtown
Code Red Cooling- Housing	Southeastern Community Action Ctr.	Highlandtown
Code Red Cooling- Housing	Eastern Community Action Center	Dunbar-Broadway
Code Red Cooling- Housing	Northern Community Action Center	Woodbourne-McCabe
Code Red Cooling- Housing	Southern Community Action Center	Cherry Hill

Code Red Cooling- Housing	Northwest Community Action Center	Forest Park
Code Red Cooling- CARE	Oliver Center	Broadway East
Code Red Cooling- CARE	Sandtown -Winchester Center	Sandtown-Winchester
Code Red Cooling- CARE	Hatton Center	Canton
Code Red Cooling- CARE	Waxter Center	Mid-Town Belvedere
Code Red Cooling- CARE	John Booth Senior Center	Highlandtown
Code Red Cooling- CARE	Zeta Center	Central Park Heights
Emergency Operation Ctr.	EOC1	Penn-Fallsway
Emergency Operation Ctr.	EOC2	New Northwood
Hospital	John Hopkins Hospital	Dunbar-Broadway
Hospital	Maryland General Hospital	Mount Vernon
Hospital	Bon Secours Hospital	Penrose/Fayette Street Outreach
Hospital	Sinai Hospital	Levindale
Hospital	Harbor Hospital Center	Middle Branch/ Reedbird Parks
Hospital	St. Agnes Hospital	Violetville
Hospital	Union Memorial Hospital	Charles Village
Hospital	Good Samaritan Hospital	Loch Raven
Hospital	John Hopkins Bayview Medical Center	Hopkins Bayview
Hospital	Mercy Medical Cen.	Downtown
Hospital	University of Maryland Medical Center	University Of Maryland
Hospital	VA Medical Center	University Of Maryland
Hospital	Kernan Hospital	Dickeyville
Non-Acute Hospital	Mt. Washington Pediatric Hospital	Mount Washington
Non-Acute Hospital	University Specialty Hospital	Otterbein

Additional critical and medical facilities may be found in Appendix H: Critical Facilities

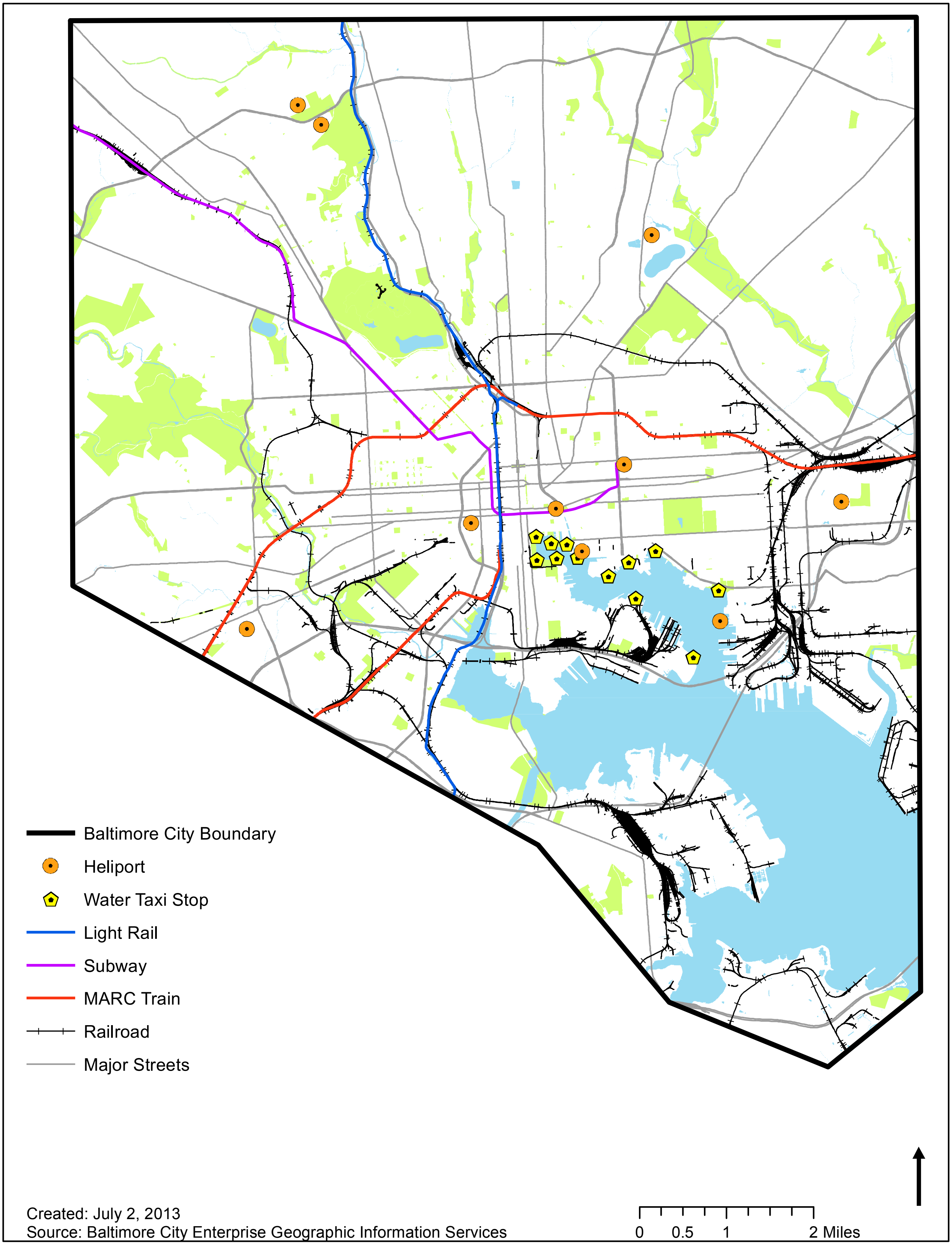


Figure 4–3 Baltimore City Transportation Systems

Baltimore I-95 and I-395 interchange *Source: flickr.com*

By evaluating key facilities, roadways, transportation corridors, and resources within the community, the vulnerability analysis of critical facilities determines the degree to which each facility is exposed to various hazards. As reviewed in the Table 4–1 Critical Facilities Located in Baltimore City, there are approximately 1,169 critical facilities within Baltimore City. The level of vulnerability and the total potential economic loss associated with each of facility will vary by hazard event and depends on a number of additional factors, including location, construction, property contents, and the economic value of the function(s) being provided by the facility. Critical facilities need to understand and respond to hazard vulnerabilities in order lessen or avoid interruption to essential services.

Transportation systems allow for movement — for emergency response as well as evacuation — and may be significantly impacted by hazard events. Figure 4–3 Baltimore City Transportation Systems, illustrates major streets and transportation systems within Baltimore.

In a hazard event, Baltimore must maintain its lifeline utility and infrastructure systems. These systems provide access and assets to respond. Communication systems need redundancy, particularly with emergency response entities, and critical City services should be evaluated for further mitigation/preparedness measures, particularly water delivery, wastewater treatment and power generation. Additionally, efforts should be made to ensure that critical evacuation routes are evaluated for various impacts. These services continue to be provided to Baltimore's residents and businesses.

Finally, high potential loss and hazardous material facilities include those facilities that would pose a danger should they be destroyed or damaged. Such facilities include hazardous waste facilities, dam structures, and any facilities housing industrial/hazardous materials. A map of vulnerable dam facilities is featured in the Flooding Risk and Vulnerability Assessment below; there are no public maps, however, of hazardous material facilities as this information is considered sensitive information. Our risk analysis will be shared with those facilities and other appropriate parties to ensure proper measures are being taken.

Some critical facilities may be more vulnerable than others depending on their age, location, or other characteristics. Additionally, facilities are impacted differently depending on the type of hazard experienced. A detailed impact assessment of critical facilities is included in the review of each hazard type below.

DETAILED VULNERABILITY ASSESSMENT BY HAZARD

Flooding

Background

At the heart of City, water of the Inner Harbor — as well as from the many tributaries that flow into it — is a central feature of Baltimore's historic landscape. Considering how closely Baltimore has developed alongside the water, it is understandable that the City has endured a history of significant flooding events. As Table 4–3 NCDC Total and Annualized Flood Events (1993-2010) in Baltimore City conveys, annualized flood occurrences in Baltimore City total approximately 2.67 annualized flood events each year, and 1.22 annualized flash flood events each year. Recognizing this historical information and anticipating future changes, flooding is considered a major hazard for the City of Baltimore.

In Baltimore, 5.19 square miles of property, or 6.4 percent of the City's total area, currently rests within the flood zone; while 3 percent of Baltimore's overall land — primarily in the Inner Harbor or the Fells Point Historic District — is within the coastal floodplain.[2] By the end of the century, approximately 180 square miles of currently dry land along Maryland's coastline is expected to be inundated. Coupled with more frequent and extreme precipitation events (See Precipitation Variability Hazard Profile in Chapter 3) these conditions could become a common hazard.

Moreover, a number of anticipated climate change impacts may intensify extent and damage from flood events. Future sea level rise (for a discussion of sea level rise, refer to the Coastal Hazards Risk and Vulnerability Assessment below) or land subsidence is an addition to storm surge increasing flood depths, thereby intensifying losses even further.

In the conduct of the vulnerability analysis, there are two types of flood events that need to be distinguished. One is a tidal influenced flood (i.e. storm surge) or/and-in-addition-to a non-tidal flood (i.e. precipitation event). For example, Isabel was a strictly a tidal flood. The flooding was the result from a storm surge that pushed the waters seven feet above the predicted tide. It is possible to have the same storm surge coupled with a precipitation event. In addition to drawing that distinction between tidal and non-tidal, the vulnerability analysis goes further by reporting out impacts on different probability flood events – that is the 100-year and the 500-year events.

Below are results and discussion on the vulnerability analysis. Some of the vulnerability analysis is based on results from HAZUS (refer back to the discussion on HAZUS-MH) that was done by both the State and the City. The vulnerability analysis continues with the Community Asset Inventory.

Vulnerability Assessment

The City utilized HAZUS modeling software, FEMA Flood Insurance Rate Maps, and NOAA's Critical Facilities Exposure Tool to determine citywide vulnerability to flooding. Results from these tools were analyzed by flood experts from the State of Maryland and Baltimore City to determine vulnerabilities in the floodplains and floodways.

Table 4–3 NCDC Total and Annualized Flood Events (1993-2010) in Baltimore City

Flood Total Events	Flood Annualized Events	Flash Flood Total Events	Flash Flood Annualized Events
48	2.67	22	1.22

Source: Table 3-27, Maryland Emergency Management Agency, 2011: 105-106

Flooding of Baltimore's Herring Run, June 2013

Source: Bob Mayes

Exposure

An evaluation of exposure identifies who and what may be vulnerable to flooding hazards. This analysis takes into consideration where flooding occurs through a process that delineates floodplains and floodways and identifies what assets or facilities are located within those areas. Maps of flooding exposure, as well as information regarding to what level various City assets are exposed to flooding, are depicted in the Inventories of community assets and critical facilities below.

Additionally, the Baltimore City Department of Planning, in partnership with FEMA, is developing Digital Flood Insurance Maps (DFIRMs) which, when complete, will provide a more accurate picture of exposure in the updated floodplain and floodway.

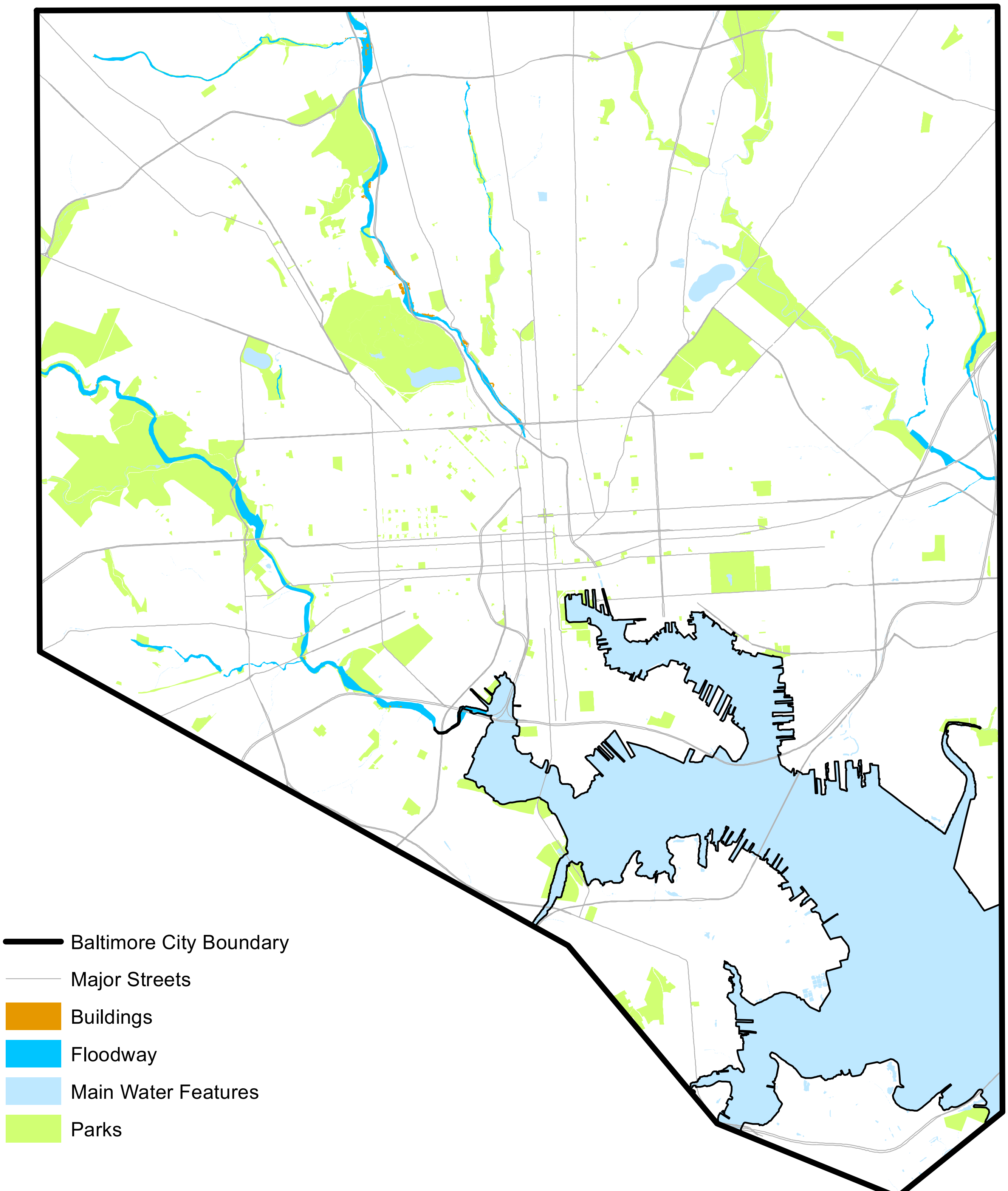
In addition to the financial damages caused by previous 100-year and greater floods, localized flooding has disrupted the lives of Baltimore residents. The map, next page (Figure 4–4 Baltimore City Floodplains and Floodway), illustrates the areas that are susceptible to flooding from 100- and 500-year flooding events. The insets (Figure 4–5, Figure 4–6, and Figure 4–7) further clarify how the structural fabric of two particular areas — Fells Point and Westport — may be impacted from such events.

Sensitivity

Considering the number of assets that are exposed to flooding hazards, sensitivity identifies the degree to which these assets are vulnerable, and how some may be more so than others. When considering flooding, for instance, a structure may be more vulnerable if the building is not compliant with Base Flood Elevation (BFE) guidelines. Additional characteristics may influence sensitivity further.

Adaptive Capacity

An asset's ability to respond to a hazard defines its adaptive capacity. In areas like Fells Point, many structures have repeatedly endured extreme flooding events. Indeed, many buildings are able to adapt, but this potential is dependent upon additional factors, including occupant understanding and behavior, or the City's recognition of future changes in hazard frequency and intensity.



Estimated Total Value of Buildings in Floodway: $30,138,166

Created: June 25, 2013
Source: Baltimore City Enterprise Geographic Information Services

0 0.5 1 2 Miles

Figure 4–4 Baltimore City Floodplains and Floodway

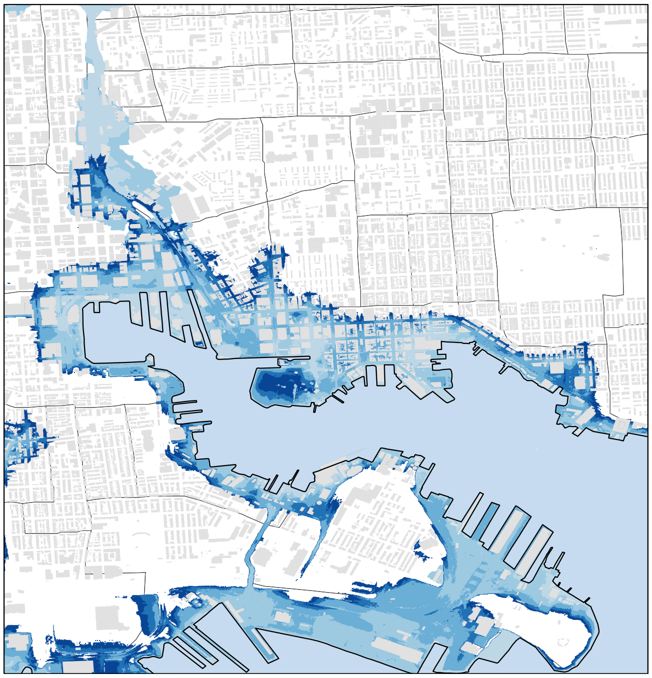


Figure 4–5 INSET | Fells Point Flood Exposure Areas

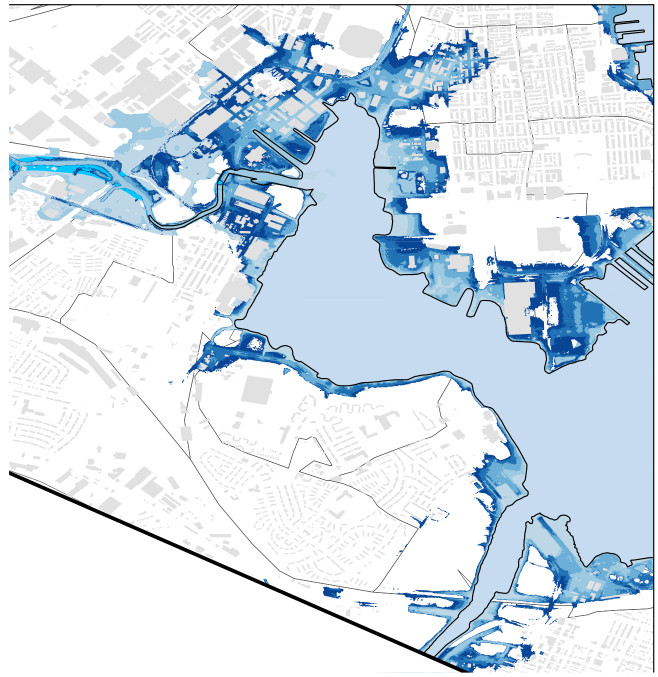
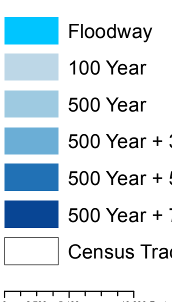


Figure 4–6 INSET | Westport Flood Exposure Areas



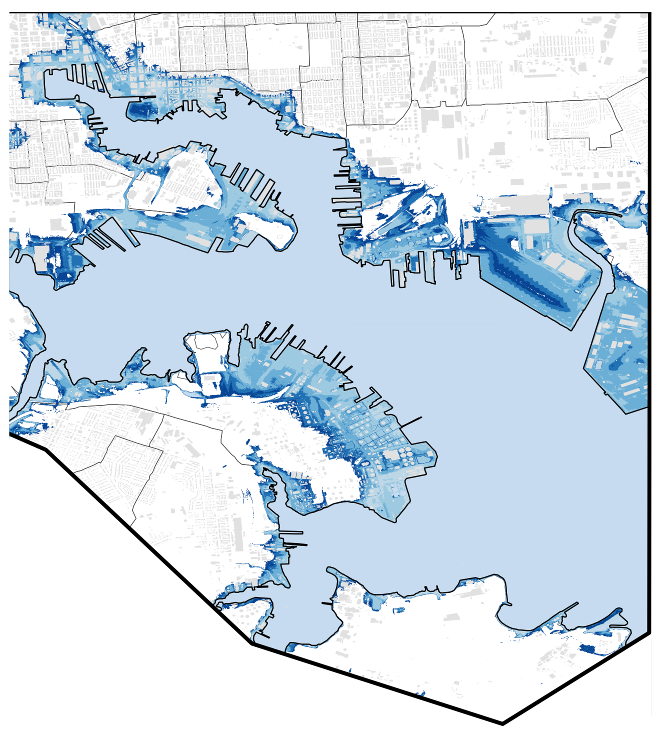


Figure 4–7 INSET | Industrial Flood Exposure Areas

Table 4–4 Sum of Parcels Located within the 100-year and 500-year Floodplains

100 Year	Sum of parcels	2941
	Sq Footage	45835550 ft
	Year Constructed*	1754- 2012
	Estimated Value	$2,659,994,010
500 Year	Sum of parcels	3027
	Sq Footage	43062241 ft
	Year Constructed**	1754 - 2012
	Estimated Value	$1,861,554,433

**1108 buildings missing information for year constructed for 100 year;*
***999 buildings missing information for year constructed for 500 year.*

Inventory of Community Assets Susceptible to Flooding

Populations and property are extremely vulnerable to flooding. Homes and business may suffer damage and be susceptible to collapse due to heavy flooding. In addition, floods may threaten water supplies and water quality, as well as initiate power outages. Floodwaters can carry chemicals (there are about a half a dozen hazardous material sites and one oil refinery within Baltimore's flood zones), sewage (four waste water facilities within flood zones), and toxins from roads, factories, and farms; therefore any property affected by a flood may be contaminated with hazardous materials.[3] Debris from vegetation and man-made structures may also become hazardous during the occurrence of a flood. During flood events, objects (floating material, e.g. wood, cars, etc.) in rivers and streams carry the force of the water behind them increasing the potential for damage to other structures like buildings and bridges. In permitting development the City needs to take into account the need and capacity of emergency personnel to respond to a facility facing a hazard – particularly flood hazards zones.

Herring Run Flooding *Source: Bob Mayes*

Table 4–5 City-Owned Facilities within the 100+500 Year floodplains

Facility Name	Neighborhood
DPW Museum	Inner Harbor
Brokerage Annex	Downtown
Wahl Bldg - (Clinic)	Downtown
Culinary Arts Bldg	Downtown
Abel Wolman Bldg	Downtown
Signet Building	Downtown
Kids Diner	Downtown
Parking Control Agency	Penn-Fallsway
Surveys & Records Office	Penn-Fallsway
Impound Lot Cashier's Booth	Penn-Fallsway
War Memorial Bldg	Downtown
Water Street	Downtown
Adminis-DPW, Director's Staff	Downtown
U.S. Custom House	Downtown
Headquarters	Downtown
Police Headquarters, Annex	Downtown
Mounted Police	Penn-Fallsway
Fort Holabird Comfort Station	Holabird Industrial Park
Fort Holabird Park Service Bldg	Holabird Industrial Park
Thames Park	Fells Point
9 N Front St	Jonestown
1840 House	Jonestown
Administative Bldg	Jonestown
Archeology Center	Jonestown
Carroll Mansion	Jonestown
Exhibition Center	Jonestown
Peale Museum	Downtown
Shingle Bldg (Overton's Old House)	Harford-Echodale/ Perring Parkway
Camp Small	Coldspring
Inner Harbor Park	Inner Harbor
Leon Day Park Baseball/ Football Fields	Gwynns Falls/Leakin Park
Port Discovery Fountain	Downtown

Table 4–6 State and Critical Facilities within FEMA 100-year flood zone

	Total Number of Critical Facilities	Critical Facilities Building and Content Values	Total Number of State Facilities	State Facilities Building and Contents Values
Baltimore City	1,049	$ 149,117,733.00	106	$ 1,127,435,779.00

Source: Table 3-30, Maryland Emergency Management Agency, 2011: 110.

A flooding vulnerability assessment estimates the number of structures that are located within the regulated 100-year floodplain and are thus susceptible to 100-year flooding. There are an estimated 2,941 facilities, valued at approximately $2,659,994,010, within the City's 100-year floodplain. (Economic loss estimates do not include calculations for contents and inventory.) Additionally, as many as 2,000 people would be displaced by a 100-year tidal flood. As many as 3,027 properties, with an estimated value of $1,861,554,433, are located within the 500-year floodplain. Table 4–4 provides details regarding the properties within the floodplain and floodways; floodplain counts are inclusive of floodway properties).

The completed vulnerability analysis found that the Inner Harbor and Downtown neighborhoods are the most vulnerable to inland flooding based on the number of city-owned structures potentially impacted (Table 4–5 City-Owned Facilities within the 100+500 Year floodplains). The Downtown neighborhood has 14 city-owned structures within the 100- and 500-year floodplains, and the Inner Harbor has two city-owned facilities. Other neighborhoods with exposed City-owned facilities include Penn-Fallsway, Holabird Industrial Park, Fells Point, Harford-Echodale/Perring Parkway, Coldspring, and the Gwynns Falls/Leakin Park neighborhoods.

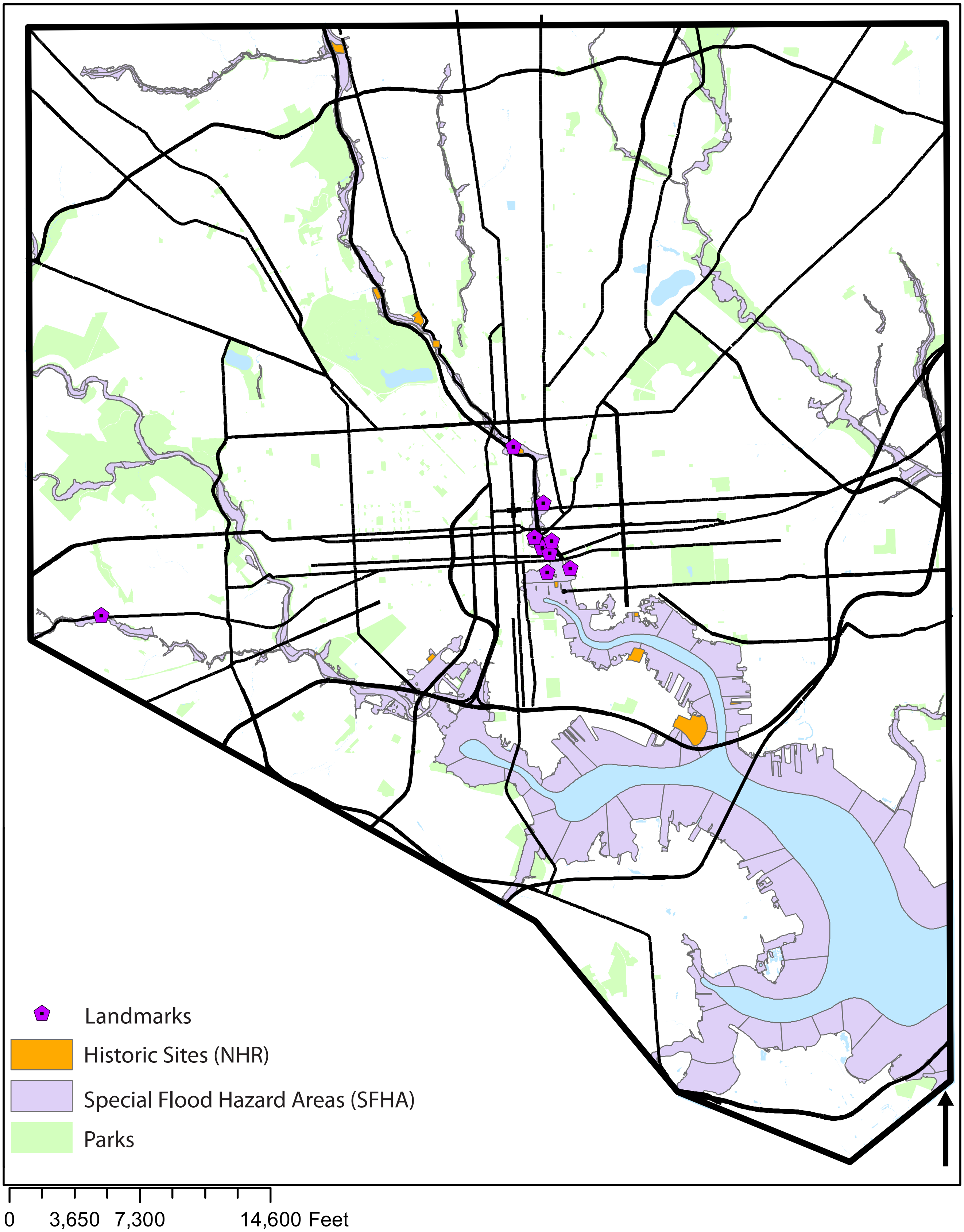
Inventory of Critical Facilities Susceptible to Flooding

For some services and facilities, even a slight chance of flooding is too great a threat. These facilities should be given special consideration when forming regulatory alternatives and floodplain management plans. Ideally, critical facilities should not be located within a floodplain if at all possible. However, due to a range of factors, many of Baltimore's critical facilities currently sit within this zone (Figure 4–12 on page 129). If a critical facility must be located in a floodplain it should be given a higher level of protection so that it can continue to function and provide services during and after a flood. According to NOAA's Critical Facilities Flood Exposure Tool, the Westport Baltimore Gas and Electric facility and the Gould Street Generating Station are vulnerable to flooding.

Table 4–7 Critical Facilities Located in Baltimore City HAZUS Coastal Flood Extents

Critical Facility	100 Year	500 year
Subway	0	0.42 miles
Railroad	15.24 miles	51.59 miles
Bridges*	3	4
Tunnels	1	1
Major Roads	15.08 miles	22.93 miles
Police Stations	0	0
Fire Stations~~	0	1
Emergency Operation Centers	0	0
Public Schools^^	0	1
Private Schools	0	0
Colleges^^	0	1
Hospitals	0	0
Nursing Homes	0	0
Cultural Facilities	3	6
Power Plants*	0	3
Waste Water Treatment Plants	0	2

Source: HAZUS; GIS Data Collections **Numbers based on HAZUS inventory/Coastal Flood Extent, not Baltimore City Data.*



Created: August 15, 2013
Source: Baltimore City Enterprise Geographic Information Services

Figure 4–8 Historic Critical Facilities in the Special Flood Hazard Areas

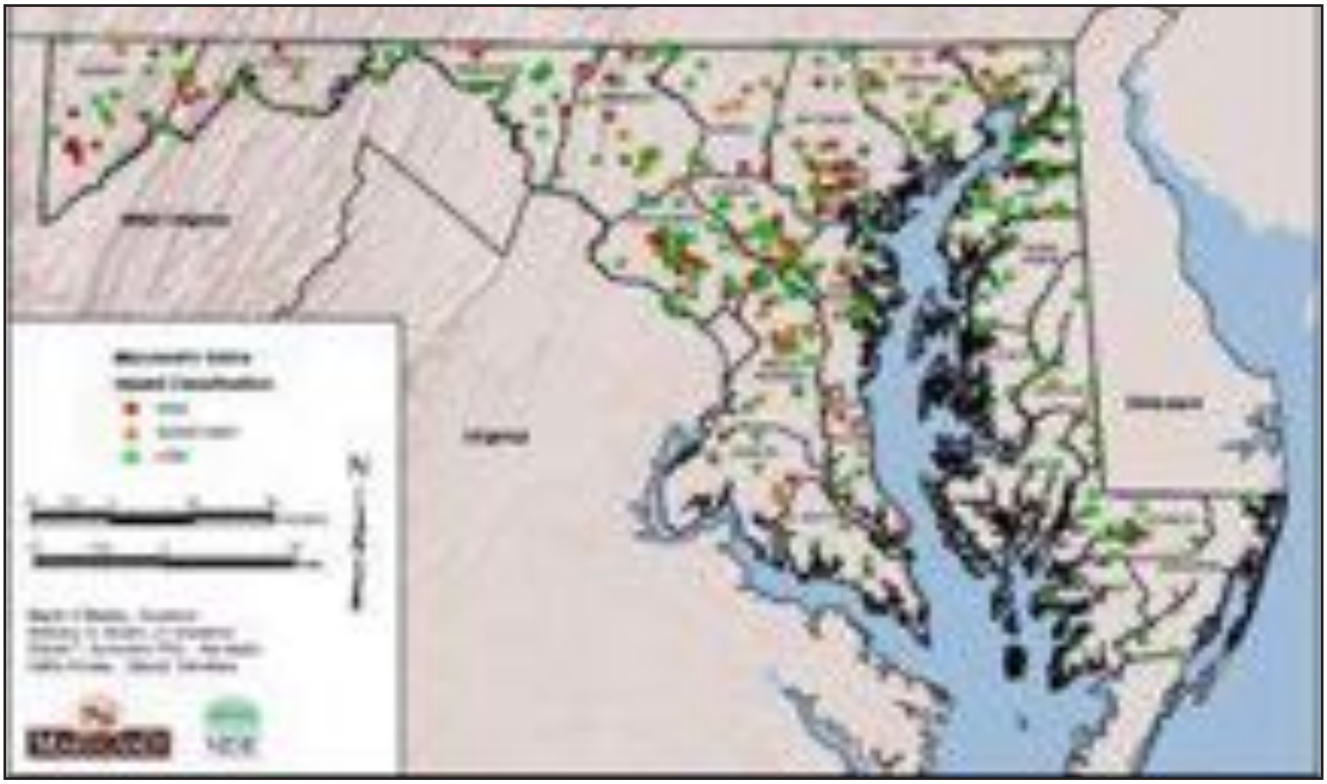


Figure 4–9 Maryland's Dams, Hazard Classifications *Source: www.mde.state.md.us*

Additionally, there are a number of State facilities within the 100-year floodplain in Baltimore City. These structures, and their contents, have an estimated value of $1.2 billion (Table 4–6 State and Critical Facilities within FEMA 100-year flood zone). HAZUS and City facility databases were used to calculate the value of facilities within the flood zone and the number of people who would potentially be impacted by inland flooding.

HAZUS-MH data was used to identify potential impact of a significant 100-year or 500-year storm (Table 4–7 Critical Facilities Located in Baltimore City HAZUS Coastal Flood Extents). A number of key facilities are located within the floodplains, and vulnerable to flooding hazards. For instance, after a 100 year storm, a total of 225 buildings may be moderately damaged, with 22 being completely destroyed. The chart also takes into consideration the additional impact of a projected sea level rise (Sea Level Rise is discussed in more detail in the Coastal Hazards Risk and Vulnerability segment below). If Baltimore were to experience a 500-year event, in addition to a possible 5 foot sea level rise, damage could cost as much as $10 billion.

Flooding from dam failure may also impact critical facilities. Transportation facilities and water/wastewater treatment infrastructure are typically vulnerable to damages from dam failure as these facilities are often located within or near floodplains that are downstream of dams. Additionally, dam failure may damage power lines and telecommunication facilities and, thus, have serious consequences in terms of power generation and communication capacity. Most importantly, however, is consideration of Critical and State facilities that are at risk from dam failure (shown in Table 4–8 Critical and State Facilities at Risk Due to Failure of High Hazard Dams, and Figure 4–9 Maryland's Dams, Hazard Classifications) With 935 critical and 128 state facilities at risk, combined total exposure is almost $1.8 billion.

Table 4–8 Critical and State Facilities at Risk Due to Failure of High Hazard Dams

Facility Type	Number of Facilities	Total Building Value Exposure	Total Contents Value Exposure	Total Exposure
Critical	935	$ 195,554,500	$ 65,184,833	$ 260,740,268
State	128	$ 1,443,862,337	$ 94,000,353	$ 1,537,862,690

Source: Tables 3-103 and 3-104, Maryland Emergency Management Agency, 2011: 254-275.

Estimated Losses

As a port City, Baltimore is very much dependent on its harbor and waterways. In 2006, the Port of Baltimore generated over 50,200 jobs, $3.6 billion in personal income, $1.9 billion in business revenues, and $388 million in state/county/municipal tax.[4] Without adequate planning and preparation, that vitality may be at risk.

In order to conduct an accurate estimate of the economic losses produced by flooding, it is necessary to know the first floor elevation for vulnerable structures, as well as the replacement costs which are calculated using information on construction materials and square footage. Such specific information, however, is not always readily available for the properties identified in the tables above. Consequently, it is difficult to develop an accurate estimation of losses. Nevertheless, it is possible to develop specific mitigation measure to address the magnitude of potential losses within the coastal flood zones. The City will share the DP3 risk assessment with various port related organizations. By combining the City's risk assessment, with their own assumptions and site knowledge about structure size, equipment, function, these entities can respond appropriately.

The table (Table 4–9 Baltimore City Flood Impact - HAZUS) details the potential losses to the structures within the 100- and 500-year floodplains, and identifies the percentage of building damage, dollar cost of building damage, cost of contents (residential interior losses) and cost of inventory (commercial and industrial material and operations losses), and total economic damage (in thousands of dollars). This analysis assumes that no flood-proofing methods are currently being employed, and that there is a two-foot flood depth for all structures within the floodplain or a four-foot flood depth for those in the floodway. Certain essential elements of flood loss estimates — including displacement costs or functional downtime costs — are not included in these evaluations. While this table provides only a broad illustration of potential losses, it demonstrates the seriousness of a wide-spread 100- or 500-year flood event.

Estimated economic loss may be associated with very different costs. For instance, in addition to structural or content damage, floods may force property owners to relocate, or an individual may lose 'service' income from being displaced from their place of business as a result of a flood. When all of these factors are taken into consideration, total losses may be much greater. In Table 4–10 Flood Loss Estimates (in Thousands of Dollars) for 100-year and 500-year Floods in Baltimore City, the Maryland Emergency Management Agency sorted these various costs by type of loss. For a 500-year flood, total economic loss would exceed $1 billion.

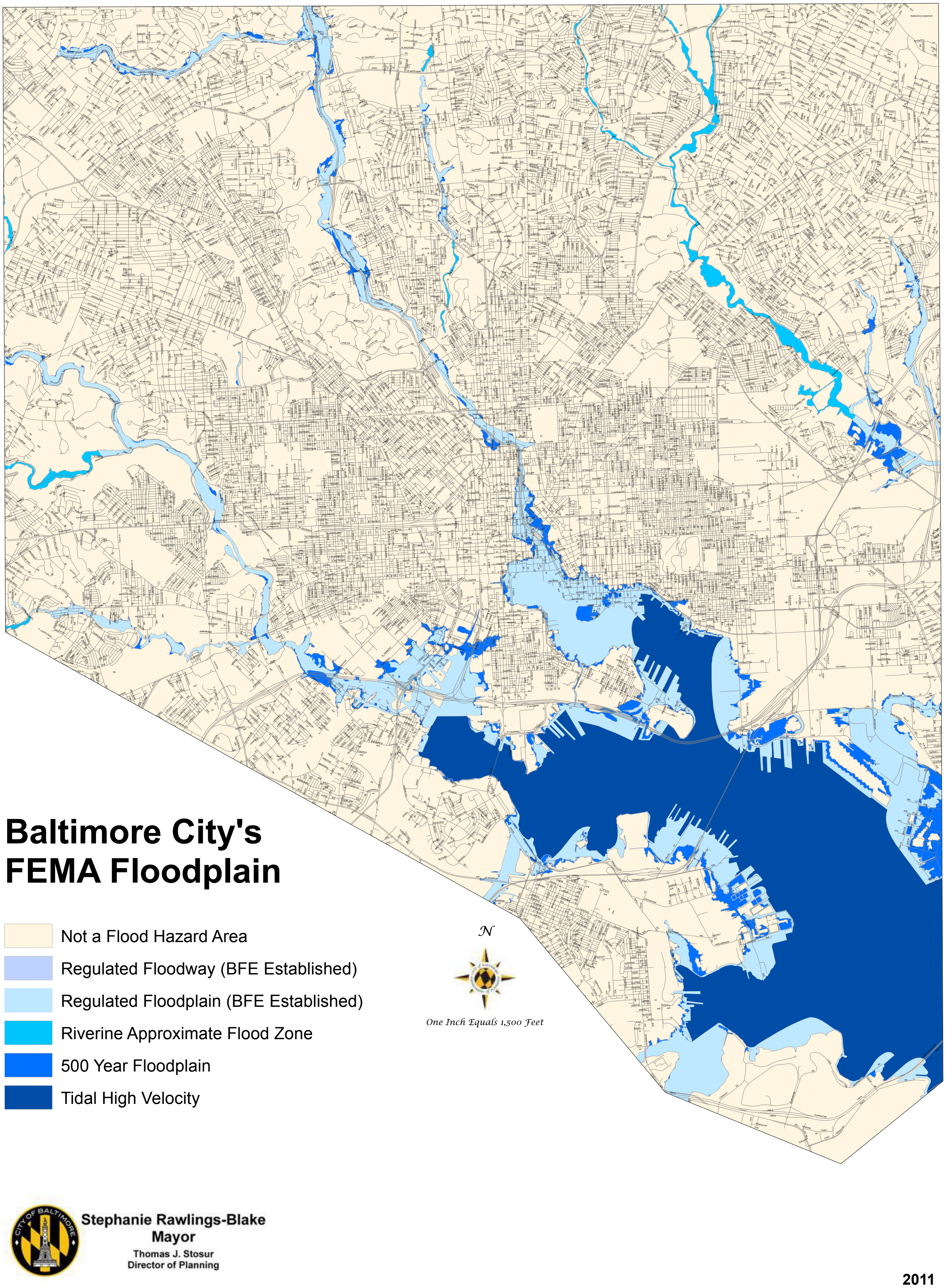
Table 4–9 Baltimore City Flood Impact - HAZUS

	% of Building Damage	Building Damage $	Contents Damage $	Inventory $	Total $
100-Yr Floodplain	79%	1,025, 399	973, 608	2,729	2,004, 798
500-Yr Floodplain	76%	1,790,423	1,705,072	6,379	3,507,857

Table 4–10 Flood Loss Estimates (in Thousands of Dollars) for 100-year and 500-year Floods in Baltimore City

Flood Type	Building	Contents	Inventory	Relocation	Income	Rental	Wage	Direct Loss	Grand Total
100-Year	200,365	387,009	19,877	663	2,436	567	8,320	7,737	626,974
500-Year	395,211	718,477	36,480	1,152	4,317	1,269	17,869	14,257	1,189,032

Source: Tables 3-32 and 3-33, Maryland Emergency Management Agency, 2011: 112-113.


Baltimore City's
FEMA Floodplain
Not a Flood Hazard Area
Regulated Floodway (BFE Established)
Regulated Floodplain (BFE Established)
Riverine Approximate Flood Zone
500 Year Floodplain
Tidal High Velocity
N
One Inch Equals 1,500 Feet
CITY OF BALTIMORE
Stephanie Rawlings-Blake
Mayor
Thomas J. Stosur
Director of Planning
2011

Coastal Hazards

Background

More than just flooding, coastal hazards may have a variety of additional consequences. The impact of a significant coastal event is greatest for those areas along and immediately near the coast, but can spread across the region. An evaluation of coastal hazards reported between 1993 and 2010 reveals that Baltimore City experienced more than one coastal event every two years (Table 4–11 NCDC Total and Annualized Coastal Hazards in Baltimore City (1993-2010), below). As discussed in the Coastal Hazards Profile of Chapter 3, these events are likely to be more frequent and intense in the future.

Table 4–11 NCDC Total and Annualized Coastal Hazards in Baltimore City (1993-2010)

Total Events	Annualized Events
10	0.56

Source: Table 3-36, Maryland Emergency Management Agency, 2011: 127.

Flooding from Hurricane Isabel Storm Surge, 2003

Vulnerability Assessment

Baltimore City, with its Harbor and close proximity to the East Coast, can be highly vulnerable to coastal hazards. Specifically, electrical and communications utilities, as well as transportation infrastructure, are vulnerable to significant coastal events. Damage to electrical lines or communication towers has the potential to cause power and communication outages. In addition to lost revenues, downed power lines present a threat to personal safety. Further, downed wires and lightning strikes have been known to spark fires (for a description of risks associated with lightning, see the Precipitation Variability Risk and Vulnerability Assessment below).

Exposure

An evaluation of exposure identifies who and what may be vulnerable to coastal hazards. This analysis takes into consideration where significant coastal storms or other coastal hazards tend to occur, and what assets or facilities may be located within those most vulnerable areas. The community assets and critical facilities inventories below identify specific properties that are exposed to coastal hazards and depict maps of exposed areas.

The City employed HAZUS modeling software, combined with expert input, to evaluate citywide vulnerability to coastal flooding. Sea, Lake, and Overland Surge from Hurricanes (SLOSH) Maps were also utilized to determine exposure. Three categories of storms were evaluated — tropical storms, in addition to Category 1 and Category 3 hurricanes — with varying levels of storm surge heights. Neighborhoods that are not at risk to storm surge were omitted from the coastal flooding analysis.

Sensitivity

Sensitivity evaluates the degree to which exposed assets are vulnerable to coastal hazards. Additionally, understanding sensitivity considers how some properties may be more vulnerable to coastal hazards than others. For instance, the sensitivity of a structure to significant coastal hazard events is based, in large part, on a particular building's construction and its location in relation to potential storm surge inundation zones. In general, mobile homes and wood-framed structures are more vulnerable to damage from wind during significant coastal events than steel framed structures. Such construction types, however, are not typical of Baltimore. Other factors — including the location, condition, and maintenance of trees — also play a significant role in determining vulnerability to damage from coastal hazards. Furthermore, as noted above, various systems are highly sensitive to the impacts of coastal hazards, including electrical and utility infrastructure.

Adaptive Capacity

An asset's ability to respond or adjust to a hazard defines its adaptive capacity. It is possible for the City to adapt to coastal hazards, but this potential is dependent upon additional factors, including a comprehensive understanding of the risks associated with coastal hazards, infrastructural and structural preparedness, and regulations for development within exposed areas.

Inventory of Community Assets Susceptible to Coastal Hazards

The vulnerability of Baltimore residents to coastal hazards is primarily based on the availability, reception, and individual understanding of early warnings. Once warned of an impending significant coastal hazard event, seeking shelter in a substantial indoor structure —one that is also wind-resistant and outside of storm surge zones — is recommended as the best protection against bodily harm.

The map to the right (Figure 4–10 Maryland Western Shore Hurricane Evacuation Study Storm, Surge Map) shows that Category 1, 2, 3, and 4 hurricanes have the potential to inundate a significant portion the City. Baltimore's harbor and waterways are the life-blood of the City, and have been a focus of industrial, commercial, and residential development in recent years.

The City utilized similar techniques when evaluating vulnerability to coastal flooding when combined with anticipated Sea Level Rise (SLR). Five SLR scenarios were evaluated. Due to the uncertainty of climate conditions, and thus of relative seal level rise projections, it can be difficult to assign quantitative probabilities to projections of sea level increases. The most current sea level data from the Maryland State Climate Change Commission, and from the Intergovernmental Panel on Climate Change, indicate that sea levels in the Baltimore region could experience an additional rise of 1.5 to 3 feet in the next 50 years. This rise could have significant impact, particularly on City and State roadway systems. The table below (Table 4–12 Critical Facilities Located in Baltimore City HAZUS Coastal Flood Extents) indicates key City-owned assets and facilities within Baltimore's 100- and 500-year floodplains, including estimates for an additional 3, 5, or 7 foot in sea level rise.

In all of Maryland, a recent study reports, approximately 800 miles of roadway are vulnerable to impact if sea levels rise more than 2 feet.[5] This same rise would affect 93 bridges, culverts, and highway structures in Maryland. If sea levels rise as much as 5 feet, which is what high end predictions suggest, an estimated 3,700 miles of road could be underwater.[6] In Baltimore, as the table above suggests, 32.35 miles of local roadway would be underwater in a 500 year event with the projected additional 5 foot sea level rise. For this reason, it is essential that transportation functionality that accommodates projected sea level rise is considered as part of future strategies.

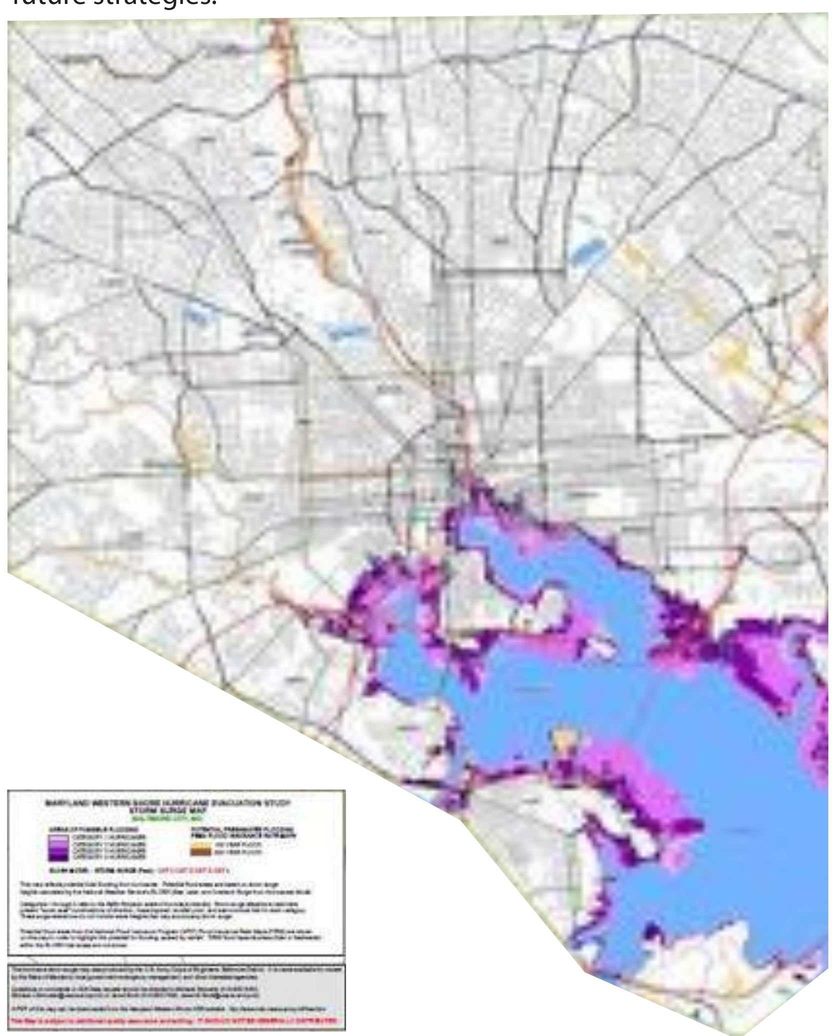


Figure 4–10 Maryland Western Shore Hurricane Evacuation Study Storm, Surge Map

Table 4–12 Critical Facilities Located in Baltimore City HAZUS Coastal Flood Extents

Critical Facility	100 Year	500 year	500 year + 3 ft SLR	500 year + 5 ft SLR	500 year + 7 ft SLR
Subway	0	0.42 miles	0.79 miles	0.79 miles	0.79 miles
Railroad	15.24 miles	51.59 miles	76.64 miles	93.59 miles	107.89 miles
Bridges*	3	4	4	4	8
Tunnels	1	1	1	1	1
Major Roads	15.08 miles	22.93 miles	26.85 miles	32.35 miles	37.14 miles
Police Stations	0	0	1	1	2
Fire Stations	0	1	1	1	1
Emergency Operation Centers	0	0	0	0	0
Public Schools	0	1	1	1	2
Private Schools	0	0	0	0	0
Colleges	0	1	1	1	1
Hospitals	0	0	0	0	0
Nursing Homes	0	0	0	0	0
Cultural Facilities	3	6	16	18	30
Power Plants*	0	3	4	4	7
Waste Water Treatment Plants	0	2	2	2	2

*Numbers based on HAZUS inventory/Coastal Flood Extent, not Baltimore City Data.

Source: HAZUS; GIS Data Collections

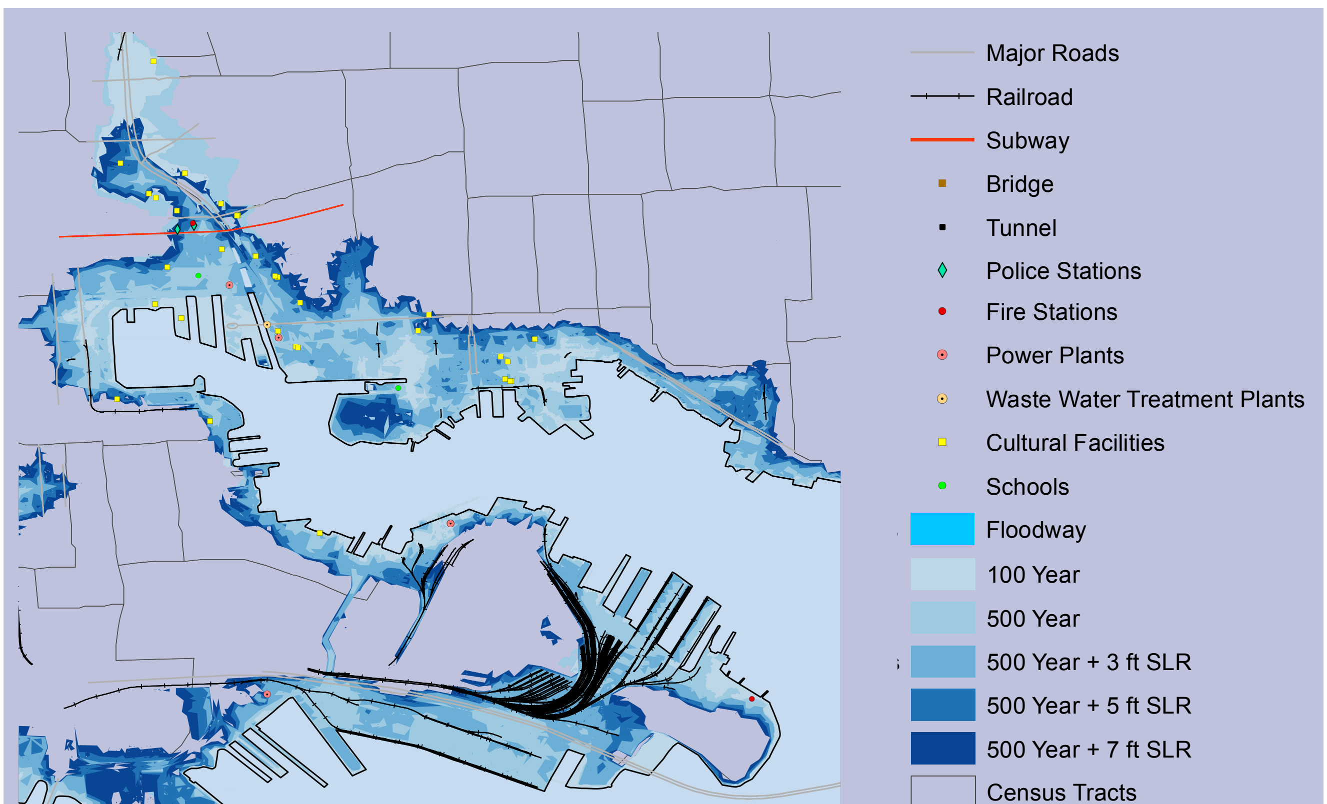


Figure 4–11 Focus Area | Critical Facilities in the Fells Point Flood Hazard Area

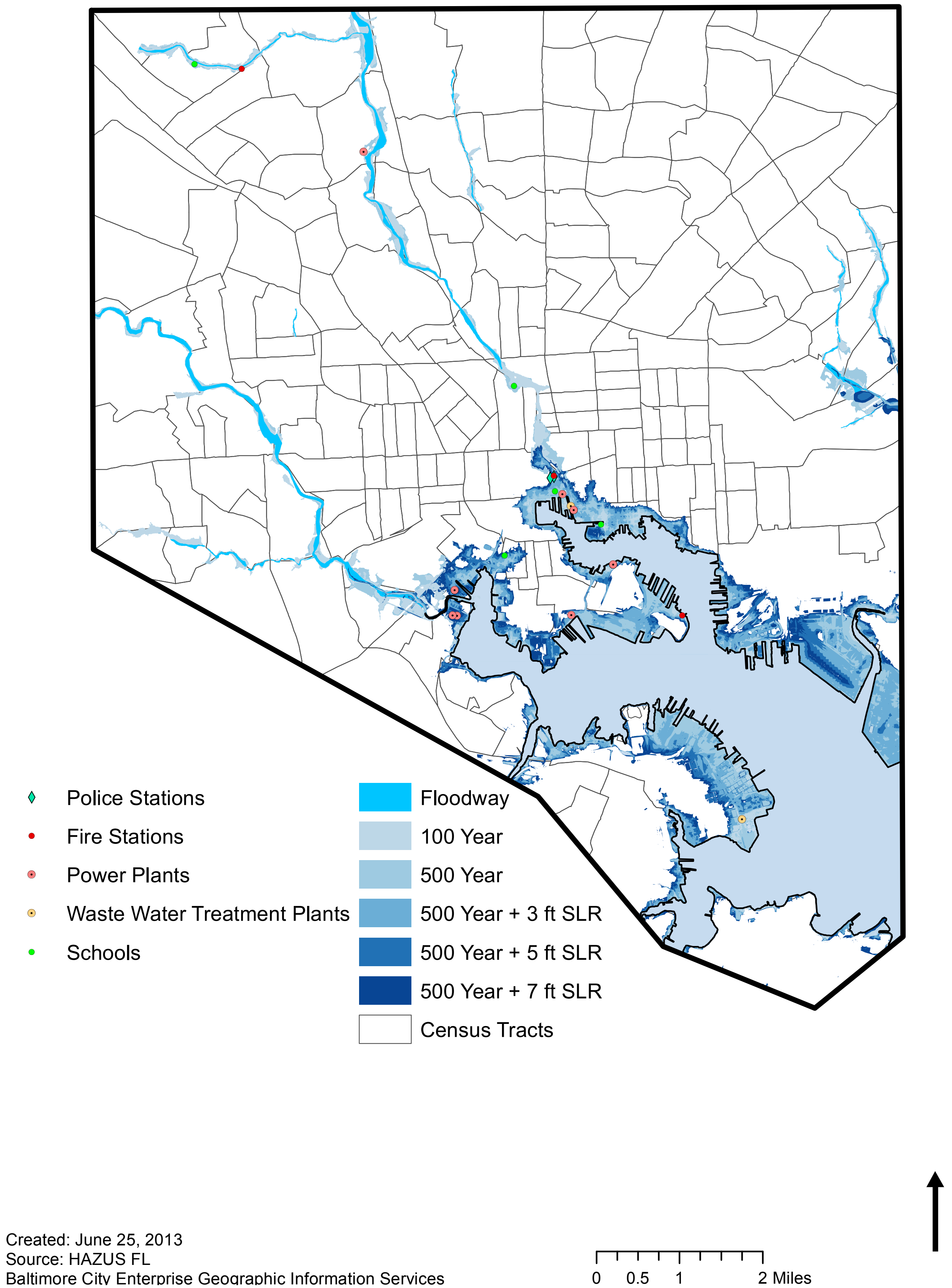


Figure 4–12 Critical Facilities in the Flood Hazard Area, Showing 3 ft, 5 ft, and 7 ft Sea Level Rise Scenarios

Inventory of Critical Facilities Susceptible to Coastal Hazards

As shown in Table 4–13 State and Critical Facilities within High Coastal Hazard Ranking Areas in Baltimore City, there are a total of 765 State facilities, valued over $7.5 billion, and 7,904 Critical facilities, valued over $3.1 billion, in Baltimore City that are considered to be at high risk from coastal hazards in general.

Critical facilities impacted by hurricane (of categories 1, 2, 3, and 4) inundation areas are the same as those that are located within flood zones (see the flooding risk and vulnerability segment above). The map on page 127 (Figure 4–12 Critical Facilities in the Flood Hazard Area, Showing 3 ft, 5 ft, and 7 ft Sea Level Rise Scenarios), notes the additional risks associated with potential sea level rise. It is difficult, however, to identify additional exposure and sensitivity to coastal hazards. For instance, all buildings in Baltimore will be exposed to high winds associated with coastal storms.

Table 4–14 HAZUS-Flood: Sum of Facilities (type) located in floodplain, below, shows the estimated number of facilities (sorted by type) and their value, susceptible to inland flooding. To ensure that these facilities continue to offer their services before, during, and after a hazard event, each will require special attention and a high level of protection.

Table 4–13 State and Critical Facilities within High Coastal Hazard Ranking Areas in Baltimore City

Total Number of Critical Facilities	Critical Facilities Building and Content Values	Total Number of State Facilities	State Facilities Building and Contents Values
7,904	$ 3,179,149,973.00	765	$ 7,596,281,448.00

Source: Table 3-42, Maryland Emergency Management Agency, 2011: 135.

Table 4–14 HAZUS-Flood: Sum of Facilities (type) located in floodplain

	100 year	500 year	500 year + 3 ft SLR	500 year + 5 ft SLR	500 year + 7 ft SLR
Facilities (type)	Number of Buildings	Number of Buildings	Number of Buildings	Number of Buildings	Number of Buildings
Hospitals	8	16	23	22	24
Schools	0	4	5	5	7
Fire Stations	0	2	2	3	3
Police Stations	0	1	3	3	6
Emergency Operation Centers	0	0	0	0	0
Power Plants	0	7	7	8	13
Waste Water Treatment Plants	0	4	4	4	4
Total Damage					
Buildings Moderately Damaged	225	475	981	1,334	1,693
Percentage of Buildings Damaged to Total Number of Buildings	79%	76%	81%	88%	88%
Buildings Completely Destroyed	22	48	60	94	174
People seeking shelter	1,093	2,409	4,090	4,928	5,694
Building Loss Total (Millions)	$2,001.74	$3,501.78	$7,033.92	$10,058.35	$13,373.50

Estimated Losses

As evidence in property loss figures (Table 4–15 Coastal Hazard Property Damage) obtained from NCDC, coastal hazard events have the potential to be very destructive. Total damages (adjusted for inflation) on an annualized basis exceeds $2 million in Baltimore City. These estimates, however, are believed to be an under-representation of the actual losses experienced due to coastal hazards considering losses from events that go unreported or that are difficult to quantify are not likely to appear in the NCDC database.

Table 4–15 Coastal Hazard Property Damage

County/City	Property Damage (Total)	Property Damage (Annualized)
Baltimore City	$ 40,107,828	$ 2,228,213

Source: Table 3-38, Maryland Emergency Management Agency, 2011: 130.

HAZUS-MH MR5 was also run for hurricane wind in order to determine potential losses due to winds associated with tropical storm and hurricanes. Annualized losses estimates based on this analysis of hurricane wind were estimated at $2.6 million in Baltimore City (shown in Table 4–16 HAZUS-MH MR5 Hurricane Wind Annualized Loss Estimates).

Table 4–16 HAZUS-MH MR5 Hurricane Wind Annualized Loss Estimates

County/City	Annualized Losses
Baltimore City	$ 2,619,000

Source: Table 3-39, Maryland Emergency Management Agency, 2011: 131.

An analysis of occupancy type (Table 4–17 HAZUS-MH MR5 Hurricane Wind Annualized Loss Estimates by Occupancy) further evaluates this estimate. In Baltimore, most damage from hurricane winds is likely to be sustained by residential structures, which account for just over $2 million in the estimated losses.

Table 4–17 HAZUS-MH MR5 Hurricane Wind Annualized Loss Estimates by Occupancy

Agricultural	Commercial	Educational	Government	Industrial	Religion/ Non-Profit	Residential
$ 2,000	$ 351,000	$ 21	$ 18,000	$ 71,000	$ 35,000	$ 2,121,000

Source: Table 3-40, Maryland Emergency Management Agency, 2011: 132.

Coastal storm approaching Baltimore City, 2013

Source: Kristin Baja

THE PORT OF BALTIMORE

History of the Port of Baltimore

Historically, the City of Baltimore was a major industrial city that relied heavily on port activities as an economic base. Though not all industry has remained, port activities continue to have a significant impact on the City's economy and Baltimore retains its predominance as a major port city in North America.

Business at the Port of Baltimore generates about 14,630 direct jobs, while about 108,000 jobs in Maryland are linked to port activities. The Port is responsible for $3 billion in personal wages and salary and more than $300 million in state and local taxes.

The Port of Baltimore, ranked as one of North America's top fifteen container ports, features both public and private marine terminals for handling cargo. In addition, the MPA has fostered economic development through cruise line operations since the opening of the Cruise Maryland Terminal in 2006.

In 2012, the Port of Baltimore received a Colliers International Port Award for its ability to maintain the delicate balance with surrounding ecological habitats and for its ability to demonstrate delicate engineering when maneuvering new, larger post-Panamax cranes under the Chesapeake Bay Bridge.[1] The 2012 North American Port Analysis also noted that Baltimore is one of only four East Coast cities expected to be post-Panamax ready for the 2015 Panama Canal Expansion. In actuality, new cranes that were installed earlier in 2013, along with the deepening and reconstruction of the Seagirt Marine Terminal, give Baltimore the distinction of being one of only two post-Panamax that have already met the conditions required for the new, larger ships.

The Maryland Port Administration

The Maryland Department of Transportation (MDOT) oversees the operations of the Maryland Port Administration (MPA), which is a public authority for managing port activities and operations. Annually, the MPA reviews and revises, if necessary, its two hurricane preparedness plans: one for Marine Terminals, and another for the Baltimore City World Trade Center. The MPA hurricane preparedness plans are intended to establish policy and procedures to prepare both vessels and facilities, and the people and personnel within, for hurricane force weather.

The plans recognize the threat to life posed by extreme coastal storms and their hazards including high winds, storm surges, heavy rains, and flooding. As part of their effort to increase preparedness for such hazards, the MPA established a maritime reporting standard for describing the following conditions:

1. **SEASONAL ALERT:** Set on June 1st and remain in effect through November 30. At this time hurricane plans should be reviewed and weather reports closely monitored for any hurricane activity.
2. **STORM CONDITION:** Set when high winds 55 mph/48kts or greater are forecast. This condition includes all phases of the approaching storm.
3. **WHISKEY: (also referred to as *HURRICANE SEASON*).** Set when gale force winds (34+mph) associated with tropical cyclone activity are expected to arrive at the Port within **72 hours**.
4. **XRAY: (also referred to as *HURRICANE WATCH*).** Set when gale force winds (34+mph) associated with tropical cyclone activity are expected to arrive at Port within **48 hours**.
5. **YANKEE: (also referred to as *HURRICANE WARNING*).** Set when gale force winds (34+mph) from a hurricane force storm are expected to arrive at the Port within **24 hours**, and as soon as practical after the storm passes.
6. **ZULU: (also referred to as *HURRICANE WARNING*).** Set when gale force winds (34+mph) from a hurricane force storm are expected to arrive at the Port within **12 hours**.

Baltimore's Seagirt Marine Terminal *Source: ChooseMaryland.org*

1 http://www.colliers.com/~/media/Files/MarketResearch/UnitedStates/MARKETS/2012%20Q2/Colliers_PortReport_2012q2_final.ashx?campaign=Colliers_Port_Analysis_NA_Aug-2012

The maritime hurricane alert conditions correlate directly with similar systems that are currently used by civilian and military agencies, as shown in Table 4–18 Comparison of Civilian, Maritime and Military Hurricane Conditions. Updated conditions are released by the Coast Guard Captain of the Port (COTP) throughout hurricane season — from June 1st to November 30th. The purpose of setting and reporting standard maritime hurricane conditions is to give the port community — including MPA personnel, ship captains, businesses and property owners, and other agencies, entities, and individuals — adequate time to prepare. A different series of preparation actions are recommended to be taken for each condition; these may include, to name just a few, steps such as advising tenants to remain at their posts or testing site operations and ensuring that emergency response systems are operational and prepared. Additionally, the plans identify procedures to be undertaken following hurricane events.

In each document, the MPA notes that the plan is "advisory in nature and does not supersede any directives or requirements established by the Maryland Emergency Management Agency's (MEMA) State of Maryland Emergency Operations Plan (EOP) or those promulgated in the U.S. Coast Guard Captain of the Port (COTP) Upper Chesapeake Bay Hurricane Contingency Plan." Furthermore, various property owners and terminal operators in the Port of Baltimore may have their own preparedness plan and requirements to complement the MPA plans; however, while these plans may be even more strict than the MPA plan, they may not be less so.

Baltimore City World Trade Center *Source: Baltimore.CityBizlist.com*

Table 4–18 **Comparison of Civilian, Maritime and Military Hurricane Conditions**

Projected Storm Path and Seasonal Considerations	Maritime Hurricane Conditions	Civilian Hurricane Conditions	Military Hurricane Conditions
1 December - 31 May	NONE	NONE	NONE
1 June - 30 November	SEASONAL ALERT (set automatically)	HURRICANE SEASON (set automatically)	SEASONAL ALERT (set automatically)
Hurricane force winds are expected within 72 hours at (geographic point)	CONDITION WHISKEY	HURRICANE SEASON	CONDITION FOUR
Hurricane force winds are expected within 48 hours at (geographic point)	CONDITION XRAY	HURRICANE WARNING	CONDITION THREE
Hurricane force winds are expected within 24 hours at (geographic point)	CONDITION YANKEE	HURRICANE WARNING	CONDITION TWO
Hurricane force winds are expected within 12 hours at (geographic point)	CONDITION ZULA	HURRICANE WARNING	CONDITION ONE
After the storm passes or when projected storm path has storm not impacting (geographic point)	Return to SEASONAL ALERT	Return to HURRICANE SEASON	RESPONSE & RECOVERY

Source: MPA Marine Terminals Plan, 2013: 12

Precipitation Variability

Background

With precipitation from atmospheric rivers, as well as other storm events, precipitation variability poses a risk - particularly from hazards during and after storm events. Hazards associated with precipitation variability manifest as a thunderstorm (with lightning and hail), winter storm, or drought (for a description of flooding hazards, see the Flooding Risk and Vulnerability Assessment above; for risks associated with strong winds, see the Wind Risk and Vulnerability Assessment).

Table 4–19 NCDC Total and Annualized Thunderstorm (Lightning & Hail) Events (1956-2010)

County/City	Total Events*	Annualized Events
Baltimore City	19	0.35

Source: Table 3-64, Maryland Emergency Management Agency, 2011: 178.
**Grand total values are not a direct sum of each of the county/city totals. The grand total events do not include zonal events.*

Significant thunderstorms are very difficult to predict, but based on past NCDC records of thunderstorm occurrence, a reasonable determination of the probability of future significant hail or lightning events can be made. Table 4–19 NCDC Total and Annualized Thunderstorm (Lightning & Hail) Events (1956-2010), indicates that Baltimore City experiences a significant thunderstorm event — one that causes injury, fatalities, and/or damage — will occur a little over once every three years.

Table 4–20 NCDC Total and Annualized Winter Storm Events (1993-2010)

Total Winter Storm Events	Annualized Winter Storm Events	Total Ice Events	Annualized Ice Events
93	5.17	4	0.22

Source: Table 3-75, Maryland Emergency Management Agency, 2011: 202-203.

In addition to thunderstorms, winter storms create dangerous conditions in Baltimore. Using data collected between 1993 and 2010, it is determined that Baltimore City already experiences an average of 5.17 winter storm events each year, and a little more than one ice event every 5 years (Table 4–20 NCDC Total and Annualized Winter Storm Events (1993-2010)). Although climate change is expected to bring an increase in winter precipitation, it is expected to be increasingly wetter than what we currently receive and precipitation will fall in liquid-form rather than frozen. Studies project a 25 percent decrease in snow volume by the year 2025 and a 50 percent decrease by the end of the century.

Finally, in addition to risks associated with extreme precipitation events, drought incidences may also present a risk in Baltimore. Due to the relatively short period of recorded NCDC drought data, it is difficult to accurately forecast future frequency of drought. However, upon examining available data, it is reasonable to assume that Baltimore City, through its management of the reservoirs, is susceptible to impacts of extended drought events. Already, significant drought events occur a little more than once every two years (Table 4–21 Annualized Drought Events, 1995-2010). Additionally, future droughts are expected as a result of more frequent extreme heat events due to the warming of Baltimore's climate (see the Extreme Heat Risk and Vulnerability Assessment later in this chapter). There may also be concern for accelerated sedimentation of the reservoirs from the combination of draught events (that stresses vegetation) and more frequent and intense precipitation events. In addition to the sedimentation these short duration storms do not allow for the saturation of soil and the recharge of groundwater that feed streams that in turn feed the reservoirs. Long-term climate forecast models suggest that a warming planet will lead to changes in precipitation distribution as well as more frequent and severe drought.

Table 4–21 Annualized Drought Events, 1995-2010

County/City	Total Events	Annualized Events
Baltimore City	9	0.56

Source: Table 3-91, Maryland Emergency Management Agency, 2011: 239

Vulnerability to Precipitation Variability

Precipitation Variability can present a number of hazards to which Baltimore may be vulnerable. Depending on the nature of the event, vulnerability may be quite different. Storm events, accompanied by hail and lightning, as well as winter storms and droughts could potentially impact Baltimore and its residents.

Exposure

An evaluation of exposure identifies who and what may be vulnerable to precipitation variability hazards. This analysis takes into consideration where precipitation variability may occur, in addition to what assets and facilities may be located within those vulnerable areas. The community assets and critical facilities inventories below will note specific properties that are exposed to precipitation variability.

However, unlike some other hazard analyses, the exposure of Baltimore to precipitation variability is not limited to specific regions or areas. Rather, exposure is extensive and the impacts are likely to affect everyone. Sensitivity, more than exposure, presents a better understanding of Baltimore's vulnerability to precipitation variability.

Sensitivity

Sensitivity evaluates the degree to which exposed assets are vulnerable to precipitation variability hazards. Additionally, understanding sensitivity recognizes the ways in which some properties may be more vulnerable to than others.

Hazards associated with thunderstorms often include lightning and hail. Building construction, location, and nearby trees or other tall structures will have a large impact on how vulnerable an individual facility is to hail or lightning strikes. A rough estimate of a structure's likelihood of being struck by lightning can be calculated using the structure's ground surface area, height, and striking distance between the downward-moving tip of the stepped leader (negatively charged channel jumping from cloud to earth) and the object.[7] In general, buildings are more likely to be struck by lightning if the structure is located on a hilltop; is tall or is surrounded by tall structures; or has large, exposed windows. Electrical and communications utilities are also vulnerable to direct lightning strikes. Communications and power supplies may be compromised during thunderstorms, and some critical facilities might not be equipped with a backup power source.

Structural vulnerability to hail is determined by a facility's construction and exposure. Metal siding and roofing is better suited to withstand the damages of a hailstorm than many other construction materials (though it may still sustain damage by denting). Exposed windows and vehicles are also susceptible.

South Ann Street, February 2010 *Source: Jed Kirschbaum*

Winter storms pose many of the same dangers as thunderstorms, but also have additional specific concerns. As in a thunderstorm, transportation and communication structures are also at risk from winter storms. The type and age of construction influences a facility's vulnerability to winter storms. Building construction type – particularly, roof span and construction method are examples of factors that determine the ability of a building to perform under severe stress from the weight of a heavy snowfall. The potential for such damage was demonstrated by a notorious incident at the B&O Railroad Museum, a historic structure and repository of irreplaceable railroad industry artifacts and antique equipment, where heavy snow collapsed the Museum's roof.

Baltimore has several thousand rowhouses with flat roofs which may be susceptible to collapse in the event of heavy snowfall. Recent experience has proven this vulnerability, and a number of roofs have collapsed in heavy winter storms. Unfortunately, the City does not maintain data on building roof type; therefore, this analysis can estimate neither the total number, nor the likely economic losses, of susceptible structures.

Winter storms may bring more than just snow. Ice storms and freezing rain events can be particularly disruptive. Freezing rain and ice can weigh down power lines, cause branches to break, and cause trees to break or become uprooted. Downed trees and power lines may disrupt traffic, hinder emergency response vehicles, and necessitate costly clean-up and disposal of debris. Damage to power lines or communication towers has the potential to cause electrical and communication disruptions for residents, businesses and critical facilities. In addition to lost revenues, downed power lines present a threat to personal safety. Furthermore, downed wires have been known to spark fires. Vulnerability to winter storm damage will vary, in large part, due to specific factors; for example, proactive measures, including regular tree maintenance and utility system winterization, can minimize property vulnerability. It is impossible to predict with certainty where lightning or hail will strike, and all counties in Maryland are susceptible to these dangers.

Likewise, while extreme precipitation may pose a danger, a lack thereof can also become a hazard. Short-term droughts can impact agricultural productivity (though not a common activity in Baltimore City) while longer term droughts are also likely to impact water supply. Groundwater is a commonly used source of water supply and is obtained from both confined and unconfined aquifers. Many individual home owners in rural areas pump groundwater from their own wells. Public water suppliers like the Washington Suburban Sanitary Commission rely on surface waters for their water supply. About two-thirds of Maryland's citizens regularly consume water that originates from a surface water source. In general, counties that have invested in water supply and distribution infrastructure are generally less vulnerable to drought. However, communities where water supplies rely on the Potomac or Susquehanna Rivers and their tributaries are more vulnerable during a drought than those using the Chesapeake Bay for water supply. This is due to the lack of recharge from surrounding watersheds that flow into the rivers.

Adaptive Capacity

An asset's ability to respond or adjust to a hazard defines its adaptive capacity. It is possible for the City to adapt to precipitation variability, but this potential is dependent upon additional factors, including a comprehensive understanding of the risks associated with precipitation variability hazards, infrastructural and structural preparedness, and regulations for development that may be exposed or highly sensitive.

Inventory of Community Assets Susceptible to Precipitation Variability

The vulnerability of Baltimore residents to precipitation variability as it specifically relates to storm events is based on a number of factors, including availability, reception and understanding of early warnings. Once warned of an impending storm hazard, individuals who immediately seek shelter in a sturdy building or metal-roofed vehicle are much safer than those who remain outdoors. Early warnings of severe storms are also vital for aircraft flying through the area.

Due to the wide scope of potential impacts from precipitation variability events, it is difficult to identify specific vulnerabilities in Baltimore's community assets. By recognizing key characteristics which would increase a structure's vulnerability (as mentioned in the sensitivity segment above), residents and City agencies can increase overall resiliency by reinforcing structural integrity and developing comprehensive preparedness guidelines.

Table 4–22 State and Critical Facilities within High Winter Storm Ranking Areas in Baltimore City			
Number of Critical Facilities	Critical Facilities Building and Content Values	Total Number of State Facilities	State Facilities Building and Contents Values
7,904	$3,179,149,973.00	765	$7,596,281,448.00
Source: Table 3-79, Maryland Emergency Management Agency, 2011: 208.			

Inventory of Critical Facilities Susceptible to Precipitation Variability

Critical facilities are vulnerable to the effects of heavy storms, particularly to impacts on energy and infrastructure systems. However, facilities are generally equally vulnerable as precipitation variability events are not usually confined to certain regions. Hospitals and other essential medical facilities depend on a continuous power supply, without which the lives of thousands of patients may be in jeopardy. Ensuring that these facilities have back-up power systems is vital. Not all critical facilities have redundant power sources and may not even be wired to accept a generator.

With regards to extreme winter storms, future plan updates should consider closer examination of critical facilities risk by looking at construction type of critical facilities in jurisdictions considered to be at higher risk of winter storms.

Estimated Losses

In Baltimore, there are roughly 7,904 critical facilities — with an approximate value of $3.2 billion — that are vulnerable to severe winter storms (Table 4–22 State and Critical Facilities within High Winter Storm Ranking Areas in Baltimore City). Meanwhile, 765 state facilities, with an estimated $7.6 billion value, are at risk from such storms.

Rain delay at Oriole Park at Camden Yards, April 2009 *Source: Karl Merton Ferron*

Wind

Background

Wind damage can come from a storm front moving through (e.g. derecho) or a tornado. Generally, every area in Maryland is vulnerable to severe winds, especially those in central Maryland and the Chesapeake Bay region. In Maryland, however, Baltimore City is not considered an area with high wind risk. Based on historical frequency of high wind event occurrences, revealed using NCDC data, a reasonable determination of probability of future high wind and tornado events can be made. Evaluating high wind events that were reported from 1956 to 2010 reveals that more than 2 high wind events occur each year (Table 4–23 NCDC Total and Annualized High Wind Events (1956-2010)).

Table 4–23 NCDC Total and Annualized High Wind Events (1956-2010)

Total Events	Annualized Events
121	2.2

Source: Table 3-58, Maryland Emergency Management Agency, 2011: 166.

Although relatively infrequent, tornadoes have had significant impacts on Maryland in the past and are likely to impact Maryland in the future. According to NCDC historical records (Table 4–24 NCDC Total and Annualized Tornado Events (1950-2010)), Baltimore experienced 4 tornado events between 1950 and 2010, or approximately .07 tornadoes each year. In other words, on average, Baltimore City is impacted by a tornado roughly once every 14 years.[8]

Table 4–24 NCDC Total and Annualized Tornado Events (1950-2010)

Total Events	Annualized Events
4	0.07

Source: Table 3-70, Maryland Emergency Management Agency, 2011: 189.

Vulnerability to High Wind Events

Tornadoes are considered to be low frequency, high-impact events. In the State of Maryland, all areas share a nearly uniform susceptibility to tornadoes. Electrical utilities and communications infrastructure are most vulnerable to tornadoes. Damage to power lines or communication towers has the potential to cause power and communication outages for residents, businesses, and critical facilities. In addition to lost revenues, downed power lines present a threat to personal safety. Furthermore, downed wires coupled with lightning strikes have been known to spark fires (for details regarding vulnerability to lightning, refer back to the Precipitation Variability Risk and Vulnerability Assessment).

Exposure

An evaluation of exposure identifies who and what may be vulnerable to high wind hazards. This analysis takes into consideration where high wind events may typically occur, in addition to what assets and facilities may be located within those vulnerable areas. The community assets and critical facilities inventories below will note specific properties that are exposed to impacts from high wind.

Sensitivity

Sensitivity evaluates the degree to which exposed assets are vulnerable to high wind hazards. Additionally, understanding sensitivity recognizes the ways in which some properties may be more vulnerable to high wind events than others. For instance, a structure's vulnerability to a tornado is based, in large part, on building construction methods and standards. In general, mobile homes and wood-framed structures are more vulnerable to damage in a tornado than steel framed structures (Baltimore, however, has a limited number of such structures). Other factors, including location as well as condition and maintenance of trees, also play a significant role in determining vulnerability.

The sensitivity of Baltimore residents to a tornado is based on a number of factors, particularly related to availability, reception, and understanding of early warnings. Once warned of an impending tornado hazard, seeking shelter indoors on the lowest floor of a substantial building, away from windows, is recommended as the best protection against bodily harm.

Adaptive Capacity

An asset's ability to respond or adjust to a hazard defines its adaptive capacity. It is possible for the City to adapt to future high wind events, but this potential is dependent upon additional factors, including a comprehensive understanding of the risks associated with high wind, an evaluation of the projected increased intensity and frequency of high wind events, infrastructural and structural resiliency and preparedness, and regulations for structures and development that may be exposed or highly sensitive.

Inventory of Community Assets Susceptible to High Wind

A majority of Baltimore City's structures were built in the late 19th or early 20th century, and are primarily constructed of heavy brick or stone. Wood frame structures that were built in the middle of the 20th century were also constructed from heavy materials. Additionally, these later structures had been built according to Baltimore's building inspection professional standards, and are thus expected able to handle a significant wind load. Baltimore's newer buildings, while not constructed with materials of the same density as the older building stock, have been subject to the International Building Code, which dictates that all construction have a wind resistance to winds of up to 160 mph.

However, two primary building classifications stand out as potentially vulnerable structures in the event of a tornado or high wind event. These structures include:

- Dilapidated structures: Well-maintained, older properties are expected to fare reasonably well in the event of a tornado or windstorm, however, there are numerous vacant and/or dilapidated structures in Baltimore City that sustain damage from wind events on a regular basis. The City expends resources by securing the area which often means 'finishing' the demolition and buttressing neighboring properties when the failure is an adjoining structure (e.g. rowhouse). These compromised structures are usually in already economically stressed areas thereby exacerbating an already difficult situation. Baltimore City Housing Authority, Baltimore Development Corporation, and the Department of Planning are assessing areas with a significant number of dilapidated structures to identify and prioritize actions that can address this hazard and other issues.

Locust Point Tornado Damage, June 2013 *Source: abc2news.com*

- Gable-roofed structures: Gable-roofed structures are primarily found in Baltimore City's low-density residential neighborhoods. While most of these areas are fairly well-maintained, and residents should have little reason to expect significant damage, the physical nature of gabled roofs makes them more susceptible to damage in the form of de-shingling or, in extreme events, de-roofing.

Additionally, vacant structures may be more vulnerable. Abandoned or vacant properties would likely not be insured and consequently, would not be rebuilt if significant damage were sustained. Should damage be so severe that the City resolves to demolish a vacant structure, the aesthetic impact on a community would leave behind empty lots among remaining houses, yielding a "gap-tooth" appearance. Gap-tooth housing — a characteristic usually found in (and contributing to) blighted neighborhoods — is an example of a secondary negative effect of hazard events.

Tornado in Baltimore, June 2013 *Source: PBS*

Damage following the June 2012 Derecho in Baltimore

Inventory of Critical Facilities Susceptible to High Wind

During a tornado or high wind event, critical facilities serve as shelter and help to ensure safe and effective emergency response. Fortunately, most police, fire, school, and major hospital facilities in the City are constructed of heavy materials. However, some critical facilities in Baltimore may still be vulnerable to strong winds. In particular, structures that were built prior to the use of building codes and consideration of construction design wind speeds for corresponding zones may be vulnerable to wind damage.

Furthermore, not all critical facilities have redundant power sources and might not even be wired to accept a generator. Future state mitigation plan updates should consider closer examination of critical facilities by looking at construction type of those facilities in jurisdictions recognized to be at higher risk of tornadoes.

Estimated Losses

In order to estimate the potential dollar losses for a high wind event, planners designed two scenarios which demonstrate possible effects of a tornado. Tornadoes, by their nature, are randomly occurring events; no particular region within a localized area such as Baltimore City is more or less at risk of a tornado occurrence. However, the damage that a tornado could potentially wreak on structures within a particular area varies significantly based on the quality and density of structures within it.

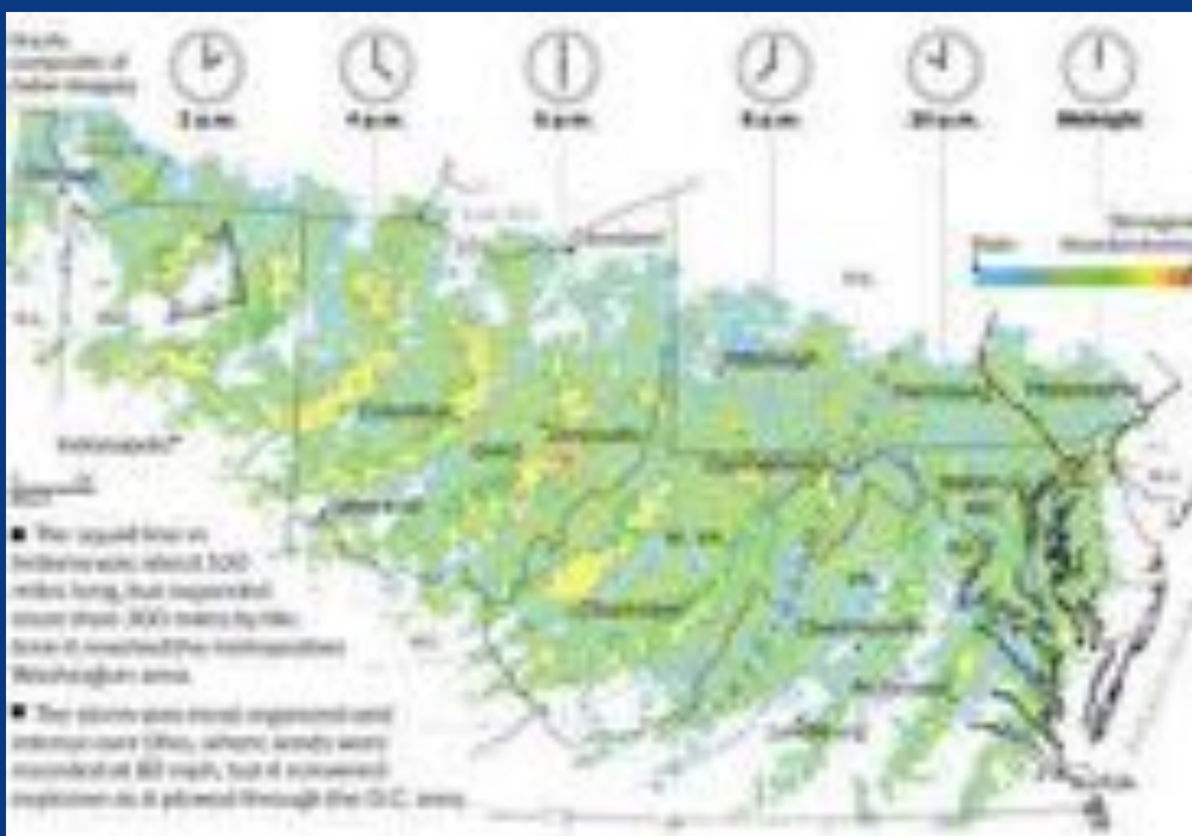
June 2012 Derecho

A derecho is a widespread, long-lived wind storm that is associated with a band of rapidly moving showers or thunderstorms. Although a derecho can produce destruction similar to that of tornadoes, the damage typically is directed in one direction along a relatively straight swath.

By definition, if the wind damage swath extends more than 240 miles (about 400 kilometers) and includes wind gusts of at least 58 mph (93 km/h) or greater along most of its length, then the event may be classified as a derecho. Derechos are most common in warm weather conditions, with more than 75% occurring between April and August. Maryland is expected to experience one derecho every four years.

The June 2012 derecho was one of the most destructive and deadly fast-moving severe thunderstorm complexes in North American history.

-Capital Weather Gang



Path and timeline of the June 2012 Derecho *Source: Washington Post*

Typically, derecho-producing storm systems move at speeds of 50 mph or greater, and a few have been clocked at 70 mph. Such rapid movement means that darkening skies and other visual cues that serve to alert one to the impending danger (e.g., gust front shelf clouds) appear on very short notice. Advance notice given by a derecho often is not sufficient for one to take protective action.

Extreme Heat

Background

Extended periods of extreme heat can tax the energy delivery system, leading to high cooling costs, and even blackouts or "brownouts." Additionally, at the same time as extreme heat may adversely affect the integrity of structures or infrastructure, other harmful costs of extreme heat are associated with human health and natural systems.

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report indicates that it is very likely that hot extremes and heat waves will become more frequent as the Earth warms. By the end of the century, the number of days above 90°F in Maryland is projected to more than double under lower greenhouse gas emissions scenarios, and roughly triple under higher emissions scenarios. Extended heat waves (temperatures above 90°F for at least three consecutive days) are expected to be much more frequent and longer lasting, particularly under higher emissions scenarios. Scientific predictions for increasing heat waves and temperature extremes are likely, with moderate confidence.[9]

Baltimore City's Inner Harbor turned a milky green color in Summer 2013 after a heat wave. Extended periods of heat reduce oxygen, killing marine life. During this July event, it was estimated that more than 200 fish were killed.
Source: Blue Water Baltimore, Huffington Post

Vulnerability to Extreme Heat

Extreme Heat events have been more frequent in recent years and are expected to increase by the end of the century. Energy and utility systems, transportation infrastructure, natural systems, and residents are all vulnerable to extreme shifts in temperature. Sensitivity to extreme heat depends on a number of location-related characteristics, including tree canopy coverage, impervious surface area, and resident demographic information (for resident vulnerability). Additionally, neighborhoods near to urban centers are more exposed to high heat conditions due to the Urban Heat Island effect.

Exposure

An evaluation of exposure identifies who and what may be vulnerable to extreme heat. This analysis takes into consideration where extreme heat may be most sever, in addition to what assets and facilities may be located within those vulnerable areas. The community assets and critical facilities inventories below will note specific properties that are exposed to extreme heat.

Sensitivity

Sensitivity evaluates the degree to which exposed assets are vulnerable to extreme heat hazards. Additionally, understanding sensitivity recognizes the ways in which some properties may be more vulnerable to extreme heat than others. For instance, a resident, structure, or asset may be more vulnerable if located in an area with minimal tree coverage. Additional characteristics, such as resident age or income, may influence sensitivity even further.

Adaptive Capacity

An asset's ability to respond or adjust to a hazard defines its adaptive capacity. It is possible for the City to adapt to extreme heat, but this potential is dependent upon additional factors, including a comprehensive understanding of the risks associated with heat-related hazards, programs to increase vegetative cover throughout the City, infrastructural and structural preparedness, and regulations for development that may be exposed or highly sensitive.

Inventory of Community Assets Susceptible to Extreme Heat

During Baltimore's hottest and most humid days, elderly residents living in neighborhoods with little tree cover are at a greater risk of suffering from heat-related impacts than are most other residents. Baltimore's neighborhoods with the lowest tree cover are shown in Figure 4–13 Baltimore City Tree Canopy by Neighborhood below. Resident income, in addition to resident age, may play a factor in an individual's ability to cope with extreme heat. For instance, when comparing the distribution of poverty throughout Baltimore's neighborhoods along with the location of low tree canopy areas, it becomes clear that areas with lower tree coverage are typically neighborhoods where residents have lower income. While it is more likely that lower income residents will not have air conditioning, those who do may experience rising electricity costs as a result of the higher energy use required to cool their homes. Additional Low Tree Canopy Neighborhoods Maps are found in Appendix K: Supporting Information.

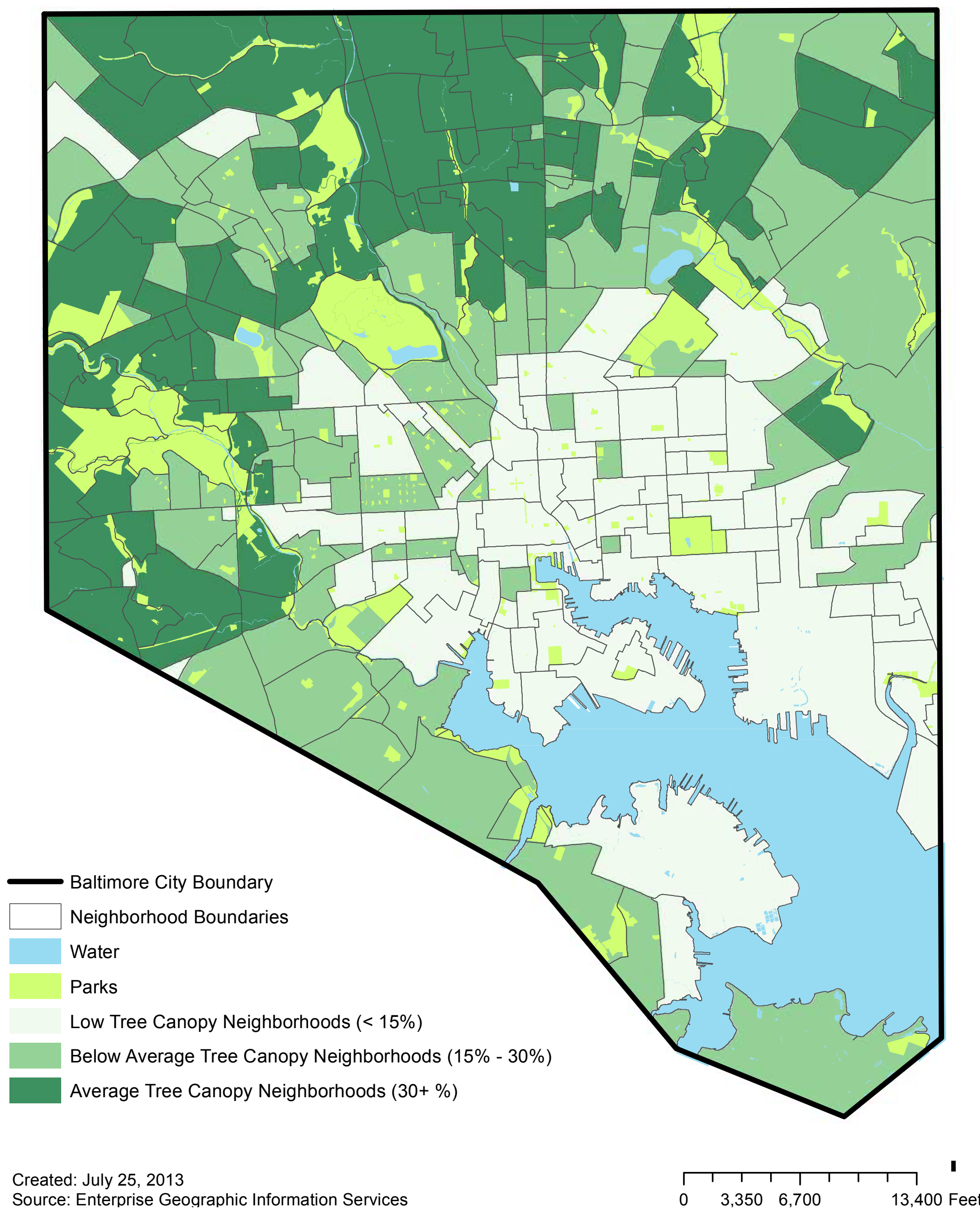


Figure 4–13 Baltimore City Tree Canopy by Neighborhood

On high heat days, residents may choose to remain indoors. However, not only will this raise risk of heat-related health impacts if homes are not equipped or utilizing A/C, but this behavior also limits economic activity. As people remain indoors, the active workforce is decreased and foot traffic in commercial areas is diminished. Likewise, business owners may also find their operating budgets have increased due to electricity usage, at the same time as revenues are dwindling.

Extreme heat will also impact natural systems. Trees have long been considered for their ability to absorb ozone pollution, and recent studies have been able to quantify that capacity.[10] In the past decade, however, Baltimore's tree canopy has been shrinking. Currently, only about 27 percent of Baltimore's landscape is covered by trees. Furthermore, between 16 – 20 percent of that canopy is considered to be unhealthy; and while we benefit from a tree's ability to absorb pollution, trees are significantly damaged by excessive pollution.[11]

The eldery are vulnerable to high heat *Source: news.com.au*

Inventory of Critical Facilities Susceptible to Extreme Heat

Baltimore's exposure to extreme heat is extensive. Aside from local characteristics which may lessen the intensity of an extreme heat event (see the discussion of tree canopy above), extreme heat has to potential to impact all areas of the City equally. For this reason, it is not possible to map particular critical facilities that may be most exposed to extreme heat. However, certain urban systems or building types are highly sensitive to the impacts associated with high heat. Infrastructure systems are quite sensitive to extreme heat. Energy systems will be taxed, which will have additional impacts on other systems and structures. Understanding this, certain facilities — including hospitals, emergency shelters, and schools — are likely to endure increased financial burdens as normal operation conditions must be maintain operations under more demanding circumstances. Additionally, impacts on critical facilities may be exacerbated by damage to transportation systems.

Estimated Losses

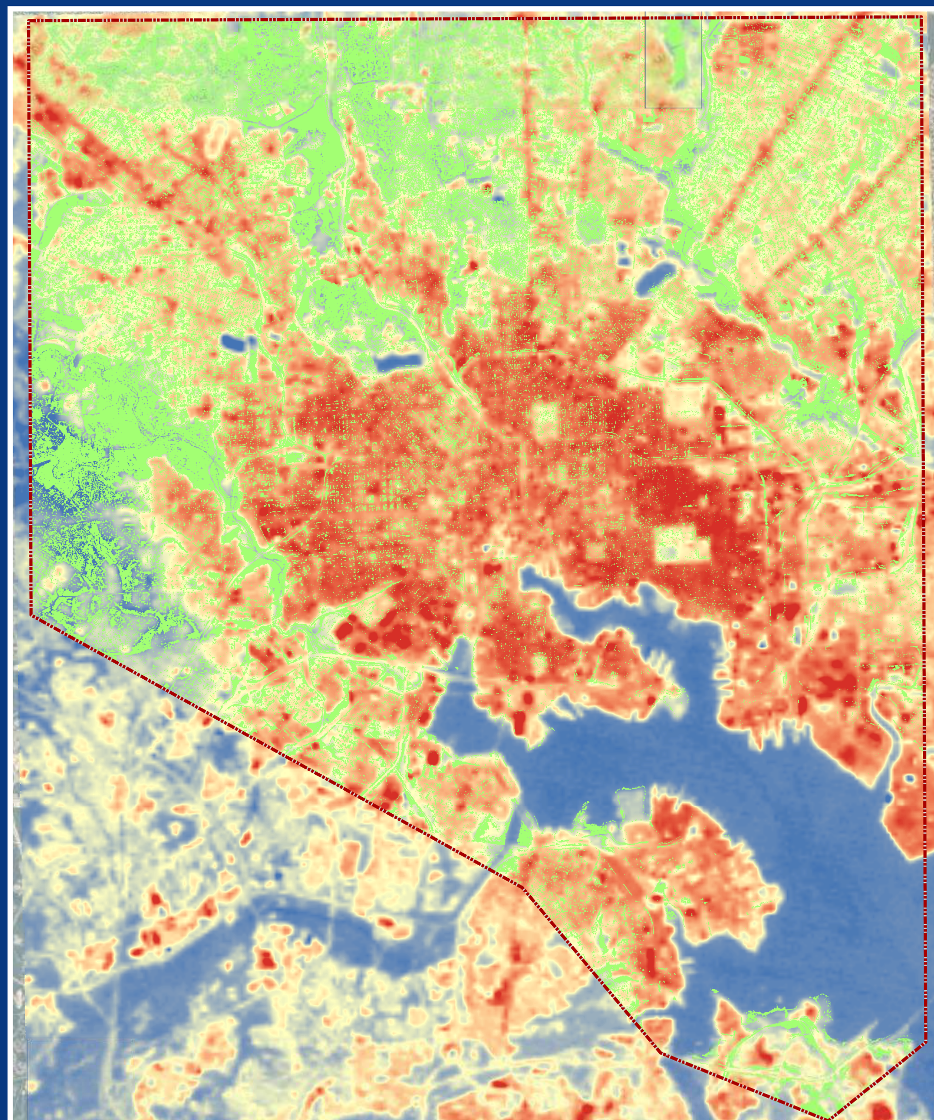
For the same reason as it is difficult to estimate the exposure of specific facilities, it is challenging to estimate potential economic losses due to extreme heat. Energy and other infrastructure systems (transportation and utility) are likely to be impacted by extreme heat. Further evaluation of existing conditions will indicate the locations of existing vulnerabilities, and the potential cost to increase resiliency of these areas.

URBAN HEAT ISLAND EFFECT

In the summer months, urban air temperatures can be up to 10°F higher than the air of surrounding suburban or rural areas — a phenomenon known as the urban heat island effect. The main cause of the urban heat island effect is urban development. Urban development commonly uses certain man-made materials, such as asphalt and concrete, that effectively retain heat. Indeed, many studies have shown the direct relationship between temperature and this sort of land cover.

The urban heat island effect is anticipated to be intensified as extreme heat events increase with climate changes. Heat events will increase in severity and intensity, especially in urban areas like Baltimore City, leading to a rise in daily temperatures.

Increasing the number of street trees and creating new urban forests are key strategies for both adapting to and mitigating the impacts of urban heat. Such strategies will be discussed in more detail in the following chapters.



TOP: Baltimore City Tree Canopy and Urban Heat *Source: AECOM*

BOTTOM: Infra-red thermal image of heat emitted in city street, 9pm *Source: urbanclimateenergy.com*

Land

Background

Earthquake events can, and occasionally do, occur in Maryland; though of much less intensity than those that occur elsewhere in the region or on the west coast. Although the area has experienced a handful of earthquakes from both inside and outside the State, land movement is more likely to be felt as a result of an earthquake that occurs in the surrounding region rather than originating within Baltimore City or Maryland. As yet, the small magnitude and minimal economic damage of previous earthquake events have not warranted the need for considerable structural retrofits or similar mitigation programs. At the regional scale, localized land subsidence, though less noticeable, can have considerable on urban systems.

The USGS recognizes four major impacts caused by land subsidence:

1. Changes in elevation and slope of streams, canals, and drains
2. Damage to bridges, roads, railroads, storm drains, sanitary sewers, canals and levees
3. Damage to private and public buildings
4. Failure of well casings from forces generated by compaction of fine-grained materials in aquifer systems

The direct consequence of regional subsidence does indeed pose a risk to Maryland (for a detailed discussion of land subsidence, please refer to the Land Hazards Profile in Chapter 3). However, due to the lack of historical data and detailed mapping, risk cannot be fully estimated for subsidence. Consequently, the probability of land subsidence is not as easily expressed in terms of specific intensity and frequency as it is for other hazards.

A more quantifiable analysis of land-related hazards may instead evaluate potential risk from karst or sinkholes. Karst formations develop in specific ways that are influenced by unique local conditions. Sinkholes can be induced through natural or human causes. Sinkholes that occur naturally usually form by the slow, downward dissolution of carbonate rock though bedrock collapse in areas that overlie caverns. Human induced sinkholes can be triggered by even a minor alteration in the local hydrology. Inadequate drainage along highways, or increased runoff from hard surfaces like concrete and pavement, can also contribute to sinkhole development.

The most important environmental issue with respect to karst is the sensitivity of aquifers to groundwater contamination. This problem is universal among all karst regions in the United States that underlie populated areas.

Vulnerability to Land Hazards

Earthquakes are low probability, high-consequence events. Although earthquakes may occur infrequently they can have devastating impacts. Ground shaking can lead to the collapse of buildings and bridges; and could disrupt gas, life lines, electric, and phone service. Deaths, injuries, and extensive property damage are also possible vulnerabilities from this hazard. Additionally, some secondary hazards caused by earthquakes include fire, hazardous material release, landslides, flash flooding, avalanches, tsunamis, and dam failure. Moderate and even very large earthquakes are possible, although usually infrequent, in areas of normally low seismic activity. Consequently, buildings in these regions are seldom designed to deal with an earthquake threat; therefore, they are extremely vulnerable.

Exposure

An evaluation of exposure identifies who and what may be vulnerable to land hazards. This analysis takes into consideration where seismic activity may occur, in addition to what assets and facilities may be located within those vulnerable areas. The community assets and critical facilities inventories below will note specific properties that are exposed to subsidence, karsts and sinkholes, or earthquakes.

Sensitivity

Sensitivity evaluates the degree to which exposed assets are vulnerable to land-related hazards. Additionally, understanding sensitivity recognizes the ways in which some properties may be more vulnerable to than others. For instance, a structure may be more vulnerable if it was not designed to withstand intense seismic activity. Additional characteristics may influence sensitivity even further.

Table 4–25 State Owned and Critical Facilities within the 100-ft Erosion Zone in Baltimore City

Critical Facilities in the Erosion Zone	State Facilities in the Erosion Zone
248	54

Source: Table 3-51, Maryland Emergency Management Agency, 2011: 153.

Adaptive Capacity

An asset's ability to respond or adjust to a hazard defines its adaptive capacity. It is possible for the City to adapt to the impacts of potential land hazards, but this capacity is dependent upon additional factors, including a comprehensive understanding of the risks associated with land hazards, infrastructural and structural preparedness, and regulations for structures or developments that may be exposed or highly sensitive.

Table 4–26 Critical Facilities Located Within Landslide Hazard Areas in Baltimore City

Critical Facilities	Critical Facilities Building and Content Values	State Facilities	State Facilities Building and Contents Values
1,055	$77,471,867	43	$149,471,406.49

Source: Table 3-84, Maryland Emergency Management Agency, 2011: 224

Inventory of Community Assets Susceptible to Land-Related Hazards

Most earthquake-related property damage, injuries, and fatalities are caused by the failure and collapse of structures due to ground shaking. The level of damage depends upon the amplitude and duration of the shaking —both of which are directly related to the earthquake size, its location and distance from the fault, and regional geology. Other damaging earthquake effects include landslides, the down-slope movement of soil and rock (mountain regions and along hillsides), and liquefaction in which ground soil loses shear strength and thus the ability to support foundation loads. In the case of liquefaction, anything relying on the substrata for support can shift, tilt, rupture, or collapse. All of Baltimore is considered to be within an expected peak acceleration zone of 8%g (refer back to Figure 3–17 on page 96 in Chapter 3). At this level any potential damage is expected to be very light.[12]

In Baltimore, sinkhole formation may be more likely than a major earthquake event. Vulnerable to urban karsts and sinkholes, however, cannot be easily associated with particular regions.

Inventory of Critical Facilities Susceptible to Land-Related Hazards

Using data from the Maryland Emergency Management Agency, Table 4–25 State Owned and Critical Facilities within the 100-ft Erosion Zone in Baltimore City, below, indicates that there are 248 Critical Facilities and 54 State facilities in the 100-ft erosion zone in Baltimore City. Likewise, there are 1,055 critical facilities, valued at $77 million, located within Baltimore's Landslide Hazard Areas (Table 4–26 Critical Facilities Located Within Landslide Hazard Areas in Baltimore City).

A retaining wall in Ellicott City, MD collapses following heavy rains *Source: dailymail.co.uk*

Estimated Losses

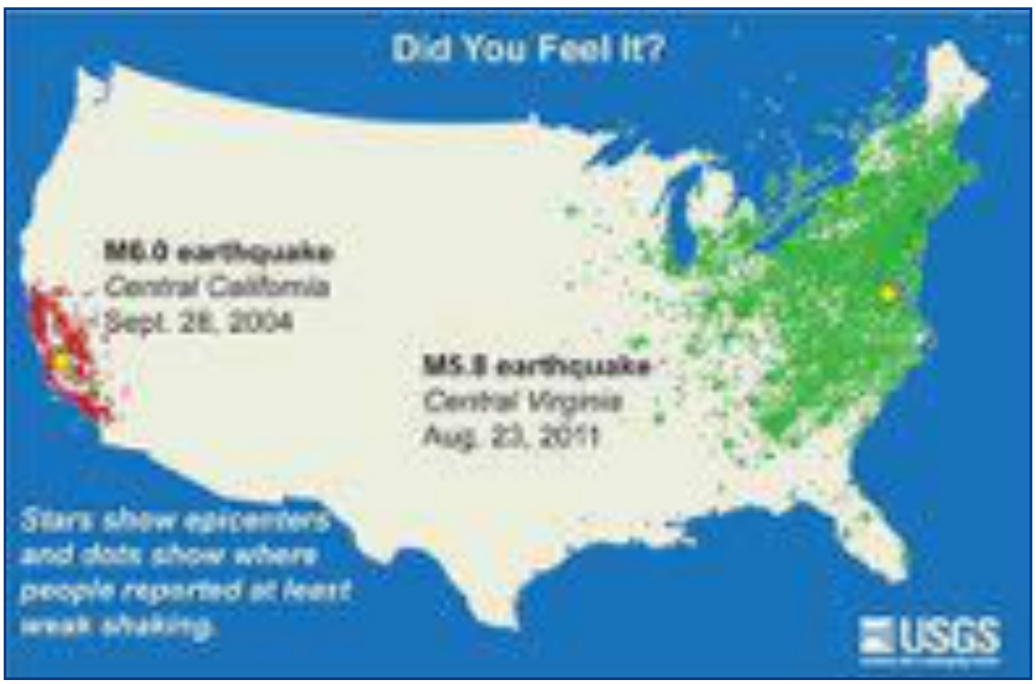
While the value of the facilities that are vulnerable to land-related hazards may be none, it is nevertheless challenging to accurately monetize the potential damages from an earthquake. Using HAZUS-MH Software, the 2011 Maryland Hazard Mitigation Plan reported that annualized direct economic losses from Earthquake events totaled $933,000 (as shown in Table 4–28 HAZUS MH-MR5 Earthquake Total Annualized loss in Baltimore City by building type based on a deterministic scenario).

The total annualized loss may be further analyzed by building type, as shown in Table 4–28 HAZUS MH-MR5 Earthquake Total Annualized loss in Baltimore City by building type based on a deterministic scenario, below. While manufactured homes are generally more vulnerable to an earthquake event, this construction type in not commonly found in Baltimore City. Rather, in Baltimore, most damage will likely be sustained by masonry structures, with an annualized loss of approximately $421,000. Dividing potential damage among building occupancy type, Table 4–29 HAZUS MH-MR5 Earthquake Total Annualized Loss by Occupancy Type, indicates that residential structures stand to sustain the most damage, costing an annualized loss of $442,000, while agricultural structures — not often found in the City — will sustain an annualized loss of only $1,000.

Table 4–27 HAZUS-MH MR5 Earthquake Annualized Losses and Direct Economic Losses Based on a Deterministic Scenario

Annualized Direct Economic Losses	Direct Economic Losses for 1998. Event in PA with a Mag. 5.2 and Depth 10km
$933,000.00	$588,000.00

Source: Table 3-97, Maryland Emergency Management Agency, 2011: 261.



USGS Central Virginia Earthquake, 2011 *Source: USGS*

Table 4–28 HAZUS MH-MR5 Earthquake Total Annualized loss in Baltimore City by building type based on a deterministic scenario

Wood	Masonry	Concrete	Steel	Manufactured Homes
$162,000	$421,000	$ 93,000	$256,000	$ -

Source: Table 3-98, Maryland Emergency Management Agency, 2011: 261-262.

Selecting Key Vulnerabilities

This plan recognizes that a number of tools for understanding natural hazard and climate impacts already exist. Perhaps most notable among these existing resources is NOAA's Coastal Services Center (CSC) Roadmap for Adapting to Coastal Risk, which includes a Risk and Vulnerability Assessment Tool (RVAT) and a Community Vulnerability Assessment Tool (CVAT). These existing tools and resources helped to establish a thorough framework for guiding the risk and vulnerability process of this plan. Learning from such tools, DP3 created an approach that was most appropriate for issues specific to Baltimore.

Specific facilities, assets, or neighborhoods within Baltimore may require additional care and attention when planning for natural hazards. Varying levels of sensitivity may be caused by general characteristics, such as the age of a structure, or specific conditions, including location or other external factors. For instance, to flooding and impacts from coastal hazards, Fells Point and Baltimore's Inner Harbor are highly vulnerable. Historic structures within those areas are even more so. At the same time, properties within floodplains and adjacent to major waterways, often repetitive loss properties, are likewise vulnerable to flooding. This is demonstrated, for example, in the commercial area of the Mt. Washington Mill, which has experienced frequent impacts from flooding in the past.

To the impacts of extreme heat, neighborhoods with the highest percentages of impervious surfaces, and least tree canopy, are most vulnerable (Table 4–30 The Top Ten Neighborhoods with the Hottest Average Summer Temperatures). Summer temperatures in these neighborhoods can reach 117°F, and even higher within primarily industrial areas. Conversely, the neighborhoods with the lowest average summer temperatures are more likely to have less land covered by impervious surfaces (Table 4–31 The Top Ten Neighborhoods with the Lowest Average Summer Temperatures).

Table 4–30 The Top Ten Neighborhoods with the Hottest Average Summer Temperatures

Name	% Impervious Surface	Avg. Temp in Summer
McElderry Park	100.0%	107.6
Patterson Park	99.9%	106.4
Patterson Place	99.9%	106.3
Highlandtown	99.5%	106.0
Brewers Hill	100.0%	105.7
Milton-Montford	100.0%	105.6
CARE	100.0%	105.4
South Baltimore	100.0%	105.2
Rosemont Homeowners/Tenants	100.0%	105.2
Ellwood Park/ Monument	97.1%	104.6
Broadway East	99.9%	104.5

Table 4–31 The Top Ten Neighborhoods with the Lowest Average Summer Temperatures

Name	% Impervious Surface	Avg Temp in Summer
Tremont	95.5%	88.7
Oaklee	99.3%	90.4
Medford	99.8%	95.9
Graceland Park	95.8%	96.1
Pimlico Good Neighbors	81.9%	96.4
O'Donnell Heights	73.0%	96.6
Fairfield Area	88.0%	97.2
Berea	77.9%	97.7
Parkside	98.6%	97.7
Hopkins Bayview	81.1%	97.8

Table 4–29 HAZUS MH-MR5 Earthquake Total Annualized Loss by Occupancy Type

Agricultural	Commercial	Educational	Government	Industrial	Religion/Non-Profit	Residential
$1,000	$386,000	$21,000	$16,000	$39,000	$29,000	$442,000

Source: Table 3-99, Maryland Emergency Management Agency, 2011: 263.

Adaptive Capacity

ADAPTIVE CAPACITY is the ability of a system (in this case, the City of Baltimore) to adjust to changes in the environment — including climate variability and extreme shifts in weather — in order to moderate potential damages or cope with the consequences of those changes.[13] Adaptive capacity informs, and is informed by, a vulnerability assessment through important insights into the factors, processes, and structures that promote or constrain the system's (City's) ability to respond to climate change or natural hazard events.[14] Systems that are resilient to climate stressors are more adaptable and flexible and generally have a higher adaptive capacity. Relatively similar hazards could have vastly different consequences depending on a system's level of adaptive capacity. While a low adaptive capacity can increase a system's vulnerability to natural hazards, a high level of adaptive capacity may lessen the degree to which a system is vulnerable.

There are two types of adaptive capacity: generic and specific. Generic adaptive capacity includes assets and entitlements that enable a system to cope and respond to a variety of stressors.[15] For example, having a well-educated and engaged community can contribute to generic capacity. On the other hand, specific adaptive capacity is the ability to respond to and recover from a specific climatic event, such as a flood, tornado, or hurricane.[16]

Adaptive capacity, of either generic or specific dimensions, can be influenced by a number of factors. In addition to the examples noted above, resource availability, socio-political barriers, and institutional responsibility, among other characteristics, can shape adaptive capacity. While the DP3 has considered adaptive capacity of the City of Baltimore as a whole, it has needed to recognize that capacity to adapt to climate change may not be equal across all populations. Research shows that adaptive capacity among individuals may be differentiated along the lines of age, race or ethnicity, religion, and gender.[17]

Adaptive Capacity Wheel and Scoring *Source: Sciencedirect.com*

Determinants of adaptive capacity are used to indicate opportunities and constraints for adaptation, as well as current assets and resources from which City may benefit. The eight determinants of adaptive capacity that are most frequently cited in scientific literature are described here.

1. **Institutions** | Includes norms and rules — both formal and informal. This may be governance mechanisms at city, state, regional, federal, or international levels, or institutional and policy frameworks. Additionally, this might include local ordinances, city plans, state and federal incentives and regulations, as well as inter-jurisdictional collaboration.

2. **Infrastructure** | Describes the basic physical structures needed for a City to function. Examples include water and sanitation systems, green infrastructure, traditional built environment, transportation networks (roads, bridges, public transportation), and energy supply systems.

3. **Wealth and Financial Capital** | Considers is the accessibility and availability of financial wealth or wealth management instruments, and includes fiscal incentives for risk management. For example, revolving funds, philanthropic initiatives, insurance, and credit can all be viewed as Wealth and Financial Capital.

4. **Social Capital Networks** | Focuses on access to — and engagement with —social groups, businesses, and organizations. Examples include public-private partnerships, organized community leadership, and interpersonal connections between city staff and external organizations.

5. **Political Capital** | Includes political leadership, political climate, decision and management capacity, and public engagement. Examples of Political Capital include leadership, motivation and vision, electoral and local politics, reputation and legitimacy, public perceptions of political leadership, and political support gained through public participation and engagement efforts.

Vulnerability generally includes three components: exposure, sensitivity and adaptive capacity *Source: Adaptingtorisingtides.org*

6. **Human Capital** | Focuses on education levels, community risk perception, human labor, and capacity of the human population. Some of the best indicators of human capital may be a community's overall education level, or the skills and knowledge of city staff.

7. **Information** | Considers access to information sources and the efficiency of early warning systems. Examples include scientific understanding of climate change impacts and associated adaptation strategies, and an effective system for sharing, discussing, and conveying climate change information, as well as adaptation strategies, at various levels.

8. **Technology** | Includes technology sources, access and transmission, and technological innovations. Examples of technology include the use of Geographic Information Systems (GIS) or Doppler Radar.

What can we do?

Hazard mitigation and climate adaptation processes help to build the City's adaptive capacity. First and foremost, by creating and maintaining the DP3 Plan, Baltimore is compliant with FEMA's requirement for an All Hazards Mitigation Plan (AHMP), and is therefore eligible for federal assistance in the event of an emergency. Such assistance leverages Baltimore's ability to respond to hazard events.

Improved adaptive capacity can ensure that a system is able to maintain ongoing functions throughout shifting conditions or hazard events. According to the Intergovernmental Panel on Climate Change (IPCC), strengthening adaptive capacity may require adjustments in behavior, as well as in resource and technology use. For each determinant, there may be room for improvement:

- Incorporate mitigation and adaptation measures into institutional framework
- Enhance the resiliency of City infrastructure
- Ensure a robust, underlying network of financial capital exists across all of Baltimore
- Educate and empower residents to increase their ability to avoid and respond to hazards
- Establish policy and procedures which support hazard mitigation and climate adaptation
- Support resident growth through educational and workforce training
- Establish an effective program for communicating hazard information
- Utilize technological tools to more accurately predict accurately vulnerability to hazards

Finally, although a considerable amount of attention is often focused on risks associated with climate change, it is important to think positively. Adaptive capacity can also help Baltimore and its residents take advantage of new opportunities or benefits that will arise because of climate change. This may be challenging to grasp. However, consider, for instance, the potential for a longer growing season that may present opportunities to cultivate new kinds of produce. Seeing climate change from both perspectives encourages flexibility and a greater propensity to adapt.