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# Baltimore County Climate Action Plan

## Resilience Assessment for General County Government Assets

April 21, 2021

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# List of Acronyms

| Abbreviation | Definition |
|---|---|
| ° C | Degrees Celsius |
| ° F | Degrees Fahrenheit |
| avg | Average |
| BMP | Best Management Practices |
| CDC | Centers for Disease Control |
| CDD | Cooling Degree Days |
| CIP | Capital Improvement Program |
| CMIP5 | Coupled Model Intercomparison Project Phase 5 |
| CS-CRAB | Coast Smart Climate Ready Action Boundary |
| Est | Estimate |
| FEMA | Federal Emergency Management Agency |
| ft | Feet |
| GCM | Global Circulation Model |
| GHG | Greenhouse Gas |
| GIS | Geographic Information System |
| GtC | Gigatons of Carbon |
| HDD | Heating Degree Days |
| HIFLD | Homeland Infrastructure Foundation-Level Data |
| HVAC | Heating Ventilation and Air Conditioning |
| IPCC | Intergovernmental Panel on Climate Change's |
| LOCA | Localized Constructed Analogs |
| MHHW | Mean Higher High Water |
| MSL | Mean Sea Level |
| NAVD | North American Vertical Datum |
| NCA4 | Fourth National Climate Assessment |
| NOAA | National Oceanic and Atmospheric Administration |
| NWS | National Weather Service |
| PMF | Probable Maximum Flood |
| RCP | Representative Concentration Pathways |
| RSLR | Relative Sea Level Rise |
| SFHA | Special Flood Hazard Area |
| SLOSH | Sea, Lake, and Overland Surges from Hurricanes |
| SLR | Sea Level Rise |
| SVI | Social Vulnerability Index |
| UMCES | University of Maryland Center for Environmental Science |
| W/m2 | Watts per square meter |
| Yr | Year |

# Executive Summary

The objective of this plan is to identify the range of future climate change for Baltimore County, assess potential impacts, and recommend adaptation options for improving County resilience for planning horizons of 2050 and 2080. The scope of this initial climate risk assessment was limited to County General Government facilities, property, and assets, which includes all County-owned facilities such as police, fire, public works, roads, social services, parks and recreation, libraries, etc. It is recognized that climate change has the potential to negatively affect a wider range of community assets in Baltimore County, including private property, neighborhoods, natural resources, and historical/cultural resources, among others. This assessment is the first step to establish the framework for assessing climate vulnerabilities and identify next steps to broaden the evaluation Countywide. The following summarizes the climate change projection recommendations, capital projects to address flood vulnerabilities at County-owned facilities, and the additional standards and procedures for consideration by the County.

## Future Climate Change Projections for Baltimore County

The plan included a review of relevant science-based literature related to observed and projected impacts from climate change. Current observations of temperatures, precipitation and sea level rise indicates that climate change has impacted the local environment in Baltimore County. Climate change modeling has shown that the effects will continue, and accelerate, in the coming decades.

To understand and predict how changes in greenhouse gases will affect the climate in Baltimore County, data from General Circulation Models, which are used to simulate the Earth's atmosphere and oceans, were compiled and analyzed. The data analysis focused on changes to temperatures, precipitation and sea level rise as the primary drivers of the local climate. Multiple future greenhouse gas scenarios (referred to as representative concentration pathways or RCPs) were reviewed, and RCP 4.5 was selected for County planning. RCP 4.5 is a mid-range scenario where emissions peak from 2040 to 2050 then stabilize and decline, resulting in stabilization of global temperatures before the end of the century

The National Oceanic and Atmospheric Administration has calculated that current global average temperatures are approximately 1.7°F (1° C) above the 20$^{th}$ century average. While daily weather fluctuations will continue to occur, the trend is continued warming through the end of the century. **The trends for all temperature projections are toward warmer temperatures and more frequent heat waves (Table E-1 and Table E-2).**

**Table E-1: Projected Extreme Heat Days (Maximum Daily Temperature above 95° F) for Baltimore County**

| Decade | Historical (avg days/year) | Projections (avg days/year) |
|---|---|---|
| 1996-2005 (Historical) | 2.8 (Historical range 0-9 days/year) | - |
| 2050 | - | 20.5 |
| 2080 | - | 25.9 |

**Table E-2: Projected Heating and Cooling Degree Days for Baltimore County**

| Decade | Cooling Degree Days in °F | Heating Degree Days in °F |
|---|---|---|
| 1996-2005 (Historical) | 600 | 2636 |
| 2050 | 971 (+371) | 2176 (-460) |
| 2080 | 1059 (+459) | 2061 (-575) |

Rising temperatures have multiple effects on the hydrologic cycle, which drives local rainfall. The relationships between temperatures and rainfall are complex, and more challenging to model than temperatures. However, the recent trend in precipitation throughout the region has been towards increased rainfall intensity, which is projected to continue into the future with warmer temperatures. **It is recommended the County adopt increased design storm precipitation rates, across all recurrence frequencies, to improve County resilience of drainage infrastructure (Table E-3).**

**Table E-3: Recommended Increase in Design Storm Precipitation**

| Decade | Percent Change |
|---|---|
| 2050 | +15% |
| 2080 | +30% |

Sea level rise (SLR) has been documented through measurements of tidal observations for over a century. The causes are attributed to melting polar ice and glaciers, expanding ocean mass from ocean warming, and shifts in ocean currents, which are all projected to continue with increasing air temperatures. The maximum range of potential SLR are as high as four to ten feet by the end of the century. **The recommended SLR estimate for resilience planning in Baltimore County is 1.6 feet by 2050 and 2.6 feet by 2080 (Table E-4). These projections are conservative, but reasonable, based on the *Sea-level Rise: Projections for Maryland 2018* report by the University of Maryland Center for Environmental Science.**

**Table E-4: Sea Level Rise Projections**

| Decade | SLR Projection | Average High Tide Elevation (NAVD 88) | Occasional Nuisance Tidal Flooding Elevation (NAVD 88) |
|---|---|---|---|
| 2020[1] | 0.45 feet | 1.3 feet | 3.1 feet |
| 2050 | 1.6 feet | 2.4 feet | 4.2 feet |
| 2080 | 2.6 feet | 3.4 feet | 5.2 feet |

Global greenhouse gas emissions, climate science and climate modeling continue to evolve. **Therefore, it is recommended that climate projections be revisited approximately every five years to capitalize on scientific developments and up-to-date emissions data, helping to ensure adequate planning is provided for future conditions.**

## Climate Vulnerabilities for Baltimore County

Climate change is expected to result in multiple impacts to Baltimore County facilities, and the services provided to its residents.

**Rising Temperatures**

- Warmer temperatures will increase cooling loads for buildings to maintain occupant comfort and protect sensitive electrical equipment.
- Public health impacts from more frequent and intense heat waves will increase demands on County services (e.g., emergency services, cooling centers, energy assistance programs, etc.).
- More frequent and intense heat waves will negatively impact the County's staff who work outdoors.
- Temperature changes may impact the County's natural resources, including forest health, cyanobacterial harmful algal bloom occurrence, and the health of temperature-sensitive species (e.g., trout).

**Storm events**

- More intense rainfall will reduce the level of service for developed storm drain networks currently in place.
- Precipitation from extreme storms will worsen flooding in vulnerable areas.
- Damages from extreme storms, such as downed trees, power outages and other impacts, may become more frequent.

**Sea Level Rise**

- SLR will worsen flooding in low-lying coastal areas from high tides and storm surges.
- SLR will reduce the capacity of storm drains that discharge to tidal waters. Higher tides and storm surges will be more likely flow up through storm drain networks.

[1] SLR projections in the scientific literature are based on change since 2000. Sea level observations were analyzed to estimate the amount of rise between 2000 and 2020.

A broad range of adaptation options were reviewed and compiled to address the impacts from changes to temperatures, precipitation and SLR. A catalog of adaptation options was developed that includes order-of-magnitude costs for use in resiliency planning.

The focus of the plan is asset level adaptation: however, in some instances, it is more efficient to implement strategies that are protective of the broader neighborhood or community. In coastal flood-prone areas, it may be more beneficial to explore larger coastal protection options (e.g., levies, floodwalls, beach nourishment, etc.) as opposed to individual asset adaptations (e.g., raising or floodproofing individual structures). The Adaptation Catalog includes adaptation options to be inclusive of these potential resiliency planning efforts beyond individual facilities.

### Infrastructure Project Recommendations to Reduce County Vulnerabilities

The following projects were identified as providing substantial benefits in terms of reducing vulnerability and expanding resilience.

- The following County-owned facilities were identified as being vulnerable to flooding. Conceptual level cost estimates for floodproofing construction are provided in present value from unit costs in the Adaptation Catalog. Refer to Appendix A.
    - Police Marine Unit – Review floodproofing options for the facility with the State of Maryland, which owns the property and buildings. The dock is owned by the County, and it is recommended the dock be upgraded to improve resilience to sea level rise and storm surge. Costs vary based on resilience needs.
    - Brooklandville Fire Department – Floodproofing is needed to protect the facility from damage from riverine flooding and raising the access road is needed to maintain operations during a flood event. Follow up building site surveys should be performed to confirm assumptions and identify all important features necessary for implementing flood adaptation. Estimated costs for floodproofing are $60,000 to $100,000. Estimated costs for raising approximately 800 feet of driveway are $600,000 to $1,800,000.
    - Watersedge Community Center – Floodproofing is needed to protect the facility from damage from storm surge flooding. Follow up building site surveys should be performed to confirm assumptions and identify all important features necessary for implementing flood adaptation. Estimated costs for floodproofing are $60,000 to $100,000.
    - Sollers Point Community Center– Floodproofing is recommended to protect the facility from damage from storm surge flooding. Follow up building site surveys should be performed to confirm assumptions and identify all important features necessary for implementing flood adaptation. Estimated costs for floodproofing are $100,000 to $180,000.
    - Northeast Regional Community Center – Floodproofing is recommended to protect the facility from damage from riverine flooding. Follow up building site surveys should be performed to confirm assumptions and identify all important features necessary for

implementing flood adaptation. Estimated costs for floodproofing are $100,000 to $180,000.

  - Sunnybrook Wells #7 and #9 – Floodproofing of the well and wellhouses is recommended to protect the facilities from damage from riverine flooding. Follow up building site surveys should be performed to confirm assumptions and identify all important features necessary for implementing flood adaptation. Estimated costs for floodproofing are $10,000 to $20,000.
  - Sanitary Sewer Pump Station floodproofing – Between this plan and the recently completed *Pump Station Resiliency Assessment,* a total of 55 pump stations were identified as having medium to high flood vulnerability. The *Pump Station Resiliency Assessment* was more detailed and reviewed as-built plans for 24 stations but did not develop cost estimates for resiliency improvements. Because of the number of stations, it is recommended that a recurring CIP budget be established to address the risks over time to improve overall system resilience. Stations should be prioritized for upgrades based on the rankings from the two assessments. Refer to Appendix F for pump station risk rankings. Cost varies per station based on individual resilience needs.

- Elevation certificates should be drafted or updated for County buildings located in or near FEMA Special Flood Hazard Areas (SFHA). Further, the County can expand this service to private property, which will support incentives and discounts through the National Flood Insurance Program. Costs vary.
- Continue to evaluate the need for stationary and portable backup power generation and the possibility of microgrids to support resilience for critical infrastructure from power outages. Expand the inventory of generators and/or develop microgrids, as necessary. Continue to install transfer switches at key facilities for rapid deployment of portable backup power. Cost varies per equipment sizing requirements and type.
- Evaluate the opportunities for upgrading HVAC systems to maintain efficiency as temperatures increase.
- Implement resiliency upgrades to raise road segments in the FEMA SFHA identified as the highest priority from the transportation analysis (Table E-5). It is further recommended to cross reference these roads with the County Fire Department's maps of roads to avoid during heavy rainfall, which may help further prioritize roads in need of improvement. Refer to Appendix J for a full list of roads identified. Cost varies per flood depth, length, cross streets, driveways and other features.

**Table E-5: Highest Ranked Roads from the Transportation Analysis of Baltimore County Roads in the Flood Zone**

| Roadway Name | Roadway Name |
|---|---|
| Leeds Ave | Windsor Mill Rd |
| Philadelphia Rd | Woodlawn Dr |
| Pulaski Hwy | York Rd |

- Conduct assessments of coastal flooding resiliency options for local neighborhoods (e.g., Turner Station, Bowley's Quarters, Swan Point, etc.). Estimated costs are $75,000 to $150,000 per assessment.
- Expand the Climate Action Plan to include community wide impacts, including historic/cultural resources, natural resources, public health, etc. Estimated costs are $75,000 to $150,000.
- Conduct detailed modeling analyses of local areas of the County at risk of flooding to incorporate future rainfall projections into flood zone extents. Further develop green infrastructure, surface conveyance and other adaptation options to improve local drainage. Costs vary.
- For flood vulnerability from impacted storm drain systems, as identified by submerged outfalls and historic streams, it is recommended that localized hydrologic and hydraulic modeling be conducted to confirm risk and for design of storm drain system improvements. Costs vary.
- It is recommended the County conducts modeling in small drainage basins (less than one square mile) at risk of inland flooding to augment the FEMA SFHA mapping and eliminate development in flood-prone areas. Costs vary.
- Evaluate revenue impacts from abandonment or buy-out of flood-prone properties. Estimated costs are $100,000 to $150,000.
- Conduct a site survey of structures at parks identified as being vulnerable to flooding and initiate projects to upgrade or relocate at risk facilities. Estimated costs are $100,000 to $200,000.

## Standards and Procedures Recommendations to Improve County Resilience

Updates to standards and procedures are needed in order to improve resiliency. As a matter of priority, development and redevelopment in vulnerable areas should be rapidly reduced as development-related County investments would become vulnerable to climate change impacts.

- The Decision Memorandum dated May 1, 2020 titled "County Flooded Property Purchase and Drainage Program Review" is incorporated by reference in the CAP. It is recommended the County implement all the recommendations from the memo as they would increase resiliency. Refer to Appendix B for the full memo.

- It is recommended that, going forward, all County codes, plans and ordinances acknowledge and address, as appropriate, climate change, sea level rise, flood vulnerability, extreme storms, and temperature increases.
    - County Master Plan and Community Plans
    - Land Preservation, Parks and Recreation Plan (2017)
    - Hazard Mitigation Plan (2015)
    - Small Watershed Action Plan(s)
    - Watershed Implementation Plans
    - Stormwater Management Regulations, Checklists, & Forms (2007 plus updates)
    - Comprehensive Manual on Design Policies (2008)
    - Local Open Space Manual (2000)
    - Landscape Manual (2000)
    - Community Plans
- It is recommended the County adopt the Maryland Coast Smart Climate Ready Action Boundary (CS-CRAB) for any new County facility. The CS-CRAB extends the coastal FEMA SFHA base flood elevation vertically by three feet, as well as inland. It is further recommended to review applicability of the CS-CRAB for private sector development through changes to the County flood plain regulations.
- The County flood plain regulations do not allow new development by right in riverine flood zones. It is recommended the County consider expanding these regulations to prohibit new construction in tidal flood zones. The goal would be to phase out and ultimately prohibit construction in vulnerable flood zones.
- Resilience should be incorporated into County review of critical privately-owned infrastructure (e.g., telecommunications towers).
- It is recommended that all County permits, reviews, and approvals incorporate flood risk and address flood resilience.
- It is recommended the County revise the criteria for CIP review to incorporate resilience metrics.
- It is recommended that standardized metrics be developed using the CDC Social Vulnerability Index, or other social equity data, to enable efficient integration of social equity considerations for planning and project selection.

In conclusion, there are relatively few County assets that were built in vulnerable locations that require adaptation for resilience. The County's sanitary sewer pump stations will require the most significant investment because of the number of facilities located in flood-prone areas. The County's vulnerable roads will also require significant investment to improve resilience to flooding. The expenditures needed to upgrade HVAC systems for County buildings, improve resiliency against power outages, and improve storm drain networks will also be substantial. Recognizing the risks, Baltimore County has been proactive and initiated efforts to identify and evaluate future climate change impacts on important County assets. The concerns, beyond County-owned facilities, are the neighborhoods and thousands of buildings that are, or will soon be, vulnerable to flooding, particularly in the coastal zone. Therefore, it is important to expand climate impact assessments beyond County-owned facilities to fully identify the scope and magnitude of potential impacts to the community in order to implement County-wide resiliency measures.

# 1. Introduction

Baltimore County is a diverse area with a variety of cultural and natural resources. At over 800,000 residents, it is one of the most populous counties in Maryland; it is also the third-largest county in land area. The County is located along the Mid-Atlantic fall line, which serves as the dividing line between the Coastal Plain and Piedmont physiographic provinces. As such, elevations range from sea level along the southern and southeastern sections of the County, rising to over 1,000 feet in the County's northwest corner.

While Baltimore County has a generally favorable climate, it is punctuated by occasional extreme weather events. Weather extremes can include flooding due to heavy rains from thunderstorms and hurricanes, coastal flooding from wind and high tides, extreme cold, heat waves, and high winds from tornadoes, hurricanes, and derechos. Climate change projections due to increasing concentrations of greenhouse gases (GHG) in the atmosphere indicate that these extreme events may increase in magnitude and frequency in the future. Climate change will exacerbate vulnerabilities from extreme events, which increases the need for well-informed planning and well-protected infrastructure. Recognizing the risks, Baltimore County has been proactive and initiated efforts to identify and evaluate future climate change impacts on important County assets.

The objective of this plan is to identify the range of future climate change for Baltimore County, assess potential impacts, and recommend adaptation options for improving resilience for County facilities and assets. The planning horizon for this plan is 2050 and 2080. To achieve the objectives, this plan includes a review of relevant science-based literature such as climate change plans, vulnerability assessments, scientific publications, and other documentation on projected impacts from climate change.

# 2. Climate Background

Weather is made up of the individual events that we can touch and feel, and climate is the expected range of weather patterns and weather events, summed cumulatively over a long period of time. Our climate is influenced by a number of geographic factors:

- Latitude
- Altitude
- Proximity to large features such as oceans, lakes, mountains and plains

***Weather is what we see and feel on any given day and climate is the expected range of weather.***

These geographic factors affect the local temperatures and atmospheric circulation patterns for wind, cloud cover, humidity, and precipitation. Baltimore County is located at the southern end of the humid continental and the northern end of the humid subtropical climate zones. Geographically, the County covers a transition zone between the two major climate subtypes. The local climate is characterized by four distinct seasons with large seasonal temperature differences: hot, humid summers and cold winters. Precipitation is relatively evenly distributed throughout the year with varying amounts of snowfall in the winter.

The principal force behind all of Earth's climate is the sun's radiation and the energy balance between how much energy is absorbed by the Earth versus energy reflected back into space. The climate cools when the energy balance is low (increased reflection) (e.g., leading to ice ages) and the climate warms when the energy balance is high (increased absorption). Increasing concentrations of heat-trapping gases in the atmosphere, referred to as greenhouse gases (Figure 2-1), have resulted in radiative forcing that is rapidly increasing the Earth's energy balance and leading to climate change (North, Pyle, & Zhang, 2014). Radiative forcing, measured as watts per square meter ($W/m^2$), has been increasing proportionally with GHG concentrations (Figure 2-2). As more energy is absorbed by the Earth, global temperatures increase, which drives other changes to climate and weather patterns. Currently, the Earth's energy balance is at a radiative forcing of approximately 3.0 $W/m^2$.

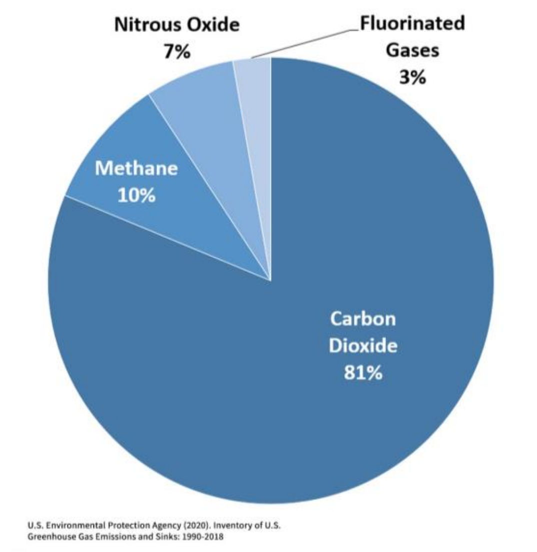



**Figure 2-1: Proportions of GHG Emissions in 2018 (USEPA, 2020b)**

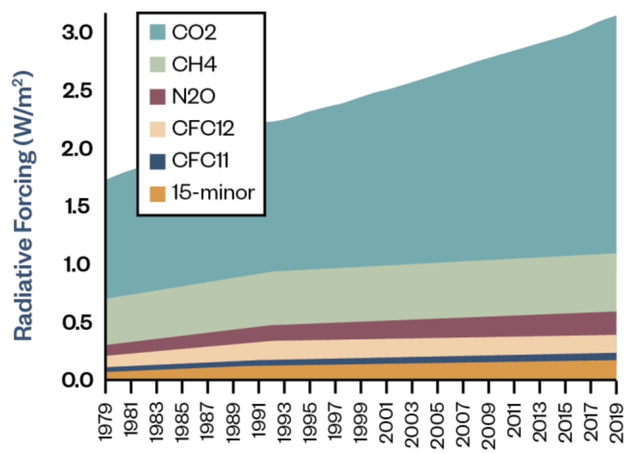



**Figure 2-2: Trends in Radiative Forcing from each type of GHG (NOAA, 2020a)**

To understand and predict how changes in radiative forcing will affect the climate, General Circulation Models (GCMs) are used to simulate the Earth's atmosphere and oceans, and the resulting weather patterns. Many research institutions around the globe have developed GCMs for analyzing global climate. These organizations frequently collaborate and compare data and modeling tools. In order to facilitate collaboration and comparison of models and results, the climate modeling community developed a set of future scenarios to serve as a common basis for climate change analyses. Referred to as Representative Concentration Pathways (RCP), these scenarios span the range of radiative forcing values through 2100 found in the peer-reviewed literature (e.g., 2.6 to 8.5 $W/m^2$) and are correlated with global GHG concentrations (Figure 2-3) (RCP Database, 2009; Van Vuuren et al, 2011).

- RCP 2.6 (i.e., radiative forcing of 2.6 $W/m^2$) corresponds to stabilization of emissions in the beginning of the century as proposed by the 2015 Paris Agreement. Note that this scenario requires a reduction below current levels of observed radiative forcing and is sometimes referred to as the aggressive GHG reduction scenario.

- RCP 4.5 emissions peak from 2040 to 2050 then stabilize and decline, resulting in stabilization of radiative forcing before the end of the century.
- RCP 6.0 emissions peak and decline around 2080, resulting in stabilization of radiative forcing after 2100.
- RCP 8.5 corresponds to growing emissions through the end of the century and a peak radiative forcing of 8.5 $W/m^2$ after 2100.

There is no assumption of likelihood in these scenarios because they are based on global decisions regarding GHG emissions. Review of projections for future climate changes for each RCP was conducted, and it was determined that RCP 2.6 may be overly optimistic given current radiative forcing levels and trends in GHG emissions. RCP 4.5 was selected as a reasonable, but conservative, scenario for Baltimore County planning.

Climate science and modeling is evolving at a rapid pace and world leaders continue to make decisions that affect GHG emissions. Therefore, it is necessary to revisit climate projections approximately every five years to capitalize on scientific developments and up-to-date emissions data, helping to ensure adequate planning is provided for future conditions.

The next section details the climate change projections for key parameters for Baltimore County.

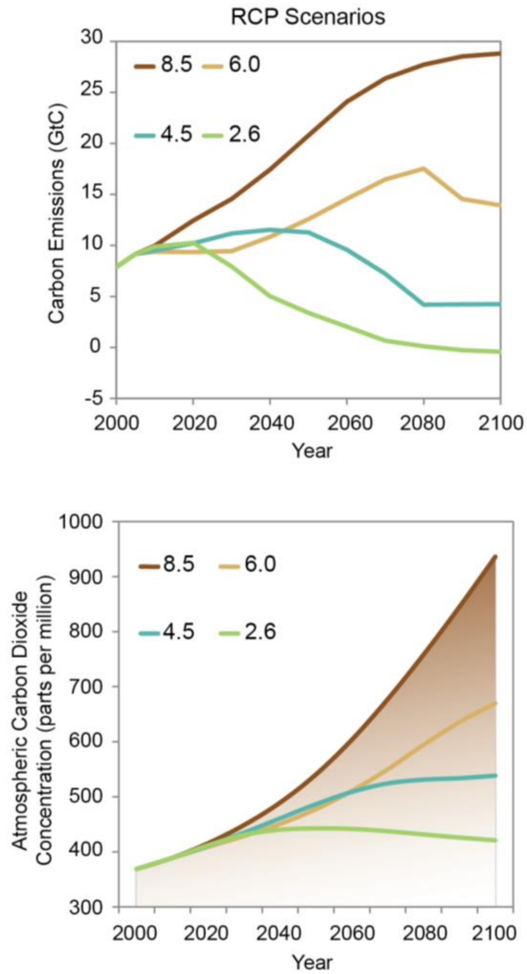



**Figure 2-3: Trends in Global GHG Emissions and Concentrations for four RCPs (Melillo, Richmond, & Yohe, 2014)**

## 3. Future Climate Change Projections for Baltimore County

Coastal areas are most directly affected by four natural responses to climate change: sea level rise, precipitation, temperature, and wind. Modeling at the local level is readily available for three of these factors: sea levels, precipitation and temperatures, and are the focus of impacts evaluated. There is limited modeling data available for local winds under climate change and are therefore not evaluated in this assessment. Further, current research is inconclusive as to the potential frequency and magnitude of hurricanes making landfall under future climate change (Wang, Liu, Lee, & Atlas, 2011; Hayhoe, 2018), hence no projections about hurricane impacts in Baltimore County were included in this assessment.[2]

Due to the variability of the climate system, scientists take the approach of presenting projections based on scenarios. The scenario approach provides a range of potential future conditions to account for the uncertainties in the climate system and future societal decisions related to managing GHGs. It is important to bear in mind that scenarios are not precise predictions of what will happen in the future but are trajectories of environmental change. These trajectories of environmental change are used to support vulnerability and risk assessments in order to develop a robust suite of adaptation options. Scenarios derived from GCMs provide guidance for directing specific adaptation strategies. Implementing adaptation for improved climate resilience is considered a no-regrets strategy because extreme weather events will continue to occur regardless of climate outcomes.


**The bulk of the impacts from climate change are felt at the local level. Many cities and counties are developing climate plans to be prepared for future conditions.**

The dataset used for future climate scenarios for Baltimore County are the Localized Constructed Analogs (LOCA) projections. The LOCA dataset was developed by various organizations including the Scripps Institution of Oceanography, U.S. Bureau of Reclamation, and the National Oceanic and Atmospheric Administration (NOAA). It provides statistically downscaled Coupled Model Intercomparison Project Phase 5 (CMIP5) climate projections for North America. CMIP5 is a set of thirty-five global climate models which served as a dataset for the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report. LOCA climate and hydrology projections are available for 32 of the CMIP5 models at a 1/16th degree spatial resolution (approximately a four mile by four mile area) and a daily temporal resolution up to the year 2100. Each of the models within the LOCA projection set contains multiple RCPs. The dataset also provides daily historical observations (1950 to 2005) for the chosen grid points for comparison. Relative humidity

[2] The Federal Emergency Management Agency (FEMA) flood elevations incorporates estimates for current storm surge and wind-driven wave heights. There is no data available to estimate how these storm-specific winds will change under climate change. This is consistent with the Maryland Coast Smart Construction Program, which is based on the FEMA flood elevations and does not use flood predictions from hurricane storm surge inundation maps (Maryland Department of Natural Resources, 2020).

projections are also available with the LOCA dataset and were used with the temperature projections to calculate the heat index.

## 3.1 Temperature

The additional radiative forcing from higher concentrations of GHGs in our atmosphere is having a direct effect on global average temperatures based on decades of observations (Figure 3-1). Currently, global average temperatures are approximately 1.7° F (1° C) above the 20th century average (NOAA, 2020b). As weather is variable, all areas of the planet do not experience the same level of warming across all seasons. While 2017 was the 4th warmest year on record globally, much of the US experienced abnormally cool temperatures in August (Figure 3-2). Despite consistent and increasing radiative forcing from GHGs, there will continue to be periods of cooler weather at the local level. For example, local cold weather temperature records still get broken, but these record lows are occurring less frequently than new high temperature records occurring in most areas of the world (USEPA, 2020a).

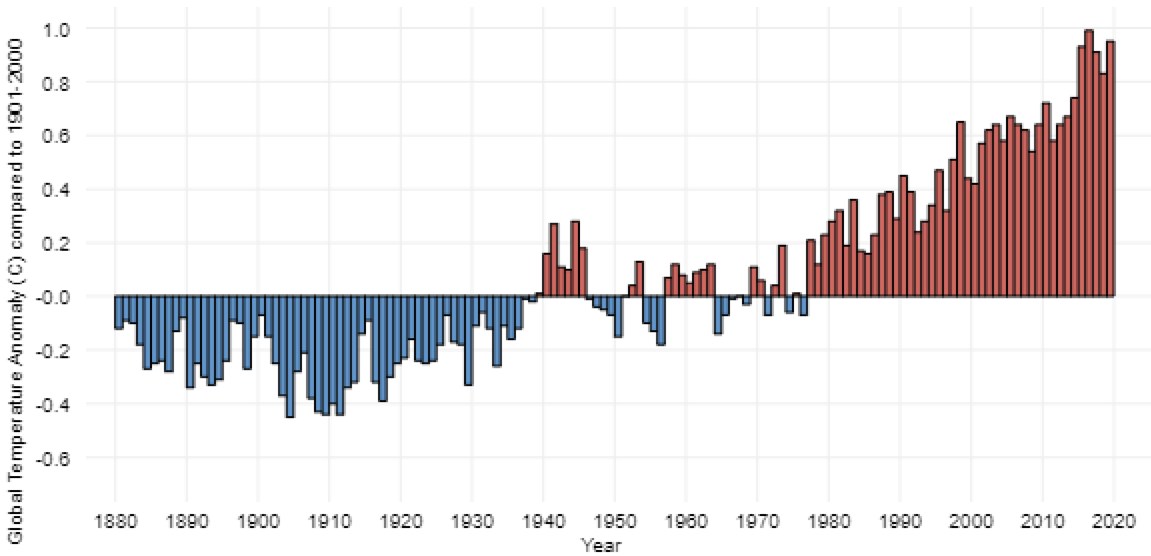



**Figure 3-1: Average Annual Temperature Difference compared to the 20th Century Average (NOAA, 2020b)**

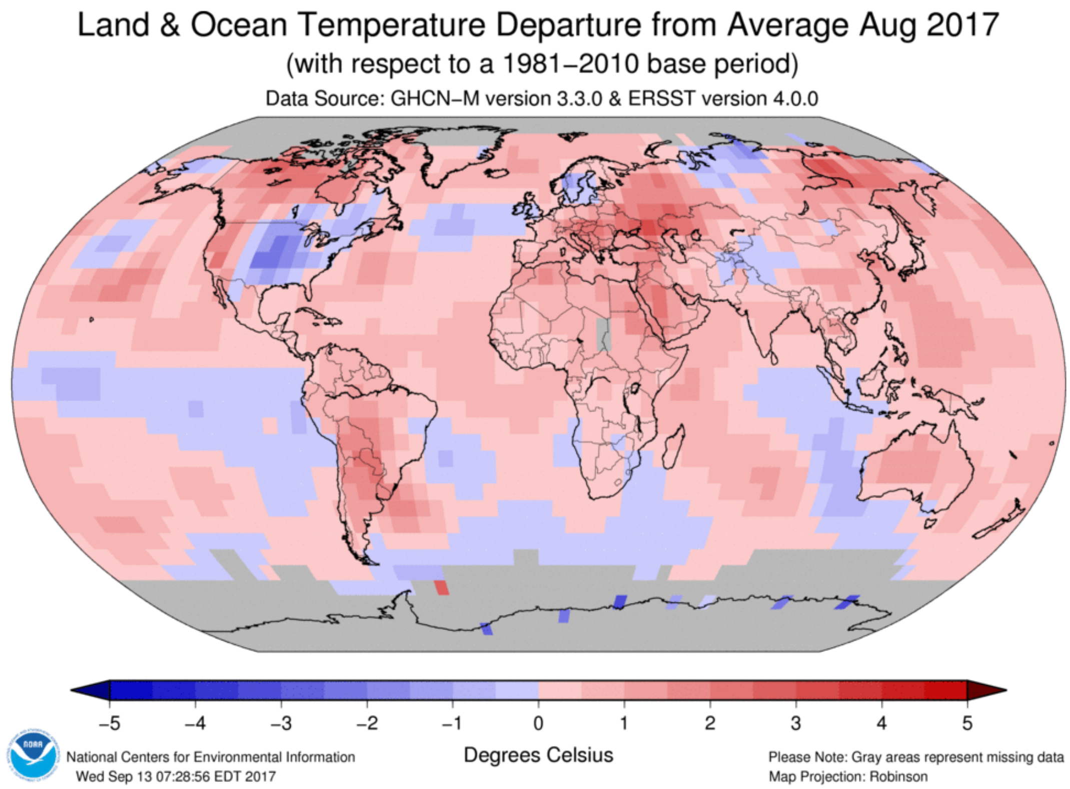



**Figure 3-2: August Global Temperature Anomaly (NOAA, 2017)**

Daily temperature data from the LOCA projection dataset were analyzed for Baltimore County to identify seasonal trends, extreme heat days (greater than 95° F), heat index, and heating and cooling degree days (HDDs and CDDs) for the future decades 2050 and 2080.

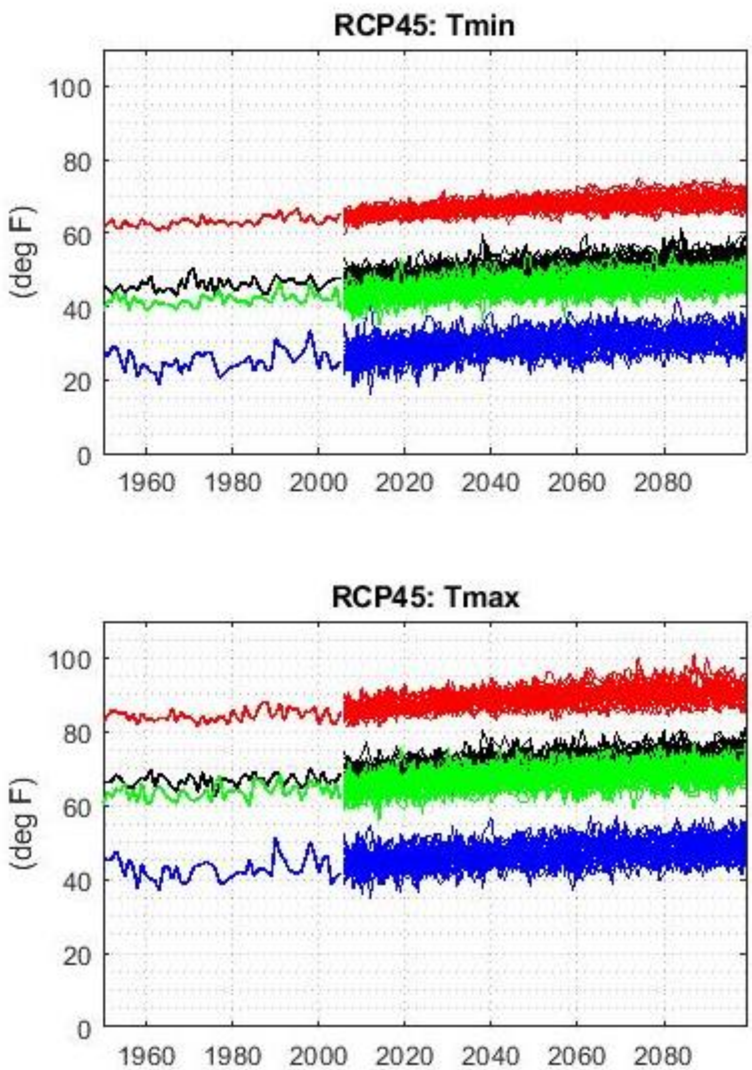



**Figure 3-3: Temperature projections by season in Baltimore County (Summer – red, Autumn – black, Spring – green, and Winter – blue). (Historical observations for 1950-2005 and projected temperature ranges from all 32 models within the LOCA dataset for 2006 to 2100.)**

Temperature trends exhibit a steady increase across all seasons for both daily high and low temperatures (Figure 3-3). Projections indicate daily variability that results in both high and low temperatures, but the average across all seasons is increasing temperatures (Table 3-1 and Figure 3-4).

**Table 3-1: Seasonal Average Temperature Changes for Baltimore County**

| Historical (1996-2005) | 2050 | 2080 |
|---|---|---|
| Summer | +4.8° F | +5.7° F |
| Fall | +4.3° F | +5.3° F |
| Winter | +3.5° F | +4.5° F |
| Spring | +3.8° F | +4.8° F |

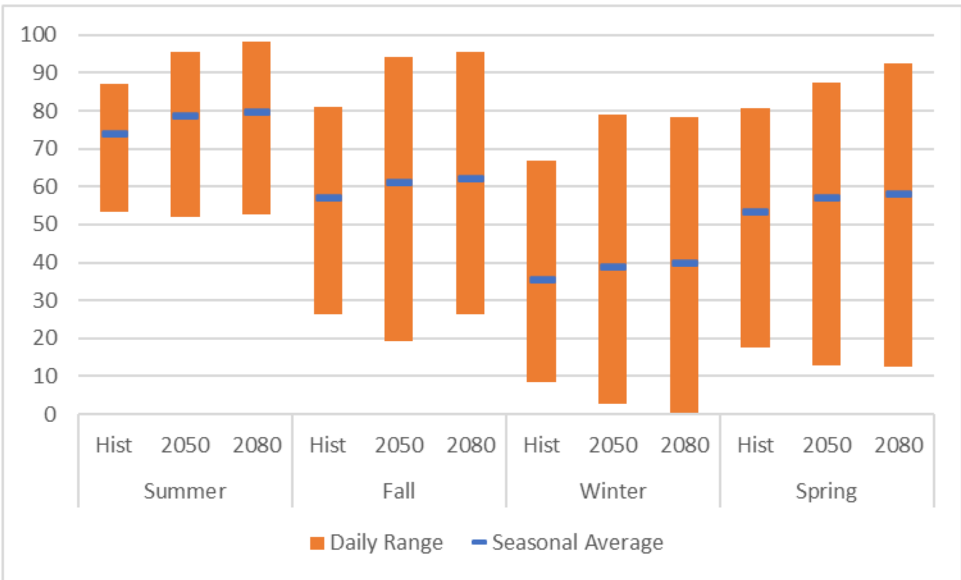



**Figure 3-4: Seasonal Average and Range of Temperatures (°F) for Baltimore County based on daily projections from 32 GCMs in the LOCA Dataset**

Extreme heat days have been defined as those on which the daily maximum temperature reaches 95° F or higher, which has been shown to result in a range of negative health effects (Maryland Department of Health and Mental Hygiene, 2016). The average number of extreme heat days per year for the 1996-2005 historical period was 2.8 days. This value increases to 20.5 days per year on average for the 2050s and reaches 25.9 days per year on average for the 2080s (Table 3-2). All of the scenarios across the 32 GCMs in the LOCA dataset exhibited increased extreme heat days over the 1996-2005 historical average.

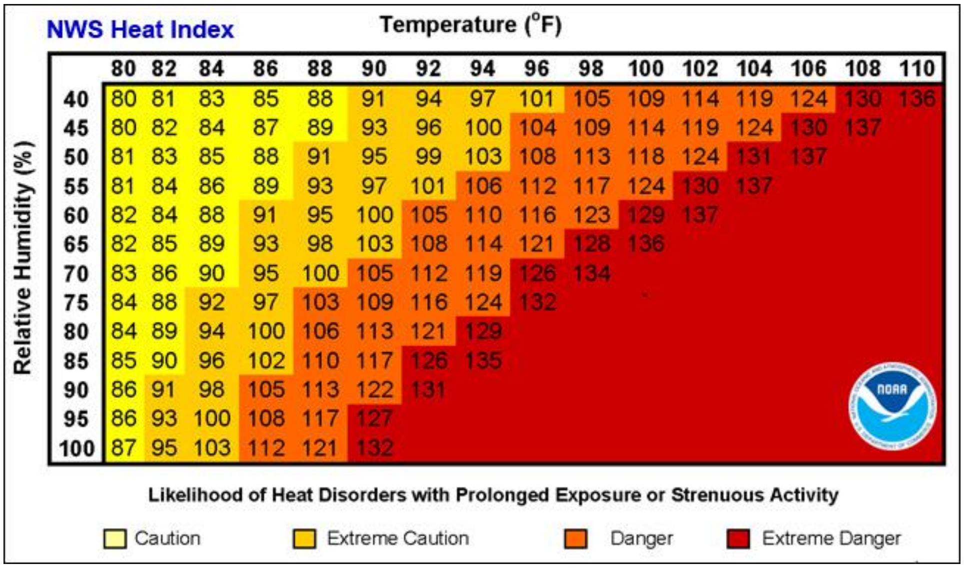
**Table 3-2: Projected Extreme Heat Days (Maximum Daily Temperature above 95° F) for Baltimore County**

| Decade | Historical (avg days/year) | RCP 4.5 Projections (avg days/year) |
|---|---|---|
| 1996-2005 (Historical) | 2.8 (Historical range 0-9 days/year) | - |
| 2050-2059 | - | 20.5 |
| 2080-2089 | - | 25.9 |

The National Weather Service (NWS) provides an equation for calculating the heat index based on the combination of daily temperatures and relative humidity values (NWS, 2020). The heat index resulting from the combination of temperature and humidity has the units of degrees Fahrenheit and can fall within four classifications depending on the risk it presents to people exposed to prolonged time outdoors (Table 3-3 and Figure 3-5). Similar to the calculation of extreme heat days, the average days per year falling under each risk category over the RCP 4.5 models for the 2050 and 2080 decades was calculated and compared to the average over the 1996-2005 decade of historical observations. In general, it was observed that the total number of days classified as Category 3 (Danger) or Category 4 (Extreme Danger) increases from 87 in the 1996-2006 decade to 109 and 111 in the 2050 and 2080 decades, respectively, which represents an increase of approximately 25% to 28%.

**Table 3-3: NWS Heat Index Risk Levels**

| Classification | Heat Index | Effect on the Body |
|---|---|---|
| Caution | 80° F - 90° F | Fatigue possible with prolonged exposure and/or physical activity |
| Extreme Caution | 90° F - 103° F | Heat stroke, heat cramps, or heat exhaustion possible with prolonged exposure and/or physical activity |
| Danger | 103° F - 124° F | Heat stroke, heat cramps, or heat exhaustion likely with prolonged exposure and/or physical activity |
| Extreme Danger | 125° F or higher | Heat stroke highly likely |



NWS Heat Index — Temperature (°F)

| Relative Humidity (%) | 80 | 82 | 84 | 86 | 88 | 90 | 92 | 94 | 96 | 98 | 100 | 102 | 104 | 106 | 108 | 110 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 40 | 80 | 81 | 83 | 85 | 88 | 91 | 94 | 97 | 101 | 105 | 109 | 114 | 119 | 124 | 130 | 136 |
| 45 | 80 | 82 | 84 | 87 | 89 | 93 | 96 | 100 | 104 | 109 | 114 | 119 | 124 | 130 | 137 | |
| 50 | 81 | 83 | 85 | 88 | 91 | 95 | 99 | 103 | 108 | 113 | 118 | 124 | 131 | 137 | | |
| 55 | 81 | 84 | 86 | 89 | 93 | 97 | 101 | 106 | 112 | 117 | 124 | 130 | 137 | | | |
| 60 | 82 | 84 | 88 | 91 | 95 | 100 | 105 | 110 | 116 | 123 | 129 | 137 | | | | |
| 65 | 82 | 85 | 89 | 93 | 98 | 103 | 108 | 114 | 121 | 128 | 136 | | | | | |
| 70 | 83 | 86 | 90 | 95 | 100 | 105 | 112 | 119 | 126 | 134 | | | | | | |
| 75 | 84 | 88 | 92 | 97 | 103 | 109 | 116 | 124 | 132 | | | | | | | |
| 80 | 84 | 89 | 94 | 100 | 106 | 113 | 121 | 129 | | | | | | | | |
| 85 | 85 | 90 | 96 | 102 | 110 | 117 | 126 | 135 | | | | | | | | |
| 90 | 86 | 91 | 98 | 105 | 113 | 122 | 131 | | | | | | | | | |
| 95 | 86 | 93 | 100 | 108 | 117 | 127 | | | | | | | | | | |
| 100 | 87 | 95 | 103 | 112 | 121 | 132 | | | | | | | | | | |

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution · Extreme Caution · Danger · Extreme Danger

**Figure 3-5: NWS Heat Index Chart**

Heating and Cooling Degree Days can be used to assess the potential seasonal energy usage for heating (HDD) and cooling (CDD), as well as to size Heating Ventilation and Air Conditioning (HVAC) equipment. Both are derived from the daily difference between the outside temperature and a theoretical optimum indoor temperature of 65° F at which neither heating nor cooling is required in a building. Upon subtracting the base temperature, negative values are summed up for a given year and designated as HDDs, which is an estimate of the degrees of heating a building will have to account for in a given year of occupancy. Similarly, positive values are summed up for a year and designated as CDDs, which is an estimate of the degrees of cooling a building will have to account for in a given year of occupancy.

As in previous calculations, the HDDs and CDDs were calculated for each of the RCP 4.5 models as an average over the 2050 and 2080 decades. The average for the models was then compared to the average for the 1996-2005 decade of historical observations (Table 3-4). For HDDs, the average annual degree days were 2176 and 2061 for the 2050 and 2080 decade, respectively. In comparison, the average annual HDDs for the historical period was 2,635. For CDDs, the average annual degree days were 971 and 1059 for the 2050 and 2080 decade, respectively. In comparison, the average annual HDDs for the historical period was 600. While there is a net reduction in total CDDs and HDDs expected in the future, the impact of changing energy usage on GHG emissions is dependent on the type and efficiency of HVAC equipment and on the use of passive building design elements that reduce the overall heating and cooling loads.[3] Another consideration would be the need to modify HVAC equipment to account for additional cooling loads in the summer.

[3] Passive design in buildings is one approach to improving building resilience to future climate change.

**Table 3-4: Projected Heating and Cooling Degree Days for Baltimore County**

| Decade | Cooling Degree Days in °F | Heating Degree Days in °F |
|---|---|---|
| 1996-2005 (Historical) | 600 | 2636 |
| RCP 4.5 2050-2059 | 971 (+371) | 2176 (-460) |
| RCP 4.5 2080-2089 | 1059 (+459) | 2061 (-575) |

## 3.2 Precipitation

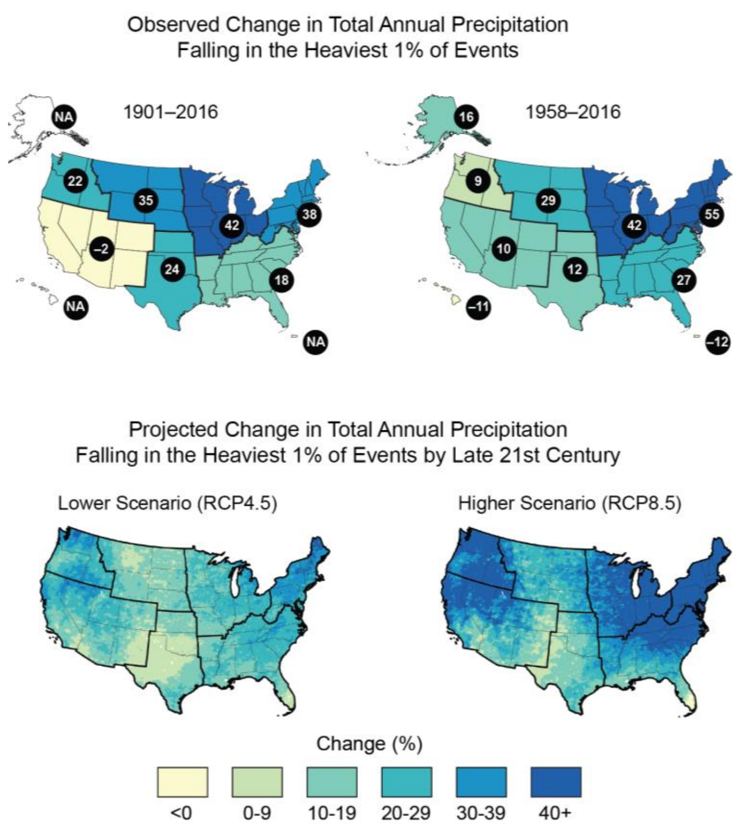



**Figure 3-6: Observed and Projected Change in Heavy Precipitation (Hayhoe et al, 2018)**

Rising temperatures have multiple effects on the hydrologic cycle, which drives local rainfall. The relationships between temperatures and rainfall are complex, which results in higher levels of uncertainty compared to the climate projections for temperature. Overall, higher temperatures are believed to intensify the Earth's water cycle. Higher temperatures increase rates of evaporation and increase the atmosphere's holding capacity for water vapor. Higher temperatures and moisture levels in the atmosphere result in greater atmospheric instability and in more frequent intense storms (Kunkel et al, 2013; Martel, Mailhot, & Brissette, 2020). However, higher temperatures can also result in drought conditions by shifting storm tracks and increasing evaporation over land areas. As a result, storm-prone areas are likely to experience increases in precipitation, while arid areas are likely to experience less precipitation and increased drought (Figure 3-6) (Hayhoe et al, 2018). It should be noted, however, areas that experience a decrease in average rainfall, could still experience extreme rainfall events.

In addition to flooding, extreme precipitation can mobilize pollutants and cause erosion, which can increase pollutant loads to rivers and streams. Other changes to the hydrologic cycle include fewer snow events due to higher temperatures.

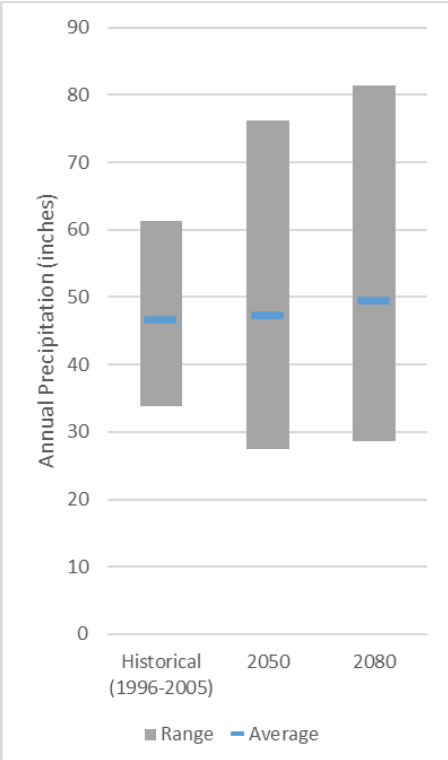



**Figure 3-7: Average and Range of Projected Precipitation**

For purposes of analyzing precipitation trends, the frequency of extreme precipitation events and the mean daily value for each of the RCP 4.5 scenarios were compiled, targeting the 2050 and 2080 decades.

Average annual precipitation is not expected to change significantly based on local projections, but the interannual variability is expected to increase substantially (Figure 3-7). In lay terms, that means that the same average precipitation is projected to derive from years of more extreme weather: with periods through the year that are as much as 10% drier and 15% wetter, for example. The average days per year with precipitation above 1 inch and 2 inches were analyzed over the 2050s decade and the 2080s decade. These were compared to the average days per year with precipitation above 1 inch and 2 inches for the 1996-2005 decade of historical observations. Table 3-5 shows an increasing trend in days per year for each of the two instances, as shown in Figure 3-8.

In addition to calculating general precipitation trends, a frequency analysis was conducted to compare the expected magnitude of 10, 50, and 100-year 24-hour storm events (from representative models of the LOCA dataset) to those derived from historical observations. The Generalized Extreme Value and Log-Pearson Type III methods were used to determine the 24-hour precipitation event corresponding to each recurrence interval (Hosking and Wallis, 1997; Singh, 2013).

**Table 3-5: Precipitation Trends for Baltimore County (mean of the 32 available RCP 4.5 models)**

| Decade | Precipitation Above 1 Inch (avg days/yr) | Precipitation Above 2 Inches (avg days/yr) |
|---|---|---|
| 1996-2005 (Historical) | 6.2 | 0.60 |
| 2050s | 6.8 | 0.84 |
| 2080s | 7.7 | 0.94 |

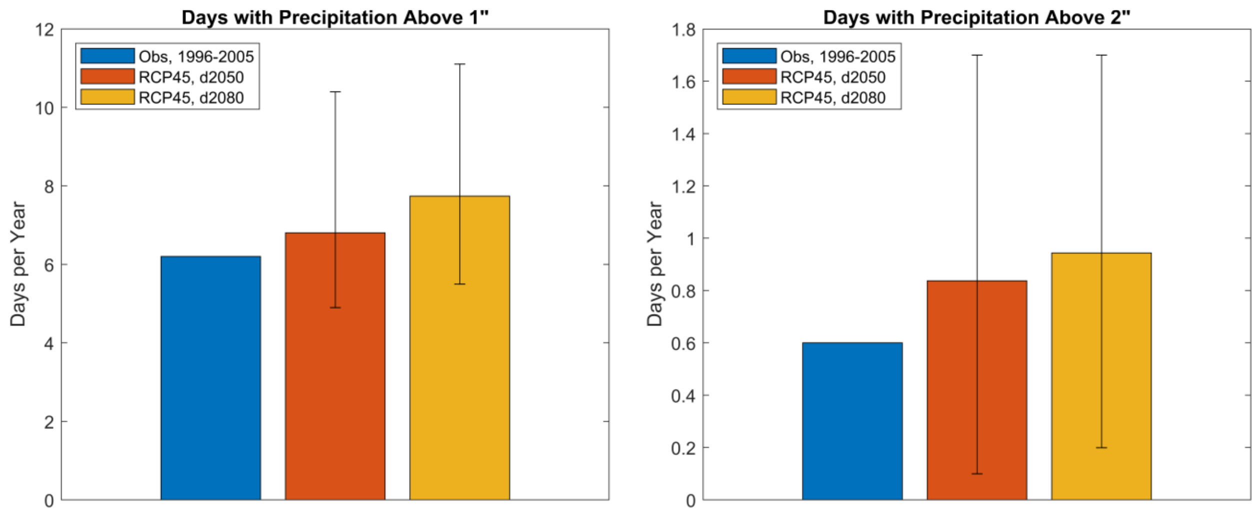



**Figure 3-8: Projections for precipitation intensity in Baltimore County. The bars show the average value over the models in the projections set. The error bar shows the variability in values in the projection set.**

As shown in Table 3-6 and Table 3-7, the high-bound model results showed a significant increase in precipitation intensity compared to recent historical trends, and the lower-bound model from the LOCA projection set showed generally reduced intensity of storm events compared to historical data. This tells us that there is wide uncertainty in extreme precipitation modeled from the GCMs. However, the recent trend in precipitation throughout the region has been towards increased rainfall intensity, which is projected to continue into the future with warmer temperatures (Thibeault and Seth, 2014; Easterling et al, 2017). Understanding the limitations of the GCMs for this type of analysis, it is recommended that future potential increases in extreme precipitation be accounted for in Baltimore County. **A 15% increase in design storm precipitation, across all recurrence frequencies, is recommended for the 2050s, and a 30% increase recommended for the 2080s.**

**Table 3-6: Precipitation Intensity Analysis for 10, 50, and 100-year 24-hour Storm Events in Baltimore County, MD for 2050**

| Recurrence Interval (year) | 2050, Low | 2050, High |
|---|---|---|
| 10 | -2% | 26% |
| 50 | -9% | 44% |
| 100 | -12% | 52% |

**Table 3-7: Precipitation Intensity Analysis for 10, 50, and 100-year 24-hour Storm Events in Baltimore County, MD for 2080**

| Recurrence Interval (year) | 2080, Low | 2080, High |
|---|---|---|
| 10 | 15% | 40% |
| 50 | -3% | 63% |
| 100 | -11% | 74% |

## 3.3 Sea Levels

*SLR poses a risk to coastal infrastructure and resident safety by increasing the chances of flooding from high tides and storm surge.*

Sea level rise (SLR) has been documented through measurements of tidal elevations over many years (Figure 3-9). The causes of sea level rise are attributed to melting polar ice and glaciers, expanding ocean mass from ocean warming, and shifts in ocean currents (Figure 3-10) (Boesch et al, 2018). The long-term average SLR for the NOAA tide gauge in Baltimore (8574680) is approximately one foot per century based on data extending back to 1900. **However, evaluation of recent data indicates that SLR is accelerating; the rate of SLR for Baltimore over the last 20 years is approximately two times the long-term average.** This finding is consistent with nearly all SLR projections, which show an acceleration of SLR driven by continued atmospheric warming and the subsequent increased rate of polar ice melt and ocean expansion.

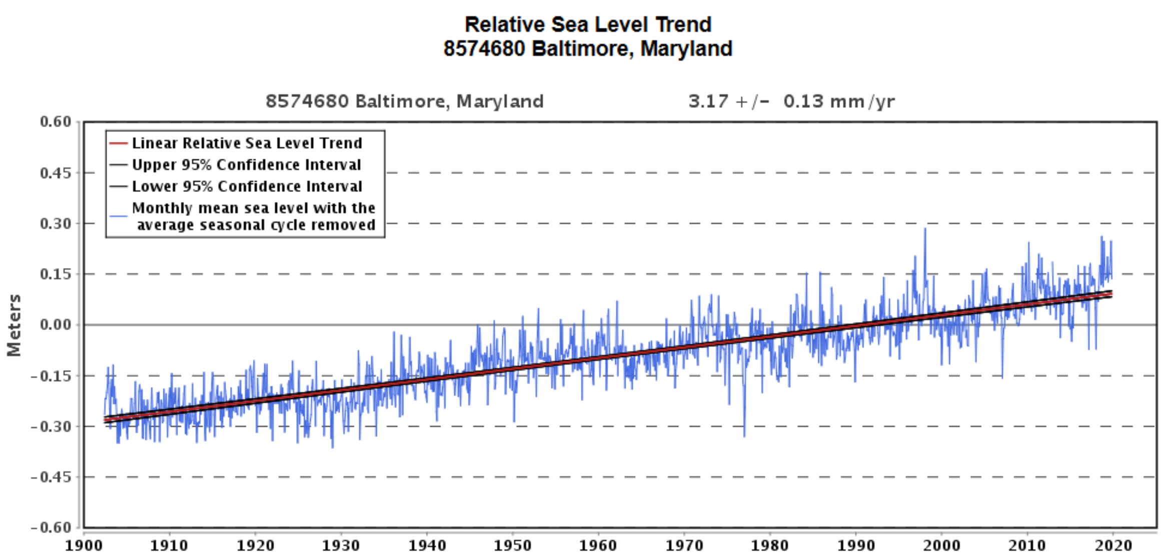



**Figure 3-9: Relative Sea Level Rise (RSLR) Trend, Baltimore, MD**

There is strong evidence that the rate of sea level rise will continue to increase. The ocean has absorbed the majority of the increased radiative forcing, which has led to increased levels of ocean heat content (NOAA, 2020c). Reduced sea ice cover reduces the reflectivity of the oceans, further increasing absorption of solar radiation. This continued rise in heat content will drive more rapid thermal expansion and sea ice melt. Similar feedback mechanisms will drive melting ice sheets and glaciers over the land surface (Ryan et al, 2019).

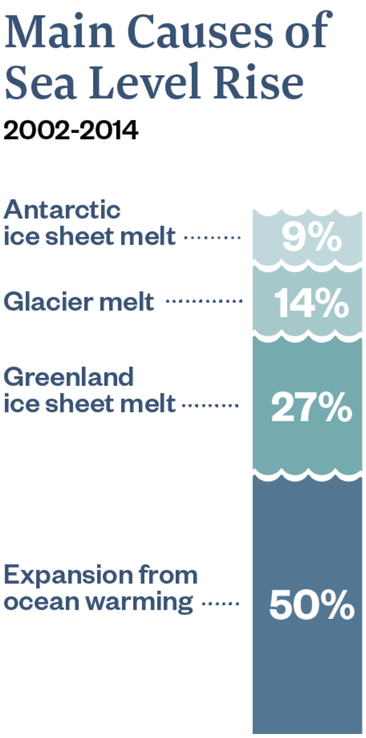



**Figure 3-10: Causes of Sea Level Rise**

The LOCA dataset described previously only included atmospheric weather data. To estimate future sea levels in 2050 and 2080, SLR projection datasets were reviewed and compared. The primary SLR projection data considered were from the reports *Sea-level Rise: Projections for Maryland 2018* and the 2017 NOAA *Global and Regional Sea Level Rise Scenarios for the United States* Technical Report NOS CO-OPS 083.

The Maryland 2018 report was developed by the University of Maryland Center for Environmental Science (UMCES), which is mandated by the Maryland Commission on Climate Change Act of 2015 to provide a set of sea-level rise projections every five years. The basis for the projections in the report are referred to as the K14[4] and DP16[5] projections. The DP16 projections were used up to the year 2050 and the K14 projections were used thereafter.

The 2017 NOAA report presented an updated set of mean sea level (MSL) scenarios, which were an important input to the 2018 Fourth National Climate Assessment (NCA4). The development process involved an assessment of the most up-to-date scientific literature on research-supported upper-end MSL projections, including recent observational and modeling literature related to the potential for rapid ice melt in Greenland and Antarctica. (DeConto and Pollard 2016, Nature)

Plots comparing the projection ranges of SLR from a 1992 base year[6] at the Baltimore, MD, tide gage are presented in Figure 3-11 and Figure 3-12. These plots illustrate the wide range of potential future SLR projections due to high uncertainty of the climate system.

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[4] The K14 SLR projection set models ice sheets, glacier and ice caps, oceanographic processes, land water storage, glacial isostatic adjustment, tectonics, and other non-climatic local effects. (Kopp et al, 2014)

[5] The DP16 SLR projections set is a refined analysis built off past assessments from the IPCC Fifth Assessment Report and includes a more modern understanding of Antarctic ice-sheet physics. (Kopp et al, 2017)

[6] Relative sea level rise is the change since a baseline year. Many studies use a baseline of 1992. The Maryland 2018 projections are based off 2000 and were adjusted to 1992 for plotting.

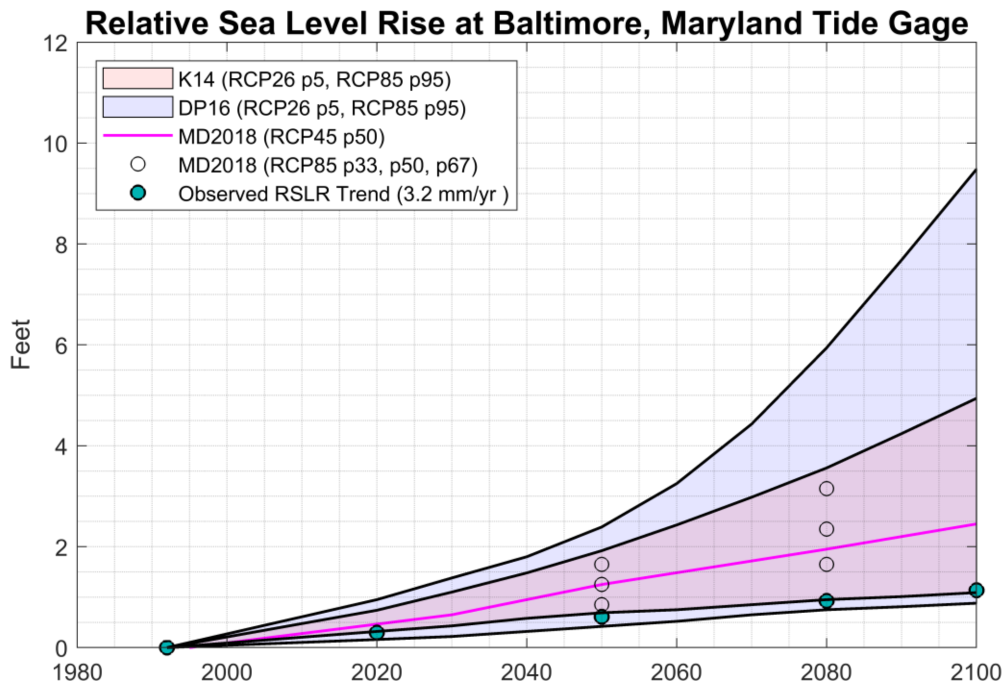


**Figure 3-11: Future Projections for RSLR for Baltimore, MD, depicting projections from K14, DP16, Maryland 2018 Report, and current linear trend**

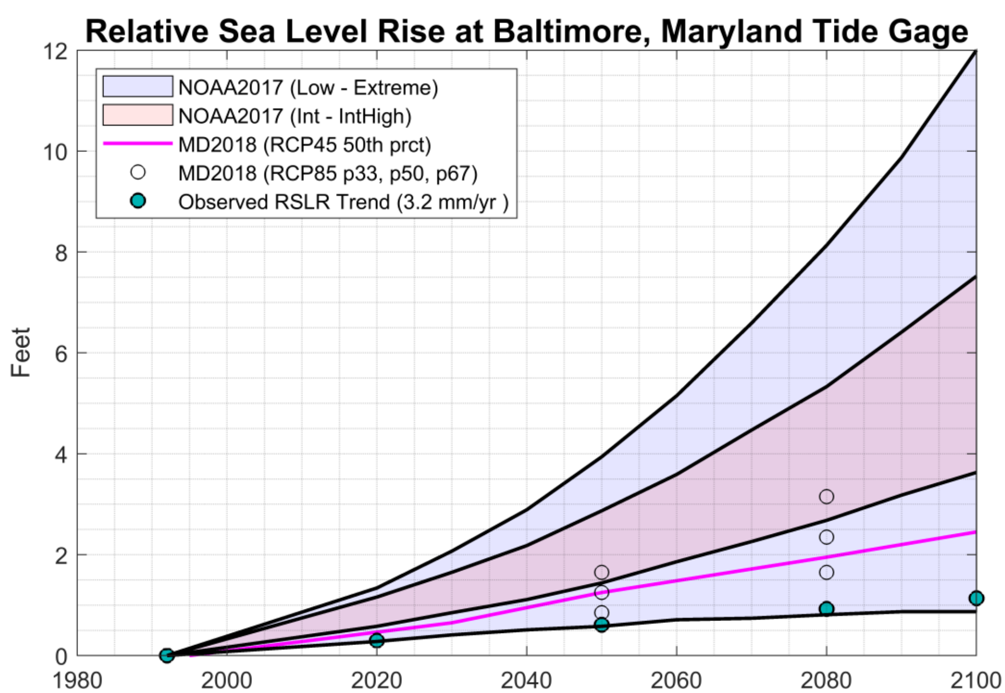


**Figure 3-12: Future Projections of RSLR for Baltimore, MD, depicting projections from NOAA 2017 Report, Maryland 2018 Report, and current linear trend**

A summary of the Maryland 2018 projection set for RCP 4.5 in 2050 and 2080 is shown in Table 3-8. The State of Maryland has not adopted an "official" projection to be used for SLR assessments in the state. The Maryland Department of Transportation Climate Change Vulnerability Viewer uses the 1% probability from the UMCES projections. The *Maryland Nuisance Flood Plan Development Guidance* (2019) indicates it is up to the community to determine thresholds for nuisance flooding. Based on available projections, it was decided to select the reasonable, yet conservative, values from those developed for the State of Maryland as the planning level for SLR for Baltimore County. **The upper end of the Likely Range for SLR shown in Table 3-8 (1.6 feet for 2050 and 2.6 feet for 2080) were selected as a planning level for Baltimore County.** Because UMCES will be updating the estimates every five years, it is recommended that Baltimore County review and update its planning projections based on these forthcoming values.

**Table 3-8: Maryland 2018 Projections for Sea Level Rise for RCP 4.5 in 2050 and 2080 (Baltimore County recommendations shown in bold)**

| Year | **Central Estimate** 50% probability SLR meets or exceeds: | **Likely Range** 67% probability lower range: | **Likely Range** 67% probability upper range: | **1 in 20 Chance** 5% probability SLR meets or exceeds: | **1 in 100 Chance** 1% probability SLR meets or exceeds: |
|---|---|---|---|---|---|
| 2050 | 1.2 ft | 0.8 ft | **1.6 ft** | 2.0 ft | 2.3 ft |
| 2080 | 1.9 ft | 1.3 ft | **2.6 ft** | 3.2 ft | 4.1 ft |

# 4. Climate Change Impacts and Adaptation Options for Baltimore County

Climate change has the potential to negatively affect a wide range of community assets in Baltimore County including buildings, infrastructure, natural resources, and historical/cultural resources, as well as the services those resources and infrastructure provide. The scope of this initial climate risk assessment was limited to County General Government facilities and assets, which includes all County-owned facilities such as police, fire,[7] public works, roads, social services, parks and recreation, libraries, etc. The following provides a summary assessment of the potential impacts and adaptation options available to the County to improve resilience for County facilities and assets.

## 4.1 Extreme Temperatures

For Baltimore County's built infrastructure, the primary consequence of higher temperatures is increased cooling loads for buildings to maintain occupant comfort and to protect sensitive electrical equipment. For new construction, building codes and standards reference recent climate data and maps for designing HVAC equipment. Further, codes such as the International Energy Conservation Code, which is included

[7] The County is not responsible for Volunteer Fire Department facilities, which are owned by individual volunteer fire companies.

in Baltimore County's building code, includes a focus on passive design elements to enable buildings to withstand more extremes in temperatures, as well as being more resilient in case of power outages.

While mechanical systems are generally designed to handle the majority of temperatures throughout the year; there is an understanding, which is included in the standard, there will be periods that are more extreme and may be outside the ability of the mechanical systems. It is generally considered that the potential for occasional less-than-ideal indoor comfort is an appropriate exchange for right-sizing equipment that will be more efficient and waste less energy the rest of the year.

The challenge is for existing buildings that were designed under different climate conditions. When a building is originally designed, all of the systems are designed to work together to operate efficiently for the climate in which it is located. It is not uncommon in older buildings where a system is upgraded with a more efficient one to develop an issue somewhere else in the building, because the systems are no longer working together (Heinking and Zussman, 2019). In newer buildings, automation systems are in place to manage multiple systems serving multiple areas/space utilizations within facilities. As building systems are upgraded, it is recommended that the performance of all building systems be evaluated together with the expected climate over the useful life of the equipment. Many County buildings are historical and will require system upgrades that will need to be consistent with the type of construction and compliant with regulations for designated structures. The goal is to provide robust performance without creating unanticipated issues for the building or occupant comfort.

Extreme heat is expected to result in other impacts to the County beyond its built environment, such as outdoor workers, County residents and natural resources. Extreme heat is expected to disproportionately affect sensitive and vulnerable populations in the County, which may put additional demands on existing services (e.g., emergency services, cooling centers, energy assistance programs, etc.). Extreme heat and climate change can also negatively impact natural resources in a variety of ways, including tree mortality, increased prevalence of toxic cyanobacteria blooms and impacts to temperature-sensitive species such as trout. It is recommended that Baltimore County conduct follow-on evaluations to quantify potential climate impacts to County residents and natural resources to plan for and implement resilience measures.

## 4.2 Extreme Storms

Extreme storms are most typically associated with high winds and flooding that damage infrastructure and impact public safety. Power outages are a common vulnerability from extreme storms. Resilience to power outages can be accomplished by installing backup power generators and/or implementing microgrids. Many existing critical facilities in the County (e.g., fire stations, pump stations, communications towers, etc.) are currently equipped with permanent backup generators. The County also has a number of portable generators and a contract for on-demand backup power with an outside vendor.[8] The County is installing transfer switches at key buildings, such as community centers, that may be needed during an emergency to facilitate a quicker switch to backup power.[9] As an alternative to

[8] The Baltimore County Property Management Division and Office of Homeland Security and Emergency Management has compiled a list of current generator/backup power available for emergency use.

[9] Upgrading buildings with transfer switches saves time when connecting portable backup power during emergencies.

traditional backup power, the County is also examining the feasibility of a microgrid for the Towson complex.[10] Implementation of a microgrid would enable electricity to be supplied in the event of a problem with the generation or transmission of electricity from the larger grid. This would provide resilience and redundancy for electricity needs at critical facilities within the grid and may preclude the need for backup power generators.

Extreme storms also bring heavy runoff that must be safely conveyed to and through local waterways to prevent localized flooding, erosion and other impacts. This section describes the climate impacts from extreme precipitation, refer to section 4.3 Flooding for a detailed discussion on flooding. This evaluation did not include a modeling analysis of the County's developed storm drain system. However, increased frequency of heavy precipitation is projected to stress existing capacity of the storm drain systems, which are typically designed to convey the 10- to 20-year storm. Further, the capacity of storm drain systems can become reduced over time due to the buildup of debris, which will exacerbate capacity issues. Some of the County's storm drain infrastructure, installed in the 1950s and 1960s. is at the end of its useful life and requires rehabilitation or replacement. Increasing the capacity of existing storm drain systems is costly and disruptive. An alternative approach would be to install vegetated best management practices (BMPs), such as green infrastructure, that reduce or slow runoff during storm events. Further, surface drainage through grassy or vegetated swales can convey larger volumes more cost-effectively than buried pipes. Heavy rains from extreme storms can also wash high loads of sediment, nutrients and other pollutants into local waterways. Green infrastructure practices slow runoff and allows for infiltration and for nutrient capture by plants and the soil.

<u>Storm Drain Microhydro Applications</u>

Microhydro has been used for electricity generation using in-line turbines in drinking water networks (Casini, 2015). This same technology could potentially be used to capitalize on large flows through storm drains. An engineering analysis would need to be conducted to identify the feasibility of storm drain microhydro using similar technology. The benefits could be an additional source of renewable electricity and a source of revenue for the County.

***Green infrastructure can help extend the level of service of existing buried drainage systems.***

While upsizing storm drains to handle more capacity may be an attractive fix, particularly for new development, direct discharge to streams contributes to channel erosion and water quality impairments. Further, piped drainage systems lose capacity over time as debris builds up and the pipes age. Baltimore County's policy is shifting away from bigger pipes and towards green infrastructure and surface drainage. This shift in policy was articulated in a County Decision Memorandum dated May 20, 2020 that included recommendations to foster green infrastructure and update the 2010 Department of Public Works Design Manual. Refer to Appendix B for a copy of the memo. These recommendations from the memo are consistent with good practices to improve resilience of the storm drain system under climate change. Many older neighborhoods were originally built with open channel swales to convey stormwater, but many of these have become blocked with fences, sheds,

[10] A microgrid is a small network of electricity users with a local source of supply that is usually attached to a centralized national grid but is able to function independently.

landscaping and other impediments to flow. This significantly contributes to local flooding. In coastal areas, surface drainage makes the best use of flat slopes and low elevations to direct water away from structures. Rehabilitating existing drainageways and constructing new surface drainage channels can provide added resilience and reduce flooding associated with drainage problems in some areas of the County.

For future design and modeling considerations, Table 4-1 to Table 4-3 present the range of potential precipitation intensities for storm drain design based on existing and projected changes in the future. Table 4-1 is reproduced from the 2010 Baltimore County Public Works Design Manual Plate DA-5, which shows the rainfall intensity based on rainfall duration at annual frequencies. Table 4-2 and Table 4-3 present the data increased based on precipitation projections for 2050 (15%) and 2080 (30%).[11] Most municipalities have elected not to update design standards based on new precipitation data or climate change projections. However, cities such as New York, Boston, and Virginia Beach have published projections as guidance for resilient new construction.

**Table 4-1: Precipitation Frequency Estimates (rainfall intensity in inches/hour) per the Baltimore County Public Works Design Manual, 2010 Plate DA-5**

| | Frequency (Years) | | | | | | |
|---|---|---|---|---|---|---|---|
| **Duration (min)** | **2** | **5** | **10** | **20** | **25** | **50** | **100** |
| 5 | 5.0 | 6.0 | 6.7 | 7.3 | 7.6 | 8.2 | 8.8 |
| 10 | 4.0 | 4.8 | 5.3 | 5.8 | 6.0 | 6.5 | 7.0 |
| 15 | 3.4 | 4.0 | 4.5 | 4.9 | 5.1 | 5.5 | 5.9 |
| 20 | 3.0 | 3.6 | 4.0 | 4.4 | 4.5 | 4.9 | 5.3 |
| 30 | 2.3 | 2.9 | 3.3 | 3.6 | 3.8 | 4.1 | 4.5 |
| 60 | 1.5 | 1.8 | 2.1 | 2.4 | 2.5 | 2.8 | 3.1 |
| 90 | 1.1 | 1.4 | 1.7 | 1.9 | 2.0 | 2.2 | 2.5 |
| 120 | 0.9 | 1.1 | 1.3 | 1.5 | 1.6 | 1.8 | 2.0 |

**Table 4-2: Precipitation Frequency Estimates (rainfall intensity in inches/hour) Projected for 2050**

| | Frequency (Years) | | | | | | |
|---|---|---|---|---|---|---|---|
| **Duration (min)** | **2** | **5** | **10** | **20** | **25** | **50** | **100** |
| 5 | 5.8 | 6.9 | 7.7 | 8.4 | 8.7 | 9.4 | 10.1 |
| 10 | 4.6 | 5.5 | 6.1 | 6.7 | 6.9 | 7.5 | 8.1 |
| 15 | 3.9 | 4.6 | 5.2 | 5.6 | 5.9 | 6.3 | 6.8 |
| 20 | 3.5 | 4.1 | 4.6 | 5.1 | 5.2 | 5.6 | 6.1 |
| 30 | 2.6 | 3.3 | 3.8 | 4.1 | 4.4 | 4.7 | 5.2 |
| 60 | 1.7 | 2.1 | 2.4 | 2.8 | 2.9 | 3.2 | 3.6 |
| 90 | 1.3 | 1.6 | 2.0 | 2.2 | 2.3 | 2.5 | 2.9 |
| 120 | 1.0 | 1.3 | 1.5 | 1.7 | 1.8 | 2.1 | 2.3 |

[11] The climate change data for precipitation are daily values, but the Baltimore County Design Manual intensity values are sub-daily. A more detailed statistical analysis could be conducted to derive sub-daily climate projections for precipitation, but given the uncertainty in the projections, it would not be expected to improve the level of precision for planning purposes.

**Table 4-3: Precipitation Frequency Estimates (rainfall intensity in inches/hour) Projected for 2080**

| | Frequency (Years) | | | | | | |
|---|---|---|---|---|---|---|---|
| Duration (min) | 2 | 5 | 10 | 20 | 25 | 50 | 100 |
| 5 | 6.5 | 7.8 | 8.7 | 9.5 | 9.9 | 10.7 | 11.4 |
| 10 | 5.2 | 6.2 | 6.9 | 7.5 | 7.8 | 8.5 | 9.1 |
| 15 | 4.4 | 5.2 | 5.9 | 6.4 | 6.6 | 7.2 | 7.7 |
| 20 | 3.9 | 4.7 | 5.2 | 5.7 | 5.9 | 6.4 | 6.9 |
| 30 | 3.0 | 3.8 | 4.3 | 4.7 | 4.9 | 5.3 | 5.9 |
| 60 | 2.0 | 2.3 | 2.7 | 3.1 | 3.3 | 3.6 | 4.0 |
| 90 | 1.4 | 1.8 | 2.2 | 2.5 | 2.6 | 2.9 | 3.3 |
| 120 | 1.2 | 1.4 | 1.7 | 2.0 | 2.1 | 2.3 | 2.6 |

## 4.3 Flooding

*Coastal flooding often comes with days of advance notification from forecasts, while inland flooding can occur with little to no warning.*

Flooding in Baltimore County can be caused by sea level rise, coastal storms and extreme precipitation. Flooding from any of these mechanisms is disruptive to the County and its residents, resulting in structural damage, erosion, roadway obstruction and public safety impacts. This section provides an overview of the types of flooding in the County and the potential adaptation alternatives available to limit impacts. Types of flooding were divided up because each flooding mechanism varies in terms of future climate change effects. Further, certain flooding can influence adaptation responses. Coastal storm surge flooding often comes with advance notification from forecasts of large storms, which enables installation of temporary measures, such as sandbags, emergency pumps and other protective measures. Storms that cause inland flooding can occur without adequate warning; thus, permanent protective measures are generally recommended.

A screening assessment of flood impacts for assets was conducted to identify those structures that are at risk of flooding in the future due to climate change. This is described in section 5 Flood Vulnerability Assessment.

### 4.3.1 Types of Flooding

**Tidal Flooding** – Coastal areas are susceptible to increasingly higher tides due to SLR. Tidal flooding, also referred to as nuisance flooding, is a repetitive flooding event that occurs based on the normal tide cycle and is unrelated to storm activity. NOAA monitors and tracks tidal flooding across the country as part of its mission but does not provide an official reference elevation for high tide flooding. Through these analyses, however, NOAA has identified approximately 1.5 feet to 2.0 feet above the normal high tide as a common threshold for minor, nuisance flooding (Sweet, Dusek, Carbin, Marra, Marcy, & Simon, 2020). Further, a similar value (1.75 feet) was referenced as a definition for nuisance flooding in the 2018 Maryland SLR report. Refer to Appendix K for additional information on the calculation of coastal flood thresholds and incorporating SLR projections.

Climate change is worsening the occurrence of high tide flooding and NOAA scientists predict that the coastal area around Baltimore County will experience tidal flooding 15 to 25 days per year by 2030 and

50 to 155 days per year by 2050 (Sweeney et al, 2020). This frequency of flooding ceases to be a nuisance and has the potential to render vulnerable coastal structures unusable.

**Storm Surge Flooding** – When storms and hurricanes occur in coastal areas, winds can push water inland from the bay, resulting in a storm surge (Figure 4-1). Storm surges can exceed normal tidal ranges by five to eight feet or more in the Baltimore County area. The Federal Emergency Management Agency (FEMA) determines the Special Flood Hazard Area (SFHA) based on the one percent probability per year[12] of flooding in coastal areas due to storm surge. FEMA may also determine moderate flood hazard areas with 0.2 percent probability per year flood vulnerability. Sea level rise serves as an additive factor that lifts the mean sea level, which then raises the height of storm surge flooding in the future.

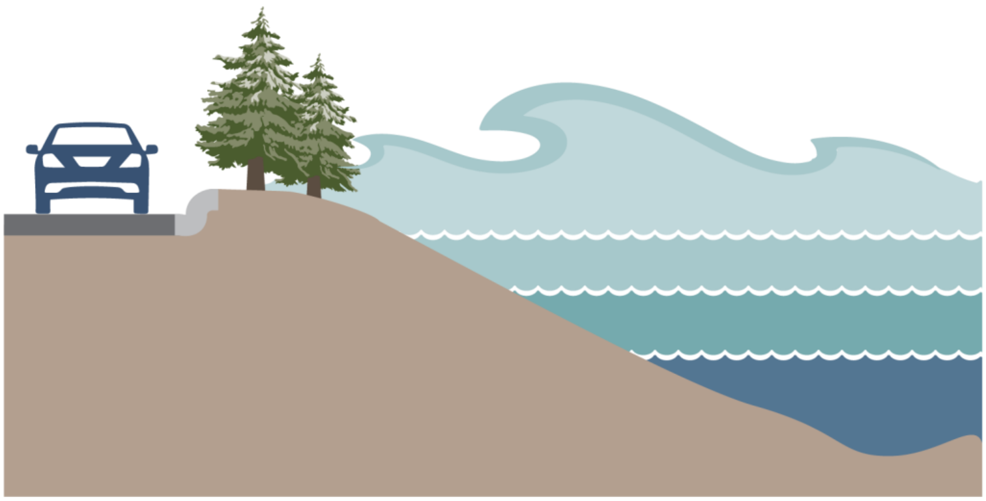


**Figure 4-1: Illustration of Coastal Flooding**

**Inland Flooding** – Flooding that results from extreme storms and excessive runoff is referred to as inland flooding. Similar to coastal flooding, FEMA delineates the SFHA and moderate flood hazard areas along streams and rivers. More frequent and severe storm events are likely to increase the potential for flooding in Baltimore County. However, predicting the effects of climate change on inland flooding is complex because 1) the difficulty of accurately predicting the probability of future extreme storms and 2) local topography will drive the depth of flooding, which requires detailed modeling to assess.

***There is no fixed boundary between coastal and inland flooding. Some areas of the County along tidal rivers can be vulnerable to both.***

[12] FEMA is transitioning away from the former terms 100-year and 500-year floods and is using the term Special Flood Hazard Area (formerly the 100-year) for areas with a one percent annual probability flood and moderate flood hazard areas (formerly the 500-year) for areas with a 0.2 percent annual probability flood.

### 4.3.2 Adaptation Alternatives for Flooding

The following describes the strategies of adaptation for increasing resilience to flooding. Specific adaptation techniques are described in the Adaptation Catalog in Appendix A.

**Relocation/Avoidance** – Relocation refers to moving community assets or services out of areas vulnerable to flooding, and avoidance is electing not to construct new facilities in vulnerable areas. Strategic retreat is a form of relocation that describes the permanent relocation of neighborhoods or structures outside of the range of flooding, returning the land to a natural state to support flood resilience. Some communities have used flood plain buyout programs to acquire vulnerable properties at high risk of recurrent flooding to reduce the community's overall flood risk. See side bar on the City of Charlotte, NC Flood plain Buyout Program. Baltimore County currently has an acquisition program for purchasing residential properties in the flood plain. Per the County Decision Memorandum, dated May 20, 2020, it was recommended to expand the program to allow case-by-case review of properties that do not meet the current criteria.

**Raise Asset** – Raising assets increases the resilience of structures, while allowing them to remain in place. Raising can be accomplished with open pilings or closed foundations. Open pilings allow flood waters to flow unimpeded, while closed foundations do not improve the capacity of the flood plain to convey flood waters. When raising assets, the new elevation should be at a minimum one foot higher than the projected flood elevation.

**Protection** – Protection includes constructing berms, floodwalls, living shorelines, revetments and other improvements to protect assets and community resources from the effects of flooding. Protection measures can range from restoration approaches to limit erosion during high tides or extreme events to extensive wall systems that physically prevent floodwater from encroaching on

City of Charlotte, NC Flood Plain Buyout Program

Since 1999, the City has purchased over 400 flood-prone houses, apartment buildings and businesses that were in flood plains throughout Charlotte-Mecklenburg County. The buyout program has converted 185 acres of developed area into public open space to allow the flood plain to function during heavy rain. Storm Water Services estimates these buyouts have avoided $25 million in losses and will ultimately avoid over $300 million in future losses.

The program provides multiple benefits for the community:

- Less tax money spent on emergency rescues
- Less tax money spent on disaster relief
- Less tax money spent to replenish the National Flood Insurance Program
- Restoring the natural flood plain to enhance water quality and the ecosystem
- Safer housing stock
- Increased opportunities for recreation and interacting with nature (e.g., greenways)

The City established a prioritization method for selecting at-risk properties and engages its Storm Water Advisory Committee to implement buyouts or other flood reduction options.

The Little Sugar Creek Greenway was built on the site of nearly 50 at-risk homes.

buildings. As with raising assets, protective berms should have a minimum of one foot of freeboard above the projected flood elevation.

**Floodproofing** – Floodproofing is the process by which the structure itself is made to be resilient to flooding. There are two types of floodproofing, dry and wet. Dry floodproofing refers to structural improvements to seal out water during floods. This entails floodproof doors and windows, structural improvements to walls to resist hydrostatic forces, raising or sealing electrical panels and other utilities and sealing other openings to keep the building interior dry. Dry floodproofing also requires a plan to deploy and maintain any floodproofing system (seals, barriers/shields) and evacuation planning to allow building occupants to safely leave the building in an emergency. Dry floodproofing should include at a minimum one foot of freeboard above projected flood elevations and/or as required by building codes. Wet floodproofing allows water to freely enter and exit the lower portions of the building, typically below-grade basements. Occupied areas of the building must be above the flood elevation and lower levels are allowed to flood. Mechanical and electrical equipment are moved to higher parts of the building to prevent damage during a flood. Wet floodproofing requires pumps and ventilation to dry out the inundated portions of the building after flood waters recede. Both dry and wet floodproofing require appropriate finishes for surfaces exposed to water. Baltimore County has a Floodproofing Grant Program to assist homeowners. Recommendations for the program as part of the County Decision Memorandum, dated May 20, 2020, were to increase funding, expand eligibility, improve program awareness and streamline the application process.

**Figure 4-2: Backup Power is a Common Adaptation for Critical Infrastructure (shown at a cell tower)**

**Backup Power** – Many facilities require power to maintain function (e.g., pump stations, cell towers, etc.). Power loss can occur during floods, which can indirectly impact important facilities. Therefore, backup power is an important adaptation option. Note that backup power generators must also be resilient against flooding to maintain functionality when needed. As noted previously, many of the County's critical facilities are currently equipped with backup power generators. For facilities that are part of a microgrid, the need for backup power may be reduced if the microgrid is resilient to flood impacts.

**Drainage System Upgrades** – Systems upgrades refers to improvements to the existing drainage networks to facilitate increased capacity or resilience to changing flood conditions. A common problem in areas affected by SLR is that coastal storm drain outfalls become inundated, which reduces the ability to drain and may actually serve as a conduit for flood waters to reach inland. Culverts used for roadways crossing streams can backup under extreme storms, resulting in backwater flooding. Increasing the capacity of culverts reduces this problem, but also requires downstream evaluation to ensure the problem is not shifted to another section of the stream. Recognizing that piped storm drains cannot convey runoff from extreme storms, some cities are developing overland flow routes and floodways in a manner that would limit impacts to structures.

As with designing building adaptations for temperature resilience, historic buildings require special consideration when implementing flood resilience to maintain the character of the structure. A number of resources are available to provide guidance on implementing flood resilience measures, including the *Flood Mitigation Guide: Maryland's Historic Buildings* (2018) by the Maryland Historic Trust and *Guidelines on Flood Adaptation for Rehabilitating Historic Buildings* (2019) by the National Park Service.

## 4.4 Adaptation Catalog

Resilience is the capacity of a community to prevent, withstand, respond to, and recover from a disruption. Adaptation is the process of adjusting to new conditions in order to reduce risks to valuable assets (USEPA, 2020c). The three primary adaptation mechanisms for reducing vulnerability and achieving resilience include reducing exposure, reducing sensitivity, and increasing adaptive capacity to climate hazards (World Bank, 2020).

- Reducing exposure requires physically relocating assets or their services away from vulnerabilities, such as relocating facilities out of current or future flood zones.
- Reducing sensitivity changes how the asset is potentially affected by hazards; an example would include floodproofing.
- Increasing adaptive capacity enhances the ability to cope or withstand effects of climate change. This could include upgraded air conditioning, tree planting and cooling centers that help people remain comfortable and healthy during extreme heat.

A fourth consideration for resilience is the ability to recover from an extreme event. It may not be feasible, or cost effective, to implement adaptations that are guaranteed to prevent all impacts. Therefore, quick response and recovery are mechanisms to offset and complement effective, feasible, resilience measures.

An Adaptation Catalog of options to improve County resilience is provided in Appendix A. The purpose of this catalog is to provide a reference for conceptual planning of adaptation. The focus of this plan is asset level adaptation. However, in some instances, it can be more effective to implement strategies that are protective of the broader neighborhood or community. For example, raising roadways in low-lying neighborhoods provides little benefit to adjacent private properties. Alternately, investing in shoreline improvements to protect both public assets and private property can be a more effective solution. As such, the catalog includes a wide range of resilience measures, beyond just what is recommended in this plan, to support future planning efforts.

## 4.5 Social Equity for Adaptation Prioritization

It is important to consider social equity when prioritizing adaptation measures. Not all communities in Baltimore County have the same level of sensitivity to climate change impacts due to social inequality. Some of the social issues to consider include financial resources, language barriers, transportation resources, etc. A useful dataset for incorporating social equity into adaptation planning is the Centers for Disease Control (CDC) Social Vulnerability Index (SVI). The SVI calculates the relative vulnerability at the U.S. Census tract level based on 15 factors grouped into four related themes (Figure 4-3). The overall ranking or a custom combination of factors can be used to support identification of vulnerable populations to support equitable implementation of adaptation.

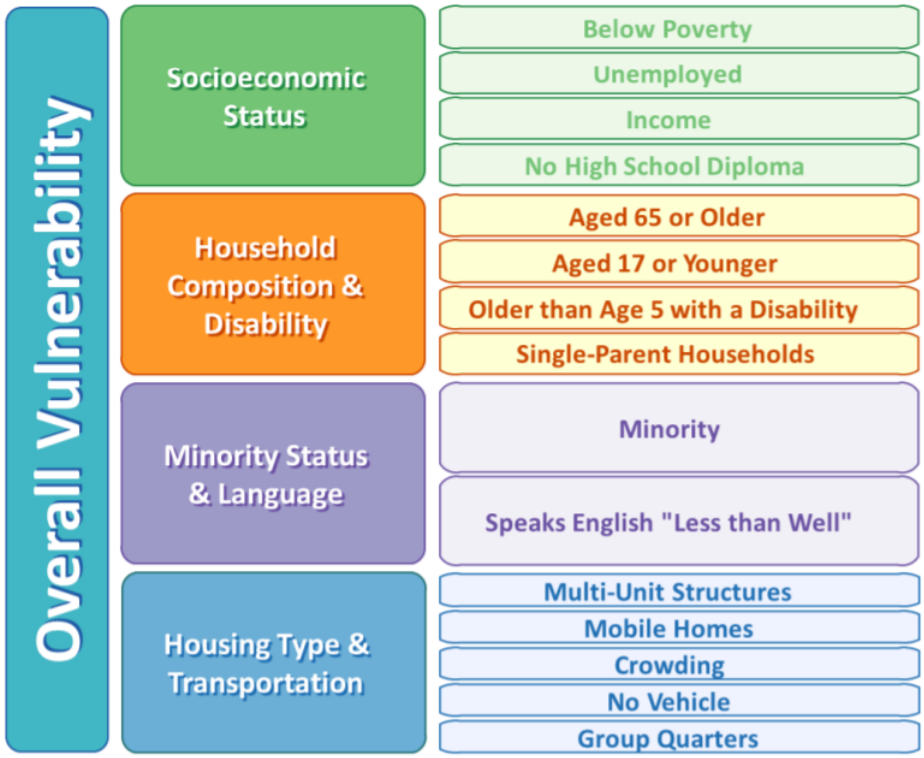


**Figure 4-3: SVI Factors and Themes (CDC, 2020)**

An example of incorporating the SVI into adaptation planning is shown in Figure 4-4. In this map, the census tracts flagged with the highest vulnerability from the SVI were cross-referenced with the percentage of impervious area, which is an indicator of urban heat island effect and lack of green space. In another example, we cross referenced the number of structures in the FEMA flood zones with the SVI. The neighborhoods with the highest SVI vulnerability and the most structures in the flood zone included the Turner Station area and the neighborhood around the Gunpowder Falls State Park Hammerman Area. There is a significant amount of data in the SVI, and further evaluation is recommended to develop comprehensive metrics for addressing social vulnerability for community-wide adaptation planning.

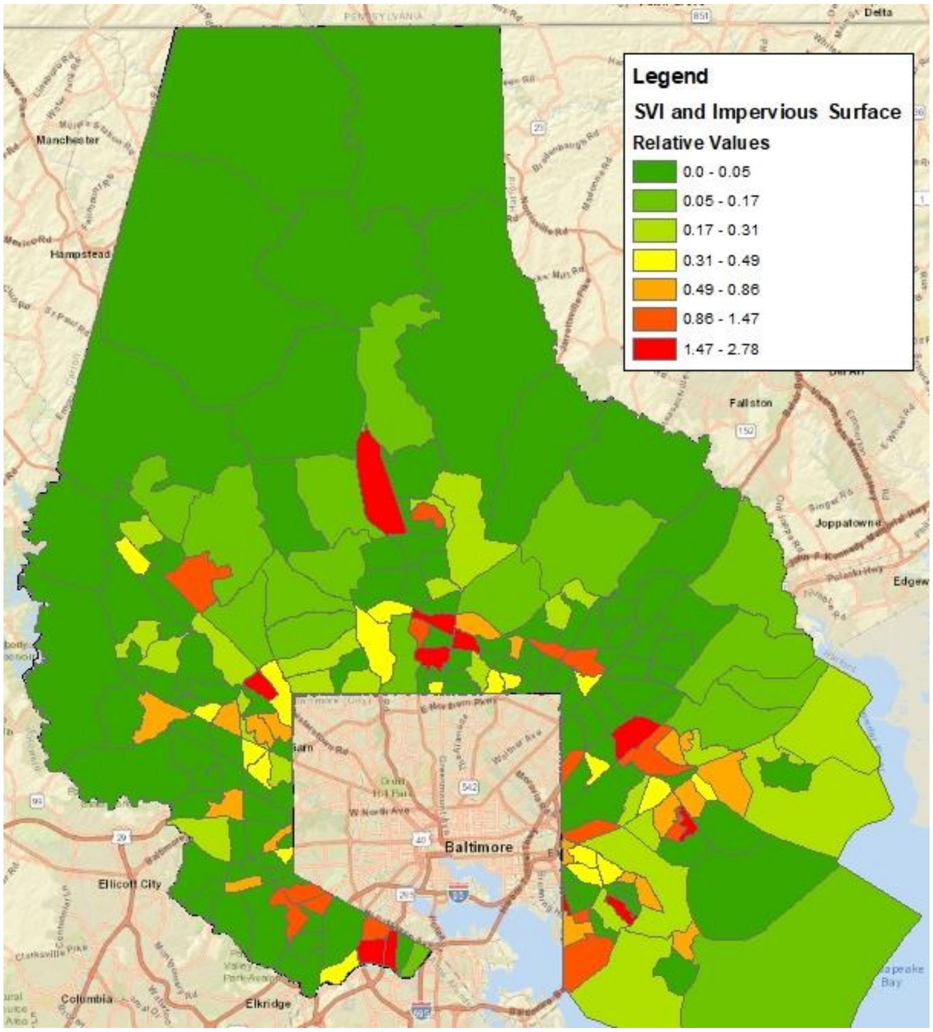


**Figure 4-4: Example of Areas of high SVI vulnerability and High Percentage of Impervious Surface**

## 5. Flood Vulnerability Assessment

All areas of the County are generally expected to have similar exposure to the effects of increasing temperatures and extreme storms. Riverine flooding and sea level rise, however, will primarily affect structures in low-lying coastal areas or close to rivers and streams. A screening assessment was conducted to identify specific County assets with high vulnerability to flooding that warrant investment in adaptation to improve resilience. The focus of the assessment was County general government owned facilities, but a subset of other structures in the County were included for informational purposes. Vulnerability and adaptation options are described for specific County general government facilities. For other community assets, refer to the assessment results in the web-based dashboard.

## 5.1 Flood Vulnerability Screening Methodology and Summary Results

The methodology for the flood screening assessment consisted of using data on the location of buildings, facilities, and assets in the County's Geographic Information System (GIS) coupled with County-wide LiDAR[13] data and FEMA flood zone data[14] to identify the ground surface elevation of buildings compared to nearby flood elevations.[15] Refer to Appendix C for a listing of the GIS data sources for this assessment. A ranking was established based on the vertical difference between the building elevation and the FEMA flood elevation to determine relative vulnerability of County assets. Sea level rise projections were incorporated into flood elevations for coastal areas. For inland areas, where it is not feasible to establish future flood elevations without substantial modeling, the elevation above the flood zone was used to rank vulnerability. Table 5-1 presents the relative vulnerability and scoring for the coastal and inland flooding assessments.

**Table 5-1: Relative Vulnerability Scenarios and Scoring**

| Vulnerability Criteria | Vulnerability Score |
|---|---|
| • Within current floodway[1] (Inland)<br>• Within future tidal range[2] (Coastal) | 5 |
| • Within current SFHA (Coastal and Inland) | 4 |
| • Within 2050 SFHA (Coastal)<br>• Within current moderate flood hazard area (Coastal or Inland)<br>• Less than or equal to 2 ft above current SFHA (Inland) | 3 |
| • Within 2080 SFHA (Coastal)<br>• Less than or equal to 5 ft above current SFHA (Inland) | 2 |
| • Outside of 2080 SFHA (Coastal)<br>• Greater than 5 ft above current SFHA (Inland) | 1 |

1 – The FEMA floodway is the area of the flood plain designated to convey flood flows. Structures in this zone reduce conveyance capacity for flood waters and are at the highest risk of damage due to depth and velocity of flows.
2 – Given the high vulnerability at these low elevations, no differentiation was made between facilities in the 2050 vs 2080 tidal range.

### 5.1.1 Tidal Flood Vulnerability

As sea levels continue to rise, natural tidal cycles will increase in elevation. Once a facility, property or structure comes within range of these tidal cycles, it will be repetitively flooded. Because tides fluctuate throughout the day, the approach for estimating future change due to SLR is described in the equation below:

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[13] LiDAR is a method for measuring distances using laser light, which is used to measure elevations over large areas from airplanes. The LiDAR data is Quality Level 1 with a vertical accuracy of 10 cm.

[14] Preliminary FEMA flood maps were used for this assessment because they were expected to be finalized shortly after publication of the County Climate Action Plan.

[15] The average of the elevation within the footprint and the lowest adjacent grade around the perimeter of buildings were used for the vulnerability assessment. Note that GIS data and LiDAR data do not account for structures that may be elevated above surrounding areas or that may have vulnerable basements.

***Mean Higher High Water Elevation (NAVD88)[16] + SLR Projection = Projected Average High Tide Elevation (NAVD88)***

This approach is consistent with that described in the NOAA *Mapping Coastal Inundation Primer* (2012). The projected tide elevations are then compared to facility elevations to determine vulnerability score. The Maryland 2018 projections are based on the change starting in 2000 to be consistent with the current tidal datum used by NOAA at its tide gauges.[17] Refer to Appendix K for additional information on the tidal datums and incorporating SLR into tidal data.

The typical maximum range for the Mean Higher High Water (MHHW) high tide in the vicinity of Baltimore County is approximately elevation 0.8 feet (NOAA, 2020d). Using projections for SLR of 1.6 feet for 2050 and 2.6 feet for 2080, elevations in the range of approximately 2.4 feet and 3.4 feet for 2050 and 2080, respectively, are at risk of future high tide flooding. Facilities below these elevations would be expected to have some level of inundation at least once per day due to normal tidal cycles and are most vulnerable to SLR.

Tidal Flooding SLR Sensitivity

Because of the high vulnerability to SLR of low-lying facilities close to the water, we reviewed the sensitivity of selecting the most conservative sea level rise for 2080 from the Maryland 2018 report (Table 3-8). This value represents the 1% probability of occurrence and is 1.5 feet higher than the recommended SLR projections. This review identified additional residential grinder pumps, the Police Marine Unit and three sewerage pump station facilities: Day Village, Fort Howard, and Lynch Point. **Overall, most County-owned facilities are not constructed in locations vulnerable to tidal flooding.**

The screening assessment identified residential sewage grinder pumps, road sections and storm drain outfalls as the only County general government assets at risk of tidal flooding. Residential sewage grinder pumps are constructed with submersible pumps; therefore, the pumps will continue to function so long as the electrical equipment is elevated or sealed. A review of the County's construction specifications for the sewage grinder pumps indicated that pump operation should generally remain resilient to flooding because of watertight and weatherproof construction. However, as these units are exposed to the elements, gaskets and seals may become less effective over time and should be periodically inspected and replaced as needed. Overall, these pumps are resilient to tidal flooding and no adaptation is recommended.

Except for potential erosion from wave action, roadways are resilient to flood impacts, but inundation of roads results in transportation impacts for residents and potentially first responders in times of emergencies. Roadway flooding places a number of neighborhoods and waterfront buildings at risk. Refer to Section 5.4 Roads and Bridge Flood Vulnerability Assessment for a discussion of nuisance flooding impacts for roadways.

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[16] Mean Higher High Water is the average of the daily observed highest tide heights for each day for the tide gauge reference data.

[17] SLR rise has continued over the last 20 years and is estimated at 0.45 feet between 2000 and 2020, based on a review of tidal observations. This value is an approximation as NOAA does not provide interim estimates of sea level elevations.

Storm drain networks become less effective when the outfalls become submerged deeper than originally designed. Higher tides due to SLR can reduce the capacity of storm drain infrastructure and, depending on elevations, can convey tidewaters inland, causing water to flow out of inlet structures. Review of the elevations of the County's storm drain outfalls revealed nearly 200 outfalls that would be inundated under high tide flooding in 2050 and 2080. The storm drain networks that are connected to these inlets were identified, and maps for each location are provided in Appendix F. It is recommended that detailed hydraulic analysis of these sections of storm drain infrastructure be conducted to identify specific impacts from high tide flooding of outfalls.

#### 5.1.2 Coastal Storm Flood Vulnerability

Coastal storm vulnerability results from the storm surge associated with high winds that push water inland, which can far exceed typical tidal ranges. As noted previously, FEMA determines the SFHA based on the one percent annual flood risk (i.e., 100-year flood), which ranges from approximately 3 to 10 feet for Baltimore County. In some areas of the County, FEMA has delineated moderate flood hazard areas with 0.2 percent annual chance of flooding (i.e., 500-year flood), but these areas do not have a flood elevation.

Another dataset available for storm surge impact assessments is the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) modeling, which is used to estimate the near worst–case scenario of flooding for each hurricane category (National Hurricane Center, 2020). Unlike the FEMA SFHA elevation, which has a one percent annual chance of occurrence, the SLOSH model results are not assigned a probability of occurrence. SLOSH model data may be used for long range hurricane planning but is not intended for regulatory purposes (U.S. Army Corps of Engineers, 2011). While Natural Resources Article § 3-1009(c) requires the State to develop siting criteria that accounts for the storm surge from a Category 2 hurricane, the Maryland Coast Smart Council's expert workgroup determined that the use of storm surge inundation maps from SLOSH modeling "would not adequately characterize flood risk or accurately predict where the water may go" (Maryland Department of Natural Resources, 2020). Therefore, these data were not used to assess vulnerability to coastal flooding.

The FEMA SFHA elevations incorporate wind, waves and tide to calculate the one percent annual probability of flooding. These elevations are raised based on SLR projections as described below:

***FEMA SFHA Base Flood Elevation (NAVD88) + SLR Projection = Projected SFHA Base Flood Elevation***

The elevations of County assets were compared to the FEMA SFHA elevation plus projected SLR for 2050 and 2080 to determine the vulnerability score (Table 5-1). The area affected by coastal storm flood vulnerability is larger than the tidal flood vulnerability and affects low-lying areas of the County. This area includes some important County general government assets as well as additional roads and residential grinder pumps.[18] A summary of the affected assets is presented in Table 5-2. In addition to

[18] Outfalls would be inundated during storm surge, but because of the low frequency of occurrence, outfalls were not assessed for this type of flooding.

these assets, 76 structures were identified at Baltimore County coastal parks that are vulnerable to flooding. Refer to Appendix D for a listing of park structures, park name and flood risk level.[19]

**Table 5-2: County Assets Vulnerable to Coastal Flooding**

| Facility | Vulnerability | Vulnerability Score |
|---|---|---|
| Police Marine Unit | Within mapped SFHA flood zone | 4 |
| Watersedge Community Center | Within mapped SFHA flood zone | 4 |
| Sollers Point Multipurpose Center and Library | Within mapped SFHA flood zone | 4 |
| 15 sewage pump stations | Within mapped SFHA flood zone | 4 |
| 16 sewage pump stations | Within 2050 SFHA and within mapped moderate flood hazard area | 3 |
| 6 sewage pump stations | Within 2080 SFHA flood zone | 2 |

### 5.1.3 Inland Flood Vulnerability

Inland flooding occurs when rainfall and runoff exceeds the capacity of rivers and streams, which exceed their banks and spread onto adjacent lands. Inland flooding can also occur when runoff exceeds the capacity of developed storm drain systems. It was beyond the scope of this plan to conduct the modeling necessary to identify sections of the County storm drain system that will be undersized due to precipitation changes from climate change. A screening assessment was conducted to identify storm drain infrastructure that intersects historic streams. These storm drains tend to be more vulnerable to surcharge from storm events because of the historic stream flows being conveyed by the pipes. Maps of these sections of storm drain infrastructure are presented in Appendix G. It is recommended that the County conduct hydraulic modeling of these networks to confirm risk and for design of system improvements.

For the County's network of rivers and streams, FEMA has determined the base flood elevations for SFHA and delineated zones of moderate flood hazard for inland areas. It is more difficult to estimate future changes to inland flooding due to climate change than for coastal flooding. Therefore, vulnerability scores were based on the elevation difference between the structure and the base flood elevations for FEMA Special Flood Hazard Areas (Table 5-1). The County general government assets that are vulnerable to inland flooding are presented in (Table 5-3). In addition to these assets, 51 structures were identified at Baltimore County inland parks that are vulnerable to flooding. Refer to Appendix D for a listing of park structures, park information and flood risk level.[19]

[19] Park structures were listed mostly as "miscellaneous structure" in the GIS data. Aerial photo review indicated many were storage buildings, bathrooms, and open pavilions, but this could not be confirmed for all sites. Major park structures, such as nature centers and offices were included separately in the GIS data.

**Table 5-3: County Assets Vulnerable to Inland Flooding**

| Facility | Vulnerability | Vulnerability Score |
|---|---|---|
| NE Regional Recreation Center | Within mapped SFHA flood zone | 4 |
| Western Solid Waste Acceptance Facility | Within mapped SFHA flood zone | 4 |
| Sunnybrook Well #7 | Within mapped SFHA flood zone | 4 |
| Brooklandville Fire Station | Less than 2 ft above mapped SFHA | 3 |
| Sunnybrook Well #9 | Less than 5 ft above mapped SFHA | 2 |
| Catonsville Service Yard | Less than 5 ft above mapped SFHA | 2 |
| 1 sewage pump station | Within FEMA Floodway | 5 |
| 2 sewage pump stations | Within mapped SFHA | 4 |
| 3 sewage pump stations | Within mapped moderate flood hazard area or less than 2 feet above SFHA | 3 |
| 1 sewage pump station | Less than 5 feet above SFHA | 2 |
| 6 Parking Lots and Garages | Varies | Varies |

## 5.2 Prioritization for Adaptation

Once vulnerable assets are identified, it is necessary to prioritize assets for adaptation, which is based on asset criticality. Other important considerations for selecting an adaptation approach are the asset occupancy and asset value, which are denoted through a weighting score. The three values of vulnerability, criticality and weighting score are multiplied together to get the asset risk rank.

***Risk Rank = Vulnerability x Criticality Score x Weighting Factor***

The criticality scoring was based on the FEMA Hazus[20] classification of the County assets. Individual assets were assigned to a Hazus classification and used to determine asset criticality (Table 5-4). A list of assets and their respective classifications are presented in Appendix E.

**Table 5-4: County Assets Classification for Criticality**

| Hazus Classification | Description | Criticality Score |
|---|---|---|
| Essential Services | Essential services include police stations, fire stations, emergency operations centers, medical facilities, schools and community centers.[1] | 5 |
| Utilities | Utilities include water, wastewater, communications and energy infrastructure. Includes utility and vehicle maintenance facilities. | 4 |
| Building Stock | Structures not included in another category | 3 |
| Transportation | Bus and rail stations | 3 |
| | Roads and bridges | See note below |
| | Parking facilities | 2 |
| High Loss Facilities | Facilities such as dams and nuclear power plants that result in higher levels of community impacts if they fail. | See note below |

1 – Schools and community centers may be used as emergency shelters during natural disasters.

[20] Hazus is a nationally applicable standardized methodology that contains models for estimating potential losses from earthquakes, floods, tsunamis and hurricanes.

**Roads and Bridges** – In most areas of the County, flooded roads and bridges can be bypassed via alternate routes. However, a major issue with flooded roads is that it slows emergency access. Therefore, a separate response time analysis was conducted to prioritize road segments for adaptation based on level of reduction in response time if blocked by flooding.

**High Loss Facilities** – There are no nuclear power plants in Baltimore County. While there are dams located in the County, these are required to safely pass the probable maximum flood (PMF), which is the theoretically largest flood resulting from a combination of the most severe meteorological and hydrologic conditions that could occur in an area. Due to the separate regulatory process and the complex modeling required to assess the effect of climate change on the PMF, dams were not included in the adaptation analysis.

In addition to criticality, a weighting factor was used to account for other aspects of County facilities that are important for asset prioritization (Table 5-5).

**Table 5-5: County Assets Weighting Factors**

| Factor | Description | Weighting Factor |
|---|---|---|
| Asset Occupancy | Facility needs to remain occupied by personnel throughout an emergency event. | 1.5 |
| Asset Value | Asset has exceptionally high value warranting additional consideration. | 1.25 |

## 5.3 Individual Facility Adaptation Recommendations

The individual facility recommendations are based on available data in the GIS. The flood vulnerability screening assessment is not able to provide precise information on vulnerabilities based on factors such as building finished floor elevation, presence of basements, number of windows and doors, height of electrical and mechanical equipment, building materials, interior uses, etc. Desktop analyses were conducted for County general government facilities with high vulnerability from the screening assessment for adaptation alternatives recommendations. These recommendations should be followed up with building site surveys to confirm assumptions and identify all important features necessary for implementing flood adaptation. This task can be used as an opportunity to develop FEMA elevation certificates for buildings without them.[21] This section describes all County general government facilities with some level of flood vulnerability from the analysis (vulnerability of 2 to 5). The list of non-county government and non-government facilities with flood vulnerability from the screening assessment are included in the web-based dashboard.

The adaptation recommendations focused on floodproofing as the preferred option. However, many of the facilities are within the current SFHA and one facility is in the FEMA floodway. It is recommended that Baltimore County review the potential to relocate these facilities out of the flood zones and return the

[21] An elevation certificate is an administrative tool of the National Flood Insurance Program to provide elevation information necessary to ensure compliance with community flood plain management ordinances.

properties to a natural condition. Relocation would serve to reduce flood vulnerability for the facility and may help reduce flood elevations by removing buildings from the SFHA.

Another consideration is that Maryland Department of Natural Resources recently released its Coast Smart Construction Program that includes a Coast Smart Climate Ready Action Boundary (CS-CRAB) that is three feet above the coastal FEMA base flood elevation (Figure 5-1) (Maryland Department of Natural Resources, 2020). Compliance with CS-CRAB is only required for capital projects that (1) are at least 50% funded with State funds, (2) cost $500,000 or more, and (3) include the construction of a new structure or the reconstruction of a structure with substantial damage. The Coast Smart Construction Program would not apply to upgrades to existing facilities that have not been damaged. However, it is recommended that Baltimore County consider the CS-CRAB elevations when implementing flood resiliency upgrades for its facilities in coastal areas. There currently is not an equivalent criterion for inland flooding, but it is under consideration by the State.

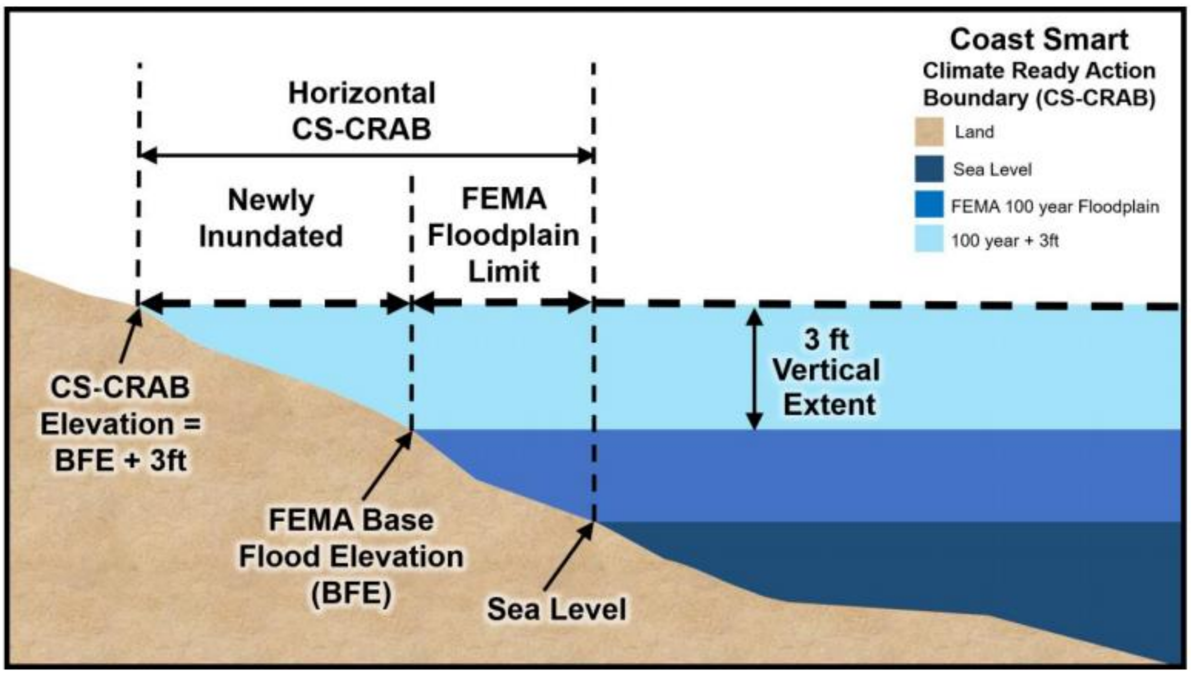


**Figure 5-1: Coast Smart Climate Ready Action Boundary (CS-CRAB) and Elevation**

### 5.3.1 Facilities Vulnerable to Coastal Storm Surge

There were 40 County general government facilities identified in the screening assessment that were determined to be at risk of coastal storm surge flooding. Three facilities are detailed below. In addition, 37 sewage pump stations were identified as vulnerable to coastal flooding. Pump stations are discussed in Section 5.3.3 below. Important non-County facilities vulnerable to flooding included one volunteer fire station (Bowley's Quarters Fire Station).[22] Results for non-county facilities are documented in the web-based dashboard.

Police Marine Unit

**Risk Rank = 30**
- Vulnerability Score = 4
    - Within current SFHA
- Criticality = 5
    - Essential Service
- Weighting Factor = 1.5
    - Asset occupancy required

**Adaptation Recommendation**
- Raise facility
- Est $120,000 to $180,000
- This property and building are owned by the State of Maryland and leased to Baltimore County.
- Review with the State options for improving resilience.
- Pier is County-owned and important to police operations
- Implement pier upgrades to improve resiliency to SLR and storm surge

[22] Volunteer fire stations are owned by the individual fire companies and not the County.

## Watersedge Community Center

**Risk Rank = 30**

- Vulnerability Score = 4
  - Within current SFHA
- Criticality = 5
  - Essential Service
- Weighting Factor = 1.5
  - Asset occupancy required when used as an emergency shelter

**Adaptation Recommendation**

- Dry floodproofing
- Est $60,000 to $100,000
- This is a newer facility, and the finished floor may be above the SFHA elevation, but the site would be surrounded by water during a flood based on flood maps.
- Consider not using for emergency shelter for coastal flooding (downgrades criticality and weighting factor)
- Center can be used for other emergencies

## Sollers Point Community Center


**Risk Rank = 30**

- Vulnerability Score = 4
  - Within current SFHA
- Criticality = 5
  - Essential Service
- Weighting Factor = 1.5
  - Asset occupancy required when used as an emergency shelter

**Adaptation Recommendation**

- Dry floodproofing
- Est $100,000 to $180,000
- This is a newer facility, and the finished floor may be above the SFHA elevation, but the site would be surrounded by water during a flood based on flood maps.
- Consider not using for emergency shelter for coastal flooding (downgrades criticality and weighting factor)
- Center can be used for other emergencies

### 5.3.2 Facilities Vulnerable to Inland Flooding

There are 19 County general government facilities identified from the screening assessment vulnerable to inland flooding. As noted previously, building surveys are recommended to confirm finished floor elevations and structural condition for floodproofing. For inland flooding vulnerability, it is also recommended that localized hydraulic modeling be conducted to confirm risk levels prior to significant investments in building level adaptations.

No adaptation options were recommended for parking lots and garages because of the limited potential for damage. In addition, seven sewage pump stations were identified as vulnerable to inland flooding. Pump stations are discussed in Section 5.3.3 below. Important non-County facilities vulnerable to flooding included two volunteer fire stations (Arbutus and White Marsh Fire Stations).[23] Results for non-county facilities are documented in the web-based dashboard.

NE Regional Recreation Center

**Risk Rank = 30**

- Vulnerability Score = 4
  - Within current SFHA
- Criticality = 5
  - Essential Service
- Weighting Factor = 1.5
  - Asset Occupancy Required

**Adaptation Recommendation**

- Dry floodproofing
- Est $30,000 to $90,000
- Consider not using for emergency shelter for flood events (downgrades criticality and weighting factor)
- Consider for reconstruction at an area outside of the flood zone
- Center can be used for other emergencies

[23] Volunteer fire stations are owned by the individual fire companies and not the County.

## Brooklandville Fire Station

**Risk Rank = 22.5**
- Vulnerability Score = 3
  - Less than 2 ft above current SFHA
- Criticality = 5
  - Essential Service
- Weighting Factor = 1.5
  - Asset Occupancy Required

**Adaptation Recommendation**
- Dry flood proofing
- Est $30,000 to $50,000
- Requires raising 800 LF of roadway
- Est $600,000 to $1,800,000

## Sunnybrook Well #7

**Risk Rank = 20**
- Vulnerability Score = 4
  - Within current SFHA
- Criticality = 5
  - Essential Service
- Weighting Factor = 1.0

**Adaptation Recommendation**
- Wet floodproofing
- Est $5,000 to $10,000

## Sunnybrook Well #9

**Risk Rank = 10**
Vulnerability Score = 2
Less than 5 feet above current SFHA
Criticality = 5
Essential Service
Weighting Factor = 1.0

**Adaptation Recommendation**
Wet floodproofing
Est $5,000 to $10,000

Catonsville Service Yard

**Risk Rank = 8**

- Vulnerability Score = 2
  - Less than 5 ft above current SFHA
- Criticality = 4
  - Utilities
- Weighting Factor = 1.0

**Adaptation Recommendation**

- None – open storage yard, limited damage from flooding

Western Acceptance Facility


**Risk Rank = 16**

- Vulnerability Score = 4
  - Within current SFHA
- Criticality = 4
  - Utilities
- Weighting Factor = 1

**Adaptation Recommendation**

- None – multi-level facility, equipment elevated within structure
- River backs up onto site, a project is underway to install a backwater prevention valve

### 5.3.3 Baltimore County Sanitary Sewer Pump Stations

Baltimore County owns and operates 121 sanitary sewer pump stations. A subset of these were evaluated in a recent report titled *Pumping Station Flood Resiliency Assessment & Evaluation Study* (2019). This study evaluated the flood risk to all the pump stations based on the criteria below.

- Tier 4 (High) – Sites that are in most susceptible areas as defined by all three flood risk categories. (location relative to the FEMA SFHA, projected sea level rise, and projected storm surge areas)

- Tier 3 (Medium) – Sites outside of the FEMA SFHA but in areas most susceptible to storm surge and sea level rise.

- Tier 2 (Low) – Sites that are only affected by storm surges for Category 3 and 4 hurricanes.
- Tier 1 (Unlikely) – Sites outside of all flood risk categories.

A subset of 24 stations were selected based on high risk and County preference for a review of as-built drawings to determine which assets at each station are most critical to normal operations and require floodproofing measures. Appendix I presents the vulnerability ranking of the pump stations from the *Pumping Station Flood Resiliency Assessment & Evaluation Study* and from this Climate Action Plan. In general, the highest risk stations were consistent between the two analyses. However, there are some differences between the results. The primary change is that the prior study used the effective flood maps and this plan used preliminary maps. A number of pump stations that were previously outside of the FEMA flood zones are in the projected flood zones per the updated maps. Additionally, the ranking of flood risks was different as the two analyses used different ranges for sea level rise risk and the CAP did not include hurricane storm surge estimates as part of the assessment.

Cost estimates for flood-proofing these facilities are not included in this plan because pump stations have building penetrations and equipment that are not typical of other buildings. For example, ventilation louvers, stationary emergency generators and complex electrical controls require more detailed design to estimate potential costs. It was the recommendation in the prior SSPS Climate Resiliency report that a cost-benefit analysis be conducted for flood mitigation alternatives for each pumping station along with detailed onsite investigations of the stations. The recommendation is reiterated in this plan to include the medium- and high-vulnerability stations identified in the two analyses and also evaluate the flood vulnerability of station access roads.

## 5.4 Roads and Bridge Flood Vulnerability Assessment

Roads and bridges are important assets to the County, necessary for economic development and a high quality of life for its residents. A screening assessment was conducted to itemize those road segments that are at risk of flooding in both coastal and inland areas. While flooding can damage roads, typically from erosion or debris at stream crossings, this assessment is focused on the transportation impacts from inundated roads or bridges.

An initial assessment quantified the length of road segments currently located in FEMA SFHA in the County, which identified nearly 90 miles of roadway. Two assessments were conducted on roads and bridges. The first quantified the road segments at risk of nuisance flooding due to SLR. The second was a transportation analysis to rank the road segments that resulted in the highest impact to emergency response times when blocked by flooding.

### 5.4.1 High Tide/Nuisance Flooding of Roadways

The State of Maryland requires communities to develop a Nuisance Flooding Plan (NFP) to address high tide flooding. Guidance developed by a multi-partner workgroup facilitated by the Maryland Department of Natural Resources recommended that each NFP include three critical components:

- Inventory of known flood hazard areas where tidal nuisance flooding occurs;
- Identification of flood thresholds/water levels/conditions that lead to tidal nuisance flooding; and

- A mechanism to document tidal nuisance flood events and response activities from 2020–2025.

The nuisance flooding analysis submitted by Baltimore County included a review of existing County data on local flooding incidents from internal records and reported to the National Fire Incident Reporting System (NFIRS). This vulnerability assessment identified roadway segments that fall within the current and future tidal ranges based on SLR described in Section 3.3 Sea Levels.

Similar to the methodology described previously, inundated roadways were identified by comparing the road elevation based on LiDAR data with the FEMA SFHA base flood elevations. However, the elevations used to calculate nuisance flooding included an additional 1.75 feet as identified by NOAA as a typical range for nuisance tides (Figure 5-2). Refer to Section 4.3.1 and Appendix K for additional details. The equation used to calculate the elevation is:

***Mean Higher High Water Elevation (NAVD88) + Nuisance Flood Depth + SLR Projection = Projected Nuisance Flood Elevation (NAVD88)***

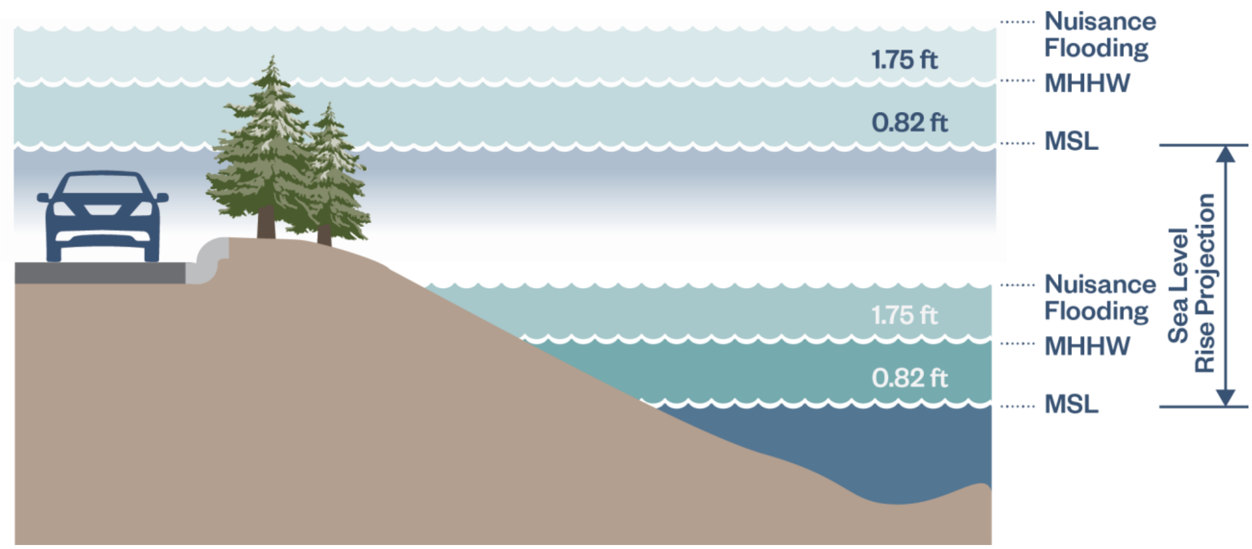


**Figure 5-2: Graphical Representation of Estimating Change in Tides due to SLR Projections (not to scale)**

Table 5-6 presents a summary of roadway segments by road classification from the comparison of the tidal elevations for 2020, 2050 and 2080 with road elevations. A full list of lengths by street name is presented in Appendix H. Note that the analysis did not assess inundation depth, so road segments at lower elevations will be more severely impacted than those at the higher end of the tidal ranges. An estimate of recent SLR is included for the 2020 scenario because it is not estimated in the Maryland 2018 SLR projections.

**Table 5-6: Summary of Roadway Segments Vulnerable to Nuisance Flooding in Baltimore County (based on recommended SLR)**

| Road Class | Previously Reported Nuisance Flooding | 2020 Tidal Range Elevation 3.1 ft | 2050 Tidal Range Elevation 4.2 ft | 2080 Tidal Range Elevation 5.2 ft |
|---|---|---|---|---|
| Interstate | 0 | 0 | 0 | 0 |
| Interstate Ramp | 0 | 1 | 1 | 1 |
| Freeway or Principal Arterial | 0 | 0 | 1 | 3 |
| Major Arterial | 0 | 15 | 16 | 18 |
| Minor Arterial | 1 | 7 | 16 | 25 |
| Major Collector (Rural) Or Collector (Urban) | 1 | 6 | 12 | 13 |
| Local Street | 15 | 124 | 263 | 378 |
| Alley or Driveway | 0 | 17 | 47 | 58 |

Road segments defined by the Baltimore County road centerline GIS database.

A sensitivity analysis was conducted to identify the quantity of roadway segments impacted by nuisance flooding using the more conservative SLR estimates in the Maryland 2018 report (Table 3-8). This value represents the 1% probability of occurrence and is up to 1.5 feet higher than the recommended SLR projections. As expected, this review identified additional road segments that would be at risk of nuisance flooding in the future (Table 5-7).

**Table 5-7: Summary of Roadway Segments Vulnerable to Nuisance Flooding in Baltimore County (based on the top 1% of SLR from the Maryland 2018 report)**

| Road Class | Previously Reported Nuisance Flooding | 2020 Tidal Range Elevation 3.1 ft | 2050 Tidal Range Elevation 4.9 ft | 2080 Tidal Range Elevation 6.7 ft |
|---|---|---|---|---|
| Interstate | 0 | 0 | 0 | 0 |
| Interstate Ramp | 0 | 1 | 1 | 2 |
| Freeway or Principal Arterial | 0 | 0 | 3 | 4 |
| Major Arterial | 0 | 15 | 16 | 36 |
| Minor Arterial | 1 | 7 | 19 | 43 |
| Major Collector (Rural) Or Collector (Urban) | 1 | 6 | 13 | 20 |
| Local Street | 15 | 124 | 339 | 564 |
| Alley or Driveway | 0 | 17 | 54 | 98 |

Road segments defined by the Baltimore County road centerline GIS database.

Local roads are the most heavily impacted from high tide flooding and few major roads are vulnerable to nuisance flooding, except at the higher end of SLR. While not directly assessed for this plan, the local roads vulnerable to nuisance flooding are indicative of low-lying neighborhoods that may also be vulnerable to the same flooding levels. Given the cost of raising these roads, which would likely do little to improve community resilience to flooding, more extensive coastal adaptation strategies are recommended to provide protection for the broader neighborhoods.

### 5.4.2 Transportation Impacts from Flooding

The major potential impact to the community from flood blockages of roads is the loss of transportation access. There is no objective measure for prioritizing roads for community resilience. Some communities base prioritization on road class and traffic volumes, others base it on access routes for emergency evacuation. The assessment for this plan was developed through discussions with County staff to identify roads that will affect the ability of emergency services (police, fire, ambulance) to reach individuals in need during flood disasters based on response time.

The analysis used the ESRI ArcGIS Online Generate Service Areas Tool to calculate response times for the police stations, fire stations and hospitals in the County. The following provides an overview of the approach. Refer to Appendix J for a more detailed description of the analysis.

- The first step was to identify the upper bound of response times for reaching the full extents of the County. This time was then broken up into four bins to characterize the shortest to longest response times.
- The analysis then identified the difference in areal extent of each response time bin, assuming all roads in the SFHA were blocked. Areas with no change in response time under this extreme condition were screened out.
- Focusing on the areas with response time differences, an iterative analysis was conducted by removing individual flooded roadways. The iterations began with the hospitals, because there are the fewest in the County (as opposed to fire stations and police stations), and response times would be the most sensitive to blocked roadways.
- The roadways that provided the highest benefit for response times to hospitals were then evaluated iteratively for both police and fire stations to quantify the response time benefits for each category.
- The top road segments were reviewed to confirm accuracy with the County's GIS. For example, the ArcGIS tool uses its own database of roads, and some had access based on right-of-way where no road exists.
- The top approximately 20 road segments that provided the most benefit to response times across all three emergency services are summarized in Table 5-8. Roads that have previously reported flooding are also noted on this list. Maps of the locations are included in Appendix J.

These roads are characterized relative to the FEMA SFHA, which has a probability of flooding of one percent per year. Some of these roadways may experience flooding more frequently. Through conversations with the County Fire Department staff, crews keep paper maps of roads to avoid during heavy rainfall based on prior experience. It is recommended to cross reference the Fire Department's maps with the list from this analysis to provide additional information on roads that experience more frequent flooding.

**Table 5-8: Prioritized Roadway Segments from Emergency Response Time Analysis for Flooding (Pink highlighting indicate the highest priority roads)**

| Roadway Name | Previously Reported Roadway Flooding | Roadway Name | Previously Reported Roadway Flooding |
|---|---|---|---|
| Campfield Rd | | Painters Mill Rd | |
| Caves Rd | | Park Heights Ave | |
| Cromwell Bridge Rd | X | Philadelphia Rd | X |
| Falls Rd | | Pulaski Hwy | |
| Gwynnbrook Ave | | Ridge Rd | |
| I-695 | | Rolling Rd | |
| I-83 | | Shawan Rd | |
| Leeds Ave | X | W Joppa Rd | |
| Liberty Rd | | Windsor Mill Rd | |
| Milford Mill Rd | | Woodlawn Dr | |
| Notchcliff Rd | X | York Rd | X |

# 6. Expanding Resilience in County Planning

Baltimore County's land resources are a valuable commodity for its residents. Some parcels of land in proximity to waterways can be even more valuable, where advantageous topography exists, despite potential risks from flooding. Given the importance of the County's planning documents for guiding future development, these reports and plans were reviewed to evaluate how the policies contribute to the resilience, vulnerability and adaptability of the County. Documents reviewed include the following:

- Master Plan 2020 (2010)
- Land Preservation, Parks and Recreation Plan (2017)
- Hazard Mitigation Plan (2015)
- Small Watershed Action Plan(s)
- Watershed Implementation Plans
- Stormwater Management Regulations, Checklists, & Forms (2007 plus updates)
- Comprehensive Manual on Design Policies (2008)
- Local Open Space Manual (2000)
- Landscape Manual (2000)
- Capital Infrastructure Planning Process
- Adopted Community Plans

Overall, these planning documents are at various stages. Some, such as the Land Preservation, Parks and Recreation Plan are currently being updated, while others have not been updated in decades. It is recommended that going forward, all plans acknowledge and address, as appropriate, climate change, SLR, flood vulnerability, extreme storms and temperature increases. Beyond County planning documents, there are a number of codes and processes that could be used to encourage adaptation projects. For example, community-specific adaptation projects that provide a community benefit could be an option in the Planned Unit Development process. Current zoning and development areas may be counter-productive with respect to flood vulnerabilities. Evaluating the overlap of Land Development Policy with high-risk flood areas would prove beneficial to preventing construction in vulnerable areas. Resilience considerations can also be incorporated into County review of critical privately-owned infrastructure.

The FEMA document *Plan Integration: Linking Local Planning Efforts* (2015) provides guidance to help communities analyze local plans to document existing integration and further integrate hazard mitigation principles into local planning mechanisms, which can serve as a useful resource for the County. Additionally, the Chesapeake and Coastal Service of the Maryland Department of Natural Resources and the Maryland Sea Grant Extension are embarking on a project to create a step-by-step guidance document on how to utilize and incorporate Maryland's 2018 sea level rise projections into planning, regulatory and site-based projects. The objective of the guidance document is to make SLR projections actionable over different time horizons and provide more direction for Maryland practitioners. This document, once available, can serve as guidance for incorporating climate vulnerabilities into County planning.

## 6.1 County Flood Plain Regulations

In order for Baltimore County to participate in the National Flood Insurance Program, under which property owners may buy Federal flood insurance, the County has to include provisions and restrictions in the building code and development regulations. The County's codes currently exceed Federal requirements in a number of ways (Baltimore County, 2020).

- Baltimore County prohibits development by right in flood plains draining areas of 30 acres or greater and restricts construction adjacent to drainage courses of any size.
- The Codes allow new construction in tidal flood plains but do not allow new development by right in riverine flood plains.
- Further, the County bases its riverine flood plains on runoff calculated as if the drainage area were developed to the maximum allowed by zoning. The reason is to prevent upstream development from putting properties into a flood plain area where one was not mapped previously.

A potential option for expanding limitations on potentially vulnerable development projects can be found in the Maryland Coast Smart Construction Program. The current program, which became effective September 2020, requires state or local capital projects, which cost $500,000 or more and 50% of the project costs are funded by the state, must comply with the Coast Smart siting and design criteria. The criteria adds three vertical feet to the FEMA SFHA base flood elevation and also extends the boundary inland until it meets the land surface (Figure 6-1), effectively creating a revised flood zone boundary. The Coast Smart program does not currently apply to inland flood boundaries, but a similar approach is under consideration by the state. The Coast Smart Program, or similar criteria, should be considered for incorporation into the County's flood plain regulations to limit construction in areas that will see higher flood vulnerability in the future.

Another important consideration is that FEMA does not map flood zones for streams with a drainage area of less than one square mile in urban areas and larger drainage areas in rural areas (FEMA, 2005).

Therefore, it is up to the community, in most cases, to map localized flood problems to guide development regulations. It is recommended that the County consider additional modeling in small drainage basins at risk of inland flooding to augment the FEMA SFHA mapping to reduce potential development in flood-prone areas. The goal would be to phase out and ultimately prohibit construction in vulnerable flood zones that will increase in risk over time.

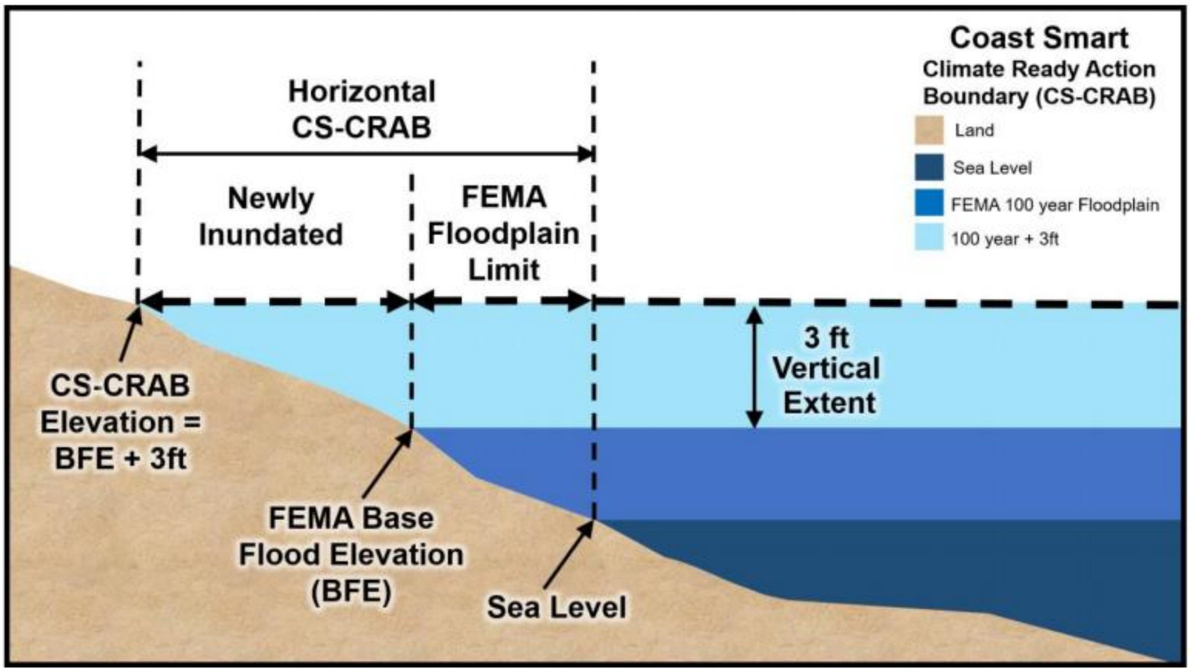


**Figure 6-1: Coast Smart Climate Ready Action Boundary (CS-CRAB) and Elevation**

Changes to development policies may have an impact on County revenues from changes to available developable land area. Further, revenue impacts may occur if repetitive flooding or SLR results in abandonment or buy-out of properties on a large scale.[24] A review of County data identified a substantial number of structures located within current FEMA SFHA. This included over 3,000 residential buildings, over 600 commercial buildings, 80 institutional structures and nearly 4,000 miscellaneous structures. **A county-wide economic analysis of potential impacts to County revenues from climate change, with a focus on SLR flooding, is recommended for further assessment to identify the potential economic impact from climate change.**

## 6.2 Integrating Resiliency into the Capital Improvement Program

There are good examples of incorporating resiliency into the capital budgeting process. The most concrete example is from FEMA, which encourages the integration of hazard mitigation into the Capital

[24] A related concern is the higher per capita cost to provide public services to isolated properties that remain after a flood event or flood buyout efforts.

Improvement Program (CIP) (FEMA, 2015). FEMA suggests three questions that local communities can ask about their CIPs and Infrastructure Policies to better incorporate hazard mitigation:

- Does the CIP provide funding for hazard mitigation projects identified in the hazard mitigation plan or include mitigation as a component to a redevelopment, renovation, or development project?
- Does the CIP limit or prohibit expenditures on projects that would encourage new development or additional development in areas vulnerable to natural hazards?
- Does your community have infrastructure policies that limit extension of existing infrastructure, facilities, and/or services that would encourage development in areas vulnerable to natural hazards?

At the local level, few examples of specific metrics for the procurement process were identified. The University of Maryland Environmental Finance Center report, *Integrating Resilience into Local Capital Improvement Programs: Best Practices for Maryland's Eastern Shore Communities* (2018), identified two case studies (Oakland, CA and Highland Park, NJ) of municipalities that included climate change and/or resilience in the CIP scoring process (Figure 6-2 and Table 6-1).

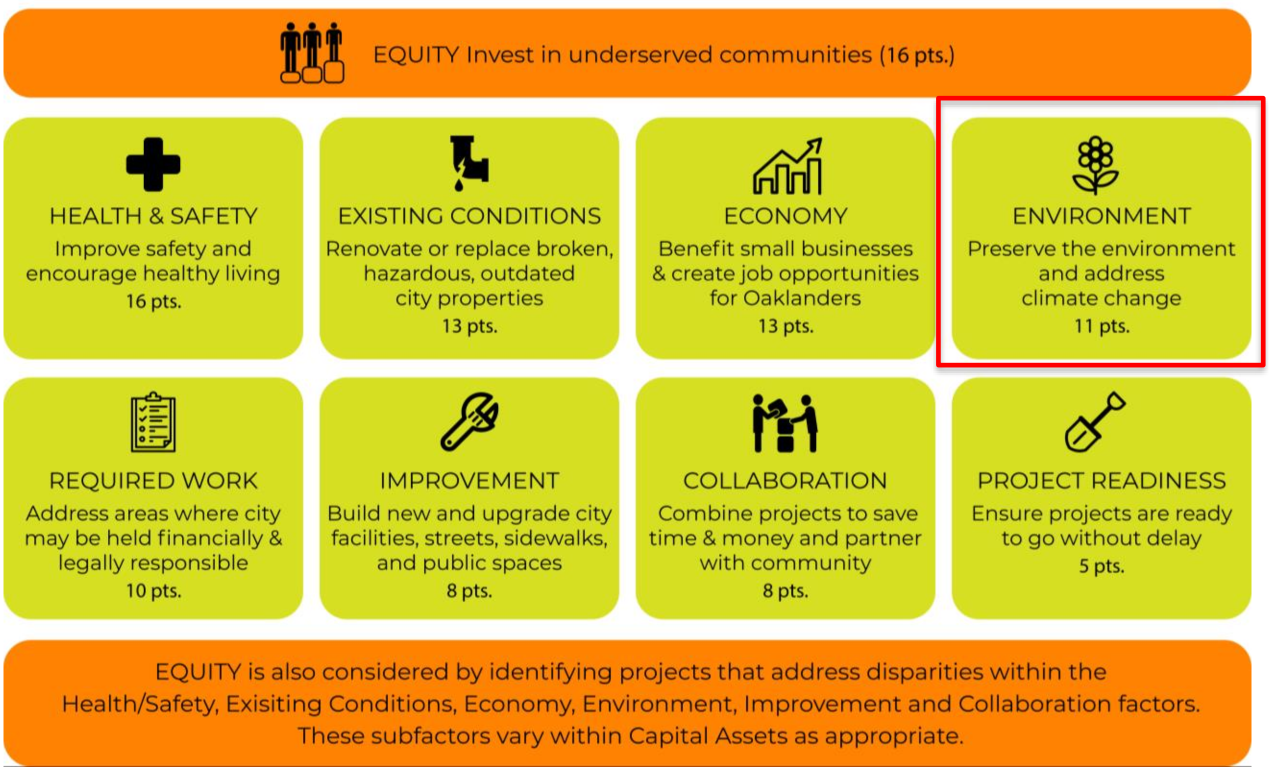


**Figure 6-2: Oakland, CA Citywide Prioritization for Capital Projects[25]**

[25] https://www.oaklandca.gov/topics/capital-improvement-program

**Table 6-1: Highland Park, NJ CIP Prioritization Scoring for Resiliency[26]**

| Scoring Criteria | Points |
|---|---|
| Project significantly enhances resiliency of town | 10 |
| Project moderately enhances resiliency of town | 5 |
| Project does not address resiliency | 0 |
| Resiliency can provide a maximum of six points out of 100 for capital project prioritization. | |

More commonly, a number of cities have highlighted the procurement process in their resiliency strategies. These cities may in time develop specific scoring metrics to implement the stated goals.

- Baltimore Disaster Preparedness and Planning Project (2018): *Develop City policy which requires new city government capital improvement projects to incorporate hazard mitigation principles.*
- Resilient Houston (2020): *Prioritize Resilience in City Budgeting, Procurement, And Capital Improvements.*
- Greater Miami, Resilient 305 (2019): *Steps include creating a baseline inventory of resilient procurement policies throughout the cities within Miami-Dade County.*
- Fort Collins, CO: *CIP updates will also revisit project prioritization by considering land-use changes, sustainability goals, evolving community values and equity.*

Since this is an emerging area, there are additional ideas that could be incorporated into the Baltimore County CIP process.

1. Project Identification – While not explicitly a procurement metric, developing studies to identify risks and vulnerabilities are necessary to ensure projects are on the County's list for consideration. For example, the County is currently developing its drainage assets inventory and management system, which is important for identifying drainage needs in the County.
2. Project Prioritization/Selection – Once projects are identified, there would need to be criteria for prioritizing and selecting projects.
    a. Does the project consider worsening extreme weather events in the future due to climate change?
    b. What is the project's effect on existing flood-prone areas?
    c. What is the project's effect on responding to emergencies/natural disasters?
    d. What is the project's effect on recovering from emergencies/natural disasters?
    e. Does the project have a positive cost benefit for infrastructure damage (i.e., cost of project vs emergency costs avoided)?
    f. Does the project have a positive cost benefit for citizen mortality/morbidity?

[26] https://www.hpboro.com/Home/ShowDocument?id=2

Baltimore County's Fiscal Year 2022 Capital Improvement Program required that departments address issues of climate change and resiliency in their submissions. The process has not concluded so there has been no analysis of the ways that agencies responded. Going forward, it is recommended the County should review and potentially revise the questions posed and criteria it used for incorporating resilience into the CIP process.

# 7. Summary Recommendations

This assessment is the first step to establish the framework for assessing climate vulnerabilities and identify next steps to broaden the evaluation Countywide. This section summarizes the climate change recommendations, projects to address vulnerabilities, and additional standards and procedures for consideration by the County.

## Climate Change Projections

The following is a summary of the climate changes projections developed for County resilience planning.

Table 7-1 and Table 7-2 present recommendations for important temperature metrics based on climate modeling.

**Table 7-1: Projected Extreme Heat Days (Maximum Daily Temperature above 95° F) for Baltimore County**

| Decade | Historical (avg days/year) | Projections (avg days/year) |
|---|---|---|
| 1996-2005 (Historical) | 2.8 (Historical range 0-9 days/year) | - |
| 2050 | - | 20.5 |
| 2080 | - | 25.9 |

**Table 7-2: Projected Heating and Cooling Degree Days for Baltimore County**

| Decade | Cooling Degree Days in °F | Heating Degree Days in °F |
|---|---|---|
| 1996-2005 (Historical) | 600 | 2636 |
| 2050 | 971 (+371) | 2176 (-460) |
| 2080 | 1059 (+459) | 2061 (-575) |

It is recommended the County adopt increased design storm precipitation rates, across all recurrence frequencies, to improve County resilience of drainage infrastructure (Table 7-3).

**Table 7-3: Recommended Increase in Design Storm Precipitation**

| Decade | Percent Change |
|---|---|
| 2050 | +15% |
| 2080 | +30% |

The recommended SLR estimate for resilience planning in Baltimore County is 1.6 feet by 2050 and 2.6 feet by 2080 (Table 7-4). These projections are conservative, but reasonable, based on the *Sea-level Rise: Projections for Maryland 2018* report by the University of Maryland Center for Environmental Science.

**Table 7-4: Sea Level Rise Projections**

| Decade | SLR Projection | Average High Tide Elevation (NAVD 88) | Occasional Nuisance Tidal Flooding Elevation (NAVD 88) |
|---|---|---|---|
| 2020[27] | 0.45 feet | 1.3 feet | 3.1 feet |
| 2050 | 1.6 feet | 2.4 feet | 4.2 feet |
| 2080 | 2.6 feet | 3.4 feet | 5.2 feet |

Global greenhouse gas emissions, climate science and climate modeling continue to evolve. Therefore, it is recommended that climate projections be revisited approximately every five years to capitalize on scientific developments and up-to-date emissions data, helping to ensure adequate planning is provided for future conditions.

## Infrastructure Project Recommendations to Reduce County Vulnerabilities

The following projects were identified as providing substantial benefits in terms of reducing vulnerability and expanding resilience.

- The following County-owned facilities were identified as being vulnerable to flooding. Conceptual level cost estimates for floodproofing construction are provided in present value from unit costs in the Adaptation Catalog. Refer to Appendix A for the Adaptation Catalog.
  - Police Marine Unit – Review floodproofing options for the facility with the State of Maryland, which owns the property and buildings. The dock is owned by the County, and

[27] SLR projections in the scientific literature are based on change since 2000. Sea level observations were analyzed to estimate the amount of rise between 2000 and 2020.

it is recommended the dock be upgraded to improve resilience to sea level rise and storm surge. Costs vary based on resilience needs.

- Brooklandville Fire Department – Floodproofing is needed to protect the facility from damage from riverine flooding and raising the access road is needed to maintain operations during a flood event. Follow up building site surveys should be performed to confirm assumptions and identify all important features necessary for implementing flood adaptation. Estimated costs for floodproofing are $60,000 to $100,000. Estimated costs for raising approximately 800 feet of driveway are $600,000 to $1,800,000.
- Watersedge Community Center – Floodproofing is needed to protect the facility from damage from storm surge flooding. Follow up building site surveys should be performed to confirm assumptions and identify all important features necessary for implementing flood adaptation. Estimated costs for floodproofing are $60,000 to $100,000.
- Sollers Point Community Center– Floodproofing is recommended to protect the facility from damage from storm surge flooding. Follow up building site surveys should be performed to confirm assumptions and identify all important features necessary for implementing flood adaptation. Estimated costs for floodproofing are $100,000 to $180,000.
- Northeast Regional Community Center – Floodproofing is recommended to protect the facility from damage from riverine flooding. Follow up building site surveys should be performed to confirm assumptions and identify all important features necessary for implementing flood adaptation. Estimated costs for floodproofing are $100,000 to $180,000.
- Sunnybrook Wells #7 and #9 – Floodproofing of the well and wellhouses is recommended to protect the facilities from damage from riverine flooding. Follow up building site surveys should be performed to confirm assumptions and identify all important features necessary for implementing flood adaptation. Estimated costs for floodproofing are $10,000 to $20,000.
- Sanitary Sewer Pump Station floodproofing – Between this plan and the recently completed *Pump Station Resiliency Assessment*, a total of 55 pump stations were identified as having medium to high flood vulnerability. The *Pump Station Resiliency Assessment* was more detailed and reviewed as-built plans for 24 stations but did not develop cost estimates for resiliency improvements. Because of the number of stations, it is recommended that a recurring CIP budget be established to address the risks over time to improve overall system resilience. Stations should be prioritized for upgrades based on the rankings from the two assessments. Refer to Appendix F for pump station risk rankings. Cost varies per station based on individual resilience needs.

- Elevation certificates should be drafted or updated for County buildings located in or near FEMA Special Flood Hazard Areas (SFHA). Further, the County can expand this service to private property, which will support incentives and discounts through the National Flood Insurance Program.

- Continue to evaluate the need for stationary and portable backup power generation and the possibility of microgrids to support resilience for critical infrastructure from power outages. Expand the inventory of generators and/or develop microgrids, as necessary. Continue to install transfer switches at key facilities for rapid deployment of portable backup power. Cost varies per equipment sizing requirements and type.

- Evaluate the opportunities for upgrading HVAC systems to maintain efficiency as temperatures increase.

- Implement resiliency upgrades to raise road segments in the FEMA SFHA identified as the highest priority from the transportation analysis (Table 7-5). It is further recommended to cross reference these roads with the County Fire Department's maps of roads to avoid during heavy rainfall, which may help further prioritize roads in need of improvement. Refer to Appendix J for a full list of roads identified. Cost varies per flood depth, length, cross streets, driveways and other features.

**Table 7-5: Highest Ranked Roads from the Transportation Analysis of Baltimore County Roads in the Flood Zone**

| Roadway Name | Roadway Name |
|---|---|
| Leeds Ave | Windsor Mill Rd |
| Philadelphia Rd | York Rd |
| Pulaski Hwy | Woodlawn Dr |

- Conduct assessments of coastal flooding resiliency options for local neighborhoods (e.g., Turner Station, Bowley's Quarters, Swan Point, etc.). Estimated costs are $75,000 to $150,000 per assessment.

- Expand the Climate Action Plan to include community wide impacts, including historic/cultural resources, natural resources, public health, etc. Estimated costs are $75,000 to $150,000.

- Conduct detailed modeling analyses of local areas of the County at risk of flooding to incorporate future rainfall projections into flood zone extents. Further develop green infrastructure, surface conveyance and other adaptation options to improve local drainage. Costs vary.

- For flood vulnerability from impacted storm drain systems, as identified by submerged outfalls and historic streams, it is recommended that localized hydrologic and hydraulic modeling be conducted to confirm risk and for design of storm drain system improvements. Costs vary.

- It is recommended the County conducts modeling in small drainage basins (less than one square mile) at risk of inland flooding to augment the FEMA SFHA mapping and eliminate development in flood-prone areas. Costs vary.

- Evaluate revenue impacts from abandonment or buy-out of flood-prone properties. Estimated costs are $100,000 to $150,000.
- Conduct a site survey of structures at parks identified as being vulnerable to flooding and initiate projects to upgrade or relocate at risk facilities. Estimated costs are $100,000 to $200,000.

### Standards and Procedures Recommendations to Improve County Resilience

Updates to standards and procedures are needed in order to improve resiliency. As a matter of priority, development and redevelopment in vulnerable areas should be rapidly reduced as development-related County investments would become vulnerable to climate change impacts.

- The Decision Memorandum dated May 1, 2020 titled “County Flooded Property Purchase and Drainage Program Review” is incorporated by reference in the CAP. It is recommended the County implement all the recommendations from the memo as they would increase resiliency. Refer to Appendix B for the full memo.
- It is recommended that, going forward, all County codes, plans and ordinances acknowledge and address, as appropriate, climate change, sea level rise, flood vulnerability, extreme storms, and temperature increases.
    - County Master Plan and Community Plans
    - Land Preservation, Parks and Recreation Plan (2017)
    - Hazard Mitigation Plan (2015)
    - Small Watershed Action Plan(s)
    - Watershed Implementation Plans
    - Stormwater Management Regulations, Checklists, & Forms (2007 plus updates)
    - Comprehensive Manual on Design Policies (2008)
    - Local Open Space Manual (2000)
    - Landscape Manual (2000)
    - Community Plans
- It is recommended the County adopt the Maryland Coast Smart Climate Ready Action Boundary (CS-CRAB) for any new County facility. The CS-CRAB extends the coastal FEMA SFHA base flood elevation vertically by three feet, as well as inland. It is further recommended to review applicability of the CS-CRAB for private sector development through changes to the County flood plain regulations.
- The County flood plain regulations do not allow new development by right in riverine flood zones. It is recommended the County consider expanding these regulations to prohibit new

construction in tidal flood zones. The goal would be to phase out and ultimately prohibit construction in vulnerable flood zones.

- Resilience should be incorporated into County review of critical privately-owned infrastructure (e.g., telecommunications towers).
- It is recommended that all County permits, reviews, and approvals incorporate flood risk and address flood resilience.
- It is recommended the County revise the criteria for CIP review to incorporate resilience metrics.
- It is recommended that standardized metrics be developed using the CDC Social Vulnerability Index, or other social equity data, to enable efficient integration of social equity considerations for planning and project selection.

In conclusion, there are relatively few County assets that were built in vulnerable locations that require adaptation for resilience. The County's sanitary sewer pump stations will require the most significant investment because of the number of facilities located in flood-prone areas. The County's vulnerable roads will also require significant investment to improve resilience to flooding. The expenditures needed to upgrade HVAC systems for County buildings, improve resiliency against power outages, and improve storm drain networks will also be substantial. Recognizing the risks, Baltimore County has been proactive and initiated efforts to identify and evaluate future climate change impacts on important County assets. The concerns, beyond County-owned facilities, are the neighborhoods and thousands of buildings that are, or will soon be, vulnerable to flooding, particularly in the coastal zone. Therefore, it is important to expand climate impact assessments beyond County-owned facilities to fully identify the scope and magnitude of potential impacts to the community in order to implement County-wide resiliency measures.

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