



U.S. Department  
of Transportation  
**Federal Highway  
Administration**

**FHWA Climate Resilience Pilot Program:**

**Maryland  
State Highway Administration**

The Federal Highway Administration’s (FHWA) Climate Resilience Pilot Program seeks to assist state Departments of Transportation (DOTs), Metropolitan Planning Organizations (MPOs), and Federal Land Management Agencies (FLMAs) in enhancing resilience of transportation systems to extreme weather and climate change. In 2013–2015, 19 pilot teams from across the country partnered with FHWA to assess transportation vulnerability to climate change and extreme weather events, and evaluate options for improving resilience. For more information about the pilots, visit [http://www.fhwa.dot.gov/environment/climate\\_change/adaptation](http://www.fhwa.dot.gov/environment/climate_change/adaptation).

**M**aryland’s transportation assets, especially those in close proximity to the state’s over 7,500 miles of shoreline and numerous rivers, are exposed to a variety of coastal and flooding hazards. Maryland State Highway Administration (SHA) conducted a vulnerability assessment in two counties. The project team developed a three-tiered vulnerability assessment and adaptation process using flood inundation modeling, mapping, vulnerability and risk ratings, and expert input. SHA engineers, planners, and maintenance personnel used the assessment results to brainstorm adaptation measures.



**Scope**

The assessment focused on two counties, selected for their differing representative locations and exposure to climate stressors (including sea level rise, storm surge, and increased intensity in precipitation). Somerset County, located on Maryland’s Eastern Shore, is representative of low-lying Eastern Shore counties between the Chesapeake Bay and Atlantic Ocean. Anne Arundel County, which abuts the Chesapeake Bay, is representative of counties along the Western Shore of Maryland. Both counties are considered at risk for sea level rise, storm surge, and riverine flooding.

Assets included in the vulnerability assessment were bridges and roadway segments. Small culverts and

drainage conveyances were more difficult to assess, due to a lack of location and condition data in some areas of the state and the complex interdependencies within each drainage area.

**Objectives**

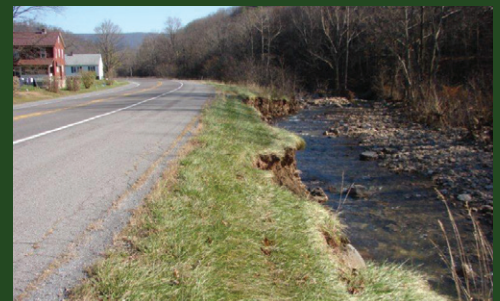
- Assess the vulnerability of SHA’s transportation assets to sea level rise, storm surge, and flooding.
- Review and consider design strategies, best management practices, planning standards, and other ways to support the adoption of adaptive management solutions to improve the resiliency of Maryland’s highway system.



Large culvert over Sawmill Creek in Anne Arundel County that is vulnerable to heavy precipitation. Photo credit: MD Department of Environment.



Roadway segment failure from a severe weather event. Photo credit: SHA.



Example of roadside erosion in Maryland. Photo credit: SHA.

# Approach

## Tier 1: Conduct preliminary screening

**Compile information about assets, historical exposure, and impacts.** Sources of asset information included SHA transportation engineers and planners, SHA and national asset data warehouses, road closure information, emergency evacuation route status, functional class, and drainage asset databases. The team used a geographic information system (GIS) to organize, present, and analyze the data in a single, cohesive format.

**Map climate scenarios for 2050 and 2100.** MD SHA partnered with the Eastern Shore Regional GIS Cooperative (ESRGC) at Salisbury University to develop GIS layers of statewide water surfaces for sea level rise projections, model coastal flooding to develop storm surge inundation maps, and model Chesapeake Bay's connected river system in the study area to map the depth of riverine flooding for precipitation events.

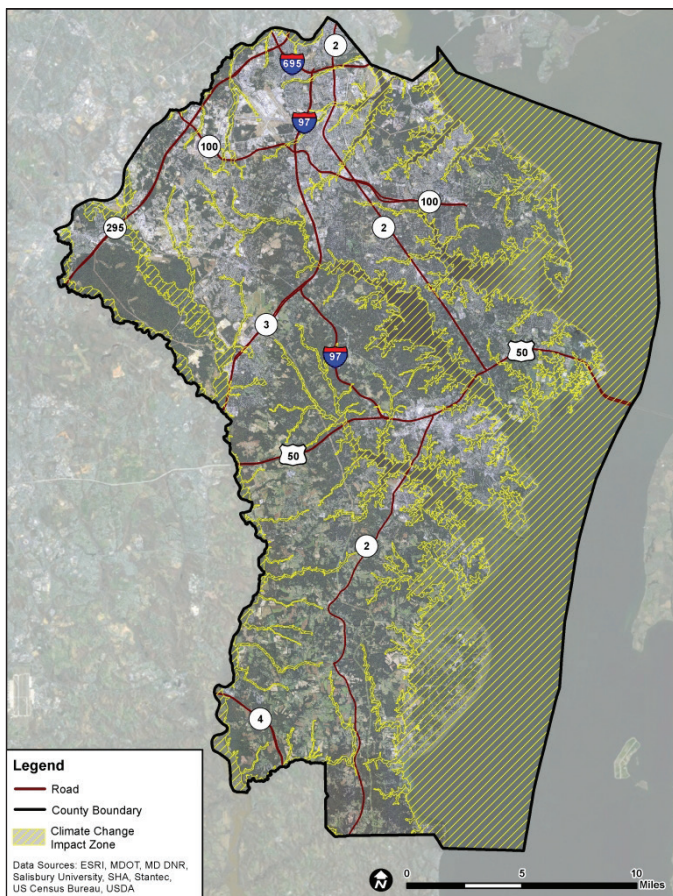


Figure 1: Climate Change Impact Zone for Anne Arundel County

**Screen for assets exposed to climate stressors.** The project team developed a Climate Change Impact Zone in GIS for each county to signify where assets could be exposed to sea level rise, storm surge, and flooding caused by heavy precipitation (see Figure 1). The Impact Zone was derived from sea level rise projections; Sea, Lake and Overland Surges from Hurricanes (SLOSH) models for a Category 3 hurricane; and Federal Emergency Management Agency (FEMA) 100-year floodplain boundaries. Assets outside of this zone were considered to have low exposure and were eliminated from more detailed analysis in order to focus the study on potentially vulnerable assets.

## Tier II: Conduct detailed vulnerability assessments by county

**Bridges.** The project team assessed bridges using the U.S. DOT Vulnerability Assessment Scoring Tool (VAST). Tool inputs included key asset information, climate data, and indicators of vulnerability. Tool outputs included scores for asset exposure, sensitivity, and adaptive capacity as well as a preliminary composite vulnerability score.

**Roads.** SHA and ESRGC developed the Hazard Vulnerability Index (HVI) to evaluate sea level rise and flooding vulnerability of roads. HVI is a calculation to compare risk of road segments based on functional class, evacuation route designation, and extent and depth of projected flooding.

**Small culverts and drainage conveyances.** Risk assessments for small culverts and drainage conveyances could not be completed due to lack of asset data and limited information regarding site hydraulics. Additional GIS reviews were conducted to identify which of these assets are in or adjacent to segments of impacted roadway identified using the HVI.

**Adjust scores and identify areas at risk.** The project team conducted a workshop with SHA's engineers to help refine the vulnerability indicators to better match the Maryland climate and asset context. The workshop participants ranked the VAST indicators based on how significant the indicators were in assessing an asset's vulnerability. More weight was given to indicators with the highest averaged rankings and those with better data quality. The VAST and HVI scores were listed and mapped for each pilot county to visualize areas at risk.

### Tier III. Specify adaptation measures on a site-specific basis

The results from VAST and HVI will inform which assets should advance to the Tier III analysis, which will utilize higher level engineering and site-specific data to determine appropriate adaptation measures.

“Climate change adaptation should be a coordinated effort, with information sharing occurring throughout the process.”

-Elizabeth Habic, MD SHA Pilot Team

## Key Results & Findings

**Vulnerability indicators.** Workshop participants identified indicators of most significance for assessing the vulnerability of the Tier II assets (see Table 1). The engineers’ input and data availability influenced the weight applied to each indicator in VAST.

**Vulnerable areas.** Geographic areas with a large number of assets ranked high-to-medium risk in this analysis were identified as “vulnerable areas at risk.” A significant portion of coastal roads within Somerset County are projected to be at risk by 2050 because the county’s flatter topography lends itself to further inland inundation of roadways. In Anne Arundel County, structures vulnerable to storm surge and sea level rise seem to cluster in certain areas, but there is no certain trend on the location of structures vulnerable to precipitation.

**Adaptation options.** The project team brainstormed general adaptation options for each of the asset categories with SHA engineers at the workshop. The options provide practitioners with an initial list of potential risk reduction measures for their review and consideration.

SHA concluded that system-wide adaptation solutions do not exist because of the many interdependencies driving vulnerability (including the nature of the climate stressor, asset characteristics, inter-related infrastructure, and the surrounding environment). For example, the conditions of nearby flood control structures need to be taken into consideration in assessing the vulnerability of SHA transportation assets and recommending adaptation options. Furthermore, most bridges, roadways, and small drainage

	Exposure	Sensitivity	Adaptive Capacity
<b>Sea Level Change</b>	<ul style="list-style-type: none"> <li>Sea Level Change Inundation Depth</li> <li>Elevation of Asset</li> </ul>	<ul style="list-style-type: none"> <li>Past Experience With Tides/Sea Level Change</li> <li>Approach Elevation</li> <li>Asset Clearance</li> </ul>	<ul style="list-style-type: none"> <li>Replacement Cost</li> <li>Detour Length</li> <li>Average Daily Traffic</li> <li>Access to Critical Areas</li> </ul>
<b>Storm Surge</b>	<ul style="list-style-type: none"> <li>Modeled Surge Inundation Depth</li> <li>Elevation of Asset</li> </ul>	<ul style="list-style-type: none"> <li>Past Experience With Storm Surge</li> <li>Scour Rating</li> <li>Condition of Bridge Substructure</li> <li>Asset Clearance</li> <li>Flood Protection</li> </ul>	
<b>Precipitation Changes</b>	<ul style="list-style-type: none"> <li>Change in Peak Discharge</li> <li>Change in Flow Velocity</li> <li>Change in Discharge Volume</li> <li>Location in 10-Year Floodplain</li> </ul>	<ul style="list-style-type: none"> <li>Past Experience With Precipitation</li> <li>Asset Clearance</li> <li>Scour Rating</li> <li>Overtop Frequency</li> </ul>	

Table 1: Vulnerability indicators that were rated “high significance” during a workshop with SHA’s engineers.

conveyances will require detailed watershed analyses to determine appropriate adaptation strategies. In the short term, enhanced maintenance programs may provide added coping capacity prior to identifying and implementing engineered solutions.

## Lessons Learned

**The tiered analysis approach was efficient.** The use of VAST to evaluate bridges and the development of HVI to evaluate roadway segments worked well and can serve as a useful model for future efforts.

**The availability of asset and climate data varied.** Asset data was most available for bridges; information on smaller culverts and drainage conveyances was more limited. As a result of limited data distinguishing

the exposure of assets to precipitation in 2050 and 2100, precipitation indicators that were ranked low significance were still used in the analysis. The project team also determined that, when assessing the vulnerability of structures to precipitation events, small, more frequent events such as the 1-year or 2-year storm are a better indicator of the structure or drainage asset vulnerability.

**Workshops provided an opportunity for comprehensive feedback from experienced personnel.** Asset-specific historic information provided by maintenance staff was utilized to validate the study's results. When available, maps particularly helped workshop participants visualize assets and their risks.

## Next Steps

**Expand the study.** SHA will evaluate the vulnerability of bridges and roadway segments statewide based on the methodology developed in the pilot. Additionally, SHA will undertake targeted data collection and broaden the scope to include other assets (e.g., drainage infrastructure, maintenance and operation facilities, and roadside assets).

**Implement Tier III analysis.** The Tier III analysis of the identified vulnerable areas at risk will involve more detailed assessments to better understand climate impacts and design adaptation strategies. Assessments may include detailed hydraulic modeling to further assess vulnerability; engineering evaluation of adaptation alternatives to assess the resiliency, costs, and environmental impacts; conflict analysis with policy and regulations; cost-benefit analyses; and assessment of the costs and risks of the “do nothing” alternative.

**Integrate into existing practices.** SHA plans to integrate the processes developed for this pilot project into current asset management and planning processes to inform policy actions and reduce vulnerability.

### For More Information

**Resources:**

**Maryland State Highway Administration  
Climate Change Adaptation Plan with Detailed  
Vulnerability Assessment**

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