

visualize
2045 **A long-range
transportation plan
for the National
Capital Region**

TPB Resiliency Study

November 2021



**RESILIENCY WHITE PAPER FOR THE VISUALIZE 2045
LONG-RANGE TRANSPORTATION PLAN
FOR THE NATIONAL CAPITAL REGION**

November 2021

ABOUT VISUALIZE 2045 & THE TPB

Visualize 2045 (approved in October 2018) is the federally required long-range transportation plan for the National Capital Region. It identifies and analyzes all regionally significant transportation investments planned through 2045 to help decision makers and the public “visualize” the region’s future. The quadrennial update to Visualize 2045 is underway, to be completed in 2022.

Visualize 2045 is developed by the National Capital Region Transportation Planning Board (TPB), the federally designated metropolitan planning organization (MPO) for metropolitan Washington. It is responsible for developing and carrying out a continuing, cooperative, and comprehensive transportation planning process in the metropolitan area. Members of the TPB include representatives of the transportation agencies of the states of Maryland and Virginia and the District of Columbia, 24 local governments, the Washington Metropolitan Area Transit Authority, the Maryland and Virginia General Assemblies, and nonvoting members from the Metropolitan Washington Airports Authority and federal agencies. The TPB is staffed by the Department of Transportation Planning at the Metropolitan Washington Council of Governments (COG).

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Introduction

For the purpose of this paper, resilience is “the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.”¹ Although such disruptions to the region’s transportation system can have many causes, this project focuses on disruptions relating to natural hazards, such as extreme heat or cold, extreme storm events, and flooding of all kinds – coastal flooding, flooding from rivers and streams, and flash floods that can occur away from bodies of water.

Metropolitan Washington has long dealt with these natural hazards, but recent trends are making it more important for the region’s leaders to plan for improved resilience. As the region’s population and infrastructure investments grow, these hazards pose increased risks to our people and economy. The past decade has seen an uptick the intensity, frequency, and duration of these natural hazards as the climate has begun to change. The importance of resilience is not only important to the region but to the nation, leading Congress to add resilience and stormwater as factors that transportation agencies must consider when planning.



Figure 1. Damage to Hunter Mill Road in Fairfax County from Tropical Storm Lee (2011). Source: Flickr/VDOT

Key Terms and Co-Benefits

Many strategies to improve resilience to natural hazards are also effective for addressing other challenges the region faces. Rather than trying to categorize a particular strategy into only one bucket, it can be helpful to think of strategies as having co-benefits across many issue areas. Some of these issue areas that overlap with resilience to natural hazards include:

- **Climate change mitigation**, which reduces or removes greenhouse gas emissions from the atmosphere.
- **Climate change adaptation**, which is very similar to climate resilience, prepares for potential climate disruptions so that the consequences can be minimized.
- **Hazard mitigation** “means any sustained action taken to reduce or eliminate the long-term risk to human life and property from hazards.”²
- **Resilience to manmade hazards** applies the resilience concept to hazards created by humans, such as hacking or acts of terrorism.
- **Social equity** refers to issues of fairness and justice. In July 2020, the National Capital Region Transportation Planning Board (TPB) adopted Resolution R1-2021 establishing equity

¹ United States Department of Transportation (USDOT) Federal Highway Administration (FHWA). December 2014. “FHWA Order 5520.” Available at: <https://www.fhwa.dot.gov/legregs/directives/orders/5520.cfm#par6>.

² 44 CFR § 201.2.

as a fundamental value and integral part of all the TPB’s work activities.³ This resolution commits the TPB to:

- Work to be anti-racist and advance equity in each debate and decision.
- Weave equity into all its activities to “ensure a more prosperous, accessible, livable, sustainable, and equitable future for all residents.”
- Act to correct inequities created by past actions and existing institutionalized policies and practices that have been exclusionary or had disparate impacts on people of color and marginalized communities.
- **Sustainability** describes approaches that meet the needs of the present without compromising the needs of future generations. Sustainability is usually described as having three interlocking components:
 - **Economic sustainability:** meeting today’s economic needs without impairing the economic, environmental, or equity needs of future generations.
 - **Environmental sustainability:** meeting today’s environmental needs without impairing the environmental, equity, or economic needs of future generations.
 - **Equity sustainability:** meeting today’s social equity needs without impairing the equity, economic, or environmental needs of future generations.

To illustrate these key terms and co-benefits, consider using solar panels and reserve batteries to power the lighting and real-time display at a bus stop.

- Resilience to natural hazards: If a storm causes power outages, the bus stop will still have power.
- Climate change mitigation: The solar power reduces greenhouse gasses (GHGs) by not using a coal-fired power plant for power.
- Climate change adaptation: Installation of the solar power prepared that bus stop to adapt to increased likelihood of extreme temperatures or storms that would cause power outages.
- Hazard mitigation: If the solar power can provide lighting during a power outage, it reduces the risk of injuries or property loss.
- Resilience to manmade hazards: If a hacker causes a power outage, the bus stop will still have power.
- Social equity: Installation can prioritize neighborhoods where more people rely on buses for transportation or where pedestrians are at higher risk from vehicle crashes.
- Sustainability: Economic sustainability is achieved by reducing the long-term power costs at the bus stop; environmental sustainability by using a renewable resource for power; and equity by applying the approach in the neighborhoods most in need of resilient power.



Figure 2. Solar-powered Capitol Bikeshare station.
Source: Flickr/WashCycle.

For the purposes of this study, resilience is defined as “the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions”⁴ caused by natural hazards.

³ COG. 2020. Resolution R1-2021 - Resolution to Establish Equity as a Fundamental Value and Integral Part of all Transportation Planning Board’s Work Activities. <https://www.mwcog.org/documents/2020/07/22/resolution-r1-2021---resolution-to-establish-equity-as-a-fundamental-value-and-integral-part-of-all-transportation-planning-boards-work-activities/>

⁴ FHWA. December 2014. “FHWA Order 5520.” Available at: <https://www.fhwa.dot.gov/legisregs/directives/orders/5520.cfm#par6>

While this study is focused on the definition of resiliency as provided above, the TPB acknowledges that the resilience of the transportation system can be viewed through other lenses, for example, the transportation system plays an important role in emergencies ranging from everyday traffic incidents to major disasters. Many events over the years, notably the attacks of September 11, 2001, serve as reminders that the region must be as prepared as possible. Preparedness and security are key concerns of and have been longstanding planning activities on the part of the Metropolitan Washington Council of Governments (COG) and the TPB. Visualize 2045 both supports and reflects a wider-ranging set of emergency preparedness planning activities. The TPB coordinates efforts with the COG’s Homeland Security and Public Safety program, which brings together emergency preparedness and public safety officials from across the region. Together, COG and the TPB help facilitate coordination across the region to ensure the preparedness, resiliency, and safety of our transportation system. Federal, state, and regional homeland security requirements are fulfilled through numerous COG committees that convene transportation and public safety subject matter experts, especially COG’s Transportation Emergency Preparedness Committee. For more information, visit mwcog.org/public-safety-and-homeland-security/.

Relationship to Other TPB and COG Work

COG and the TPB are working extensively with their member agencies and partners on approaches to prepare the region for climate change and other hazards. This white paper is a product of the second of three recent and ongoing complementary studies:

1. COG’s 2030 Climate and Energy Action Plan contains voluntary actions relating to both mitigation and adaptation/resilience. As a COG product, the 2030 Plan provides a cross-sector approach with only high-level information relating to transportation resilience.
2. The TPB Resiliency Study: Adaptation Planning and Coordination takes a deeper dive into preparing the region for transportation resilience. This study looks at resilience to natural hazards that have always occurred in the region as well as the increase in intensity, frequency, and duration of natural hazards due to climate change. This white paper is a product of the TPB Resiliency Study.
3. The TPB Climate Change Study of 2021 is evaluating scenarios of strategies for reducing GHG emissions from the transportation sector.

This TPB Resiliency Study, and the products and activities associated with the study, promote the implementation of several of the COG 2030 Climate and Energy Action Plan initiatives. This study researched and documented existing work by transportation agencies to plan for resilience as part of the TPB’s efforts to:

- Respond to federal planning requirements.
- Advance important planning work and regional coordination on the topic of resiliency, one of the TPB’s policy priorities.

Report Structure

This report will be included as an appendix to the Visualize 2045 update. This report describes how the TPB is incorporating resilience into its long-range transportation planning. The purpose of this report is to understand the current landscape of resilience-related work for transportation infrastructure so that COG and the TPB can identify next steps and resilience strategies to undertake or support. This report includes the following sections:

- **Section 1: Defining Resilience:** Definition of resilience and how other transit agencies, particularly metropolitan planning organizations (MPOs) and regional departments of transportation (DOTs), are defining resilience.
- **Section 2: Federal Requirements:** The federal regulations that require COG and other planning agencies to incorporate resilience into their transportation planning.
- **Section 3: TPB Resilience and Climate Work:** Initiatives that COG and the TPB have already implemented related to resilience and climate change preparedness.
- **Section 4: Public Opinion and Equity Considerations:** Public perceptions and equity considerations to take into account when incorporating resilience into transportation planning.
- **Section 5: Vulnerability Analysis Summary:** Summary of high-level findings from vulnerability assessments of different agencies.
- **Section 6: Strategies for Resilience:** Summary of high-level resilience strategies of different agencies.
- **Section 7: MPO Role:** The TPB's role in advancing resiliency planning and regional coordination.
- Conclusion

Section 1: Defining Resilience

COG and the TPB are working extensively on approaches to prepare the region for climate change and other hazards. Both boards have established climate change goals via the October 2020 Resolution R45-2020. Key elements of the resolution relevant to this study include:

- Committing to becoming a Climate Ready Region and making significant progress toward being a Climate Resilient Region by 2030.
- Recognizing the need to incorporate equity principles and expand climate change education to influence member jurisdictions’ ability to reach the climate mitigation and resiliency goals.

The TPB has not defined resilience, but COG’s 2030 Climate and Energy Action Plan provided initial definitions of a Climate Ready Region and a Climate Resilient Region:

- The region will be a Climate Ready Region when all local governments have assessed current and future climate risks and are actively integrating climate planning into government planning, operations, and communications.
- A Climate Resilient Region will be achieved when the region has the “ability to adapt and absorb against disturbances caused by current and future, acute and chronic climate impacts and successfully maintain essential functions.”

This study follows the Federal Highway Administration’s (FHWA) lead, defining resilience as “the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.”⁵ The study focuses on the narrow set of disruptions that can occur because of natural hazards. The natural hazards examined for this project are hazards the region already faces but that are expected to increase in intensity, frequency, and duration because of our changing climate. These hazards include extreme heat or cold, extreme storm events, and flooding of all kinds – coastal flooding, flooding from rivers and streams, and flash floods that can occur away from bodies of water.



Figure 3 A flooded street and crosswalk.
Source: Amanda Farber

Many state DOTs, MPOs, and local governments are describing resilience using terms similar to FHWA’s, as they prepare for and recover from disruptive events while improving daily operations to adapt to gradual climate change. Table 1 provides examples of how resilience was described in some documents of the region’s jurisdictions. Table 2 provides some examples from outside the region. These tables do not show formally adopted definitions of resilience for each agency, but rather give examples of how various plans and documents have described resilience.

Table 1: Examples of How the TPB Member Documents Describe Resilience

Agency (Document)	Definition
Arlington County, Virginia (Community Energy Plan)	“The ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions caused by

⁵ Federal Highway Administration. December 2014. “FHWA Order 5520.” Available at: <https://www.fhwa.dot.gov/legisregs/directives/orders/5520.cfm#par6>

Agency (Document)	Definition
	deliberate attacks, accidents, climate change, or weather-related threats or incidents.” ⁶
Charles County, Maryland (Climate Resilience Action Strategy)	“The ability to prepare for, recover from, and adapt to climate change impacts and the capacity of a system to maintain essential functions before, during, and after a hazard strikes.” ⁷
Government of DC (Resilient DC)	“Urban resilience is the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and thrive no matter what kinds of chronic stresses and acute shocks they experience.” ⁸
Maryland DOT (2020 Annual Attainment Report)	“Provide a resilient multimodal system by anticipating and planning for changing conditions and hazards whether natural or man-made.” ⁹
Montgomery County, Maryland (Climate Action Plan)	“Ability to withstand and recover from a climate hazard.” ¹⁰

Table 2: Examples of How Other Agencies Have Defined Resilience

Agency (Document)	Definition
Delaware DOT (Strategic Implementation Plan for Climate Change, Sustainability and Resilience for Transportation)	“Encompass[ing] the ability to withstand and recover from an incident in order to provide critical transportation services during the incident and through the recovery process.” ¹¹
Hampton Roads, Virginia Planning District Commission (Climate Change in Hampton Roads)	“The ability to recover quickly with minimal lasting damage from an event.” ¹²
Metropolitan Council, St. Paul, MN (2040 Thrive MSP)	“Resilience strategies recognize the difficulty of predicting what the impacts of climate change will be and emphasize increasing our flexibility to survive and thrive regardless of how climate change develops.” ¹³

⁶ Arlington County. 2019. Community Energy Plan. <https://arlingtonva.s3.amazonaws.com/wp-content/uploads/sites/13/2019/10/Final-CEP-CLEAN-003.pdf>

⁷ Charles County. 2020. Charles County Climate Resilience Action Strategy. [https://go.boarddocs.com/md/chrisco/Board.nsf/files/BRPH9Y477904/\\$file/Charles%20County%20Climate%20Resilience%20Action%20Strategy%207.13.2020.pdf](https://go.boarddocs.com/md/chrisco/Board.nsf/files/BRPH9Y477904/$file/Charles%20County%20Climate%20Resilience%20Action%20Strategy%207.13.2020.pdf)

⁸ 100 Resilient Cities and Government of the District of Columbia. 2019. Resilient DC: A Strategy to Thrive in the Face of Change.

⁹ MDOT. 2020. 2020 Annual Attainment Report. https://mdot.maryland.gov/OPCP/Attainment_Report_2020_01_12_LR_Single.pdf

¹⁰ Montgomery County. 2020. Montgomery County Climate Action Plan. <https://www.montgomerycountymd.gov/green/Resources/Files/climate/draft-climate-action-plan-printable.pdf>

¹¹ DelDOT. 2017. Strategic Implementation Plan for Climate Change, Sustainability and Resilience for Transportation.

¹² Hampton Roads Planning District Commission. 2010. Climate Change in Hampton Roads: Impacts and Stakeholder Involvement. Available at: https://www.hrpdcva.gov/uploads/docs/Climate_Change_Final_Report_All.pdf

¹³ Metropolitan Council. 2040 Thrive MSP: One Vision, One Metropolitan Region. Available at: [https://metro council.org/Planning/Publications-And-Resources/Thrive-MSP-2040-Plan-\(1\)/ThriveMSP2040.aspx](https://metro council.org/Planning/Publications-And-Resources/Thrive-MSP-2040-Plan-(1)/ThriveMSP2040.aspx)

Agency (Document)	Definition
Northeast Ohio Areawide Coordinating Agency, Cleveland, OH (Aim Forward 2040)	“Resiliency is a process for managing complex infrastructures rather than a single outcome ... Embedded in [the resiliency framework] is the capability to protect its assets, anticipate and detect threats, prevent risks of known failures, withstand unanticipated disruptions, and respond and recover rapidly when the worst does happen.” ¹⁴
NVRC (Resilient Critical Infrastructure: A Roadmap for Northern Virginia)	“Resilient systems work to ‘ensure that functionality is retained and/or can be re-instated despite some failures or operational disturbances’. (from Moench and Tyler’s Framework for Urban Climate Resilience)” ¹⁵
San Diego Association of Governments, San Diego, CA (San Diego Forward)	“Making our region more resilient to the consequences of climate change means increasing the capacity of our communities, economy, and environment to cope with hazardous events such as storms, heat waves, wildfires, and ongoing drought.” ¹⁶

¹⁴ Northeast Ohio Areawide Coordinating Agency (NOACA). June 2017. “Aim Forward 2040.” Available at: <http://www.noaca.org/index.aspx?page=7544>

¹⁵ NVRC and COG. 2018. Resilient Critical Infrastructure: A Roadmap for Northern Virginia. <https://www.novaregion.org/DocumentCenter/View/11933/Resilient-Roadmap-Final-PDF>

¹⁶ SANDAG. San Diego Forward: The Regional Plan. Available at: http://www.sdfoward.com/pdfs/Final_PDFs/The_Plan_combined.pdf

Section 2: Federal Requirements

This research study responds to federal regulations in addition to proactively planning for the region’s future. In 2015, Congress enacted provisions in the Fixing America’s Surface Transportation (FAST) Act requiring transportation agencies to consider resilience in their transportation planning processes; however, the method through which they consider resilience is up to individual agencies. Table 2 shows federal resilience regulations for MPOs and provides the regulatory source and context in which the regulation applies.

Looking forward, the re-authorization of the FAST Act in September 2021 will likely include funds set aside for resilience grants, emergency evacuation needs, and making resilience a core part of the federal-aid highway program.¹⁷

Table 3: Federal Regulations That Direct Resilience Considerations for MPOs

Type	Regulatory Text	Source and Context
Factor into planning	Each MPO shall carry out a continuous, cooperative, and comprehensive metropolitan transportation planning process that provides for “consideration and implementation of projects, strategies, and services that will address the following factors: ... (9) Improve the resiliency and reliability of the transportation system and reduce or mitigate stormwater impacts of surface transportation.”	23 CFR Part 450.306(b) As a Factor in the 3C Planning Process
Consult with other agencies	“(b) In developing metropolitan transportation plans and TIPs, the MPO should consult with agencies and officials responsible for other planning activities within the MPA that are affected by transportation (including State and local planned growth, economic development, tourism, natural disaster risk reduction, environmental protection, airport operations, or freight movements) or coordinate its planning process (to the maximum extent practicable) with such planning activities.”	23 CFR Part 450.316(b) Interested parties, participation and consultation
Assess capital investment strategies	“The metropolitan transportation plan shall, at a minimum, include ...” an “assessment of capital investment and other strategies to preserve the existing and projected future metropolitan transportation infrastructure, provide for multimodal capacity increases based on regional priorities and needs, and reduce the vulnerability of the existing transportation infrastructure to natural disasters.”	23 CFR Part 450.324(f)(7) Metropolitan transportation plan contents

Other federal laws and policies emphasize the importance of considering resilience, but do not place requirements on state DOTs and MPOs:

- In 2015’s FAST Act, Congress established a goal of the National Highway Freight Program to “improve the ... resiliency of freight transportation in rural and urban areas.” (23 U.S.C. 167).

¹⁷ Coalition for Smarter Transportation. N.d. FAST Act Re-Authorization Resource Center. <http://www.smartertransportation.org/fast-act-re-authorization-resource-center/>

- FHWA's 2014 Order 5520 Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events directs the agency to encourage state DOTs and MPOs to integrate resilience into transportation planning.
- The United States Department of Transportation (USDOT) Strategic Plan for FY 2018-2022 commits DOT to "increase its effectiveness in ensuring that infrastructure is resilient enough to withstand extreme weather."
- 44 CFR Part 201 directs all states to prepare and submit to the Federal Emergency Management Agency (FEMA) a state hazard mitigation plan which identifies vulnerabilities, develops long-term strategies for risk reduction, and communicates implementation approaches and priorities. A FEMA-approved hazard mitigation plan is a requirement for receiving non-emergency disaster assistance, including funding mitigation projects.¹⁸
- The Department of Homeland Security's 2013 National Infrastructure Protection Plan prioritizes funding efforts where they can have the biggest effect on America's resilience to risk.

¹⁸ More information on the purpose and requirements of State hazard mitigation planning is available on FEMA's website at <https://www.fema.gov/hazard-mitigation-planning>.

Section 3: COG and TPB Resilience Publications



*TPB Resiliency Study refers to this project

Further details on COG publications follow:

- **2013:** Climate Energy and Environment Policy Committee (CEEPC) Final 2013-2016 Action Plan.
 - The CEEPC Action Plan is a list of short-term goals and actions that will assist the region in achieving the long-term Region Forward targets and goals in the 2008 National Capital Region Climate Change Report.
- **2014:** Building a Climate Resilient National Capital Region report.¹⁹
 - From fall 2013 to spring 2014, the National Capital Planning Commission (NCP), the General Services Administration (GSA), the National Aeronautics and Space Administration (NASA), COG, the U.S. Global Change Research Program, and the Smithsonian Institution sponsored two series of webinars and workshops to assist with climate adaptation planning and improve regional coordination. This report describes the project outcome.
- **2015:** Climate Energy and Environment Policy Committee Final 2013-2016 Action Plan Resource Guide (updated July 2015)
 - The resource guide provides a description, best practice examples, and resources for all the implementation actions in the 2013-2016 CEEPC Action Plan. The purpose of the Resource Guide is to assist COG member jurisdictions with understanding and implementation of the actions in the 2013-2016 CEEPC Action Plan.
- **2017:** Environmental Justice Toolkit²⁰
 - Guidance to policymakers on incorporating social equity, cultural sensitivity, and community health considerations into air quality, climate, and energy planning.
- **2020:** Metropolitan Washington 2030 Climate and Energy Action Plan²¹
 - Builds on previous regional action plans and establishes priority collaborative actions for COG’s CEEPC members to work on together over 10 years to help move the region towards meeting its 2030 goals.
- **2021:** COG meets global standards for climate planning.
 - The Global Covenant of Mayors for Climate and Energy (GCoM) found COG’s regional greenhouse gas emission reduction goals and Metropolitan Washington 2030 Climate and Energy Action Plan fully compliant with the global standards of best practices for climate planning. GCoM awarded COG “Mitigation” and “Adaptation” achievement badges in recognition. Metropolitan Washington is the first region in the United States to achieve this status.²²

¹⁹ Building a Climate Resilient National Capital Region | Metropolitan Washington Council of Governments (mwkog.org)

²⁰ COG. 2021. Environmental Justice Toolkit. <https://www.mwkog.org/documents/2017/07/27/environmental-justice-toolkit/>

²¹ COG. 2020. Metropolitan Washington 2030 Climate and Energy Action Plan.

²² Metropolitan Washington meets global standards for climate planning - News Release - News | Metropolitan Washington Council of Governments (mwkog.org)

Section 4: Public Opinion and Equity Considerations

Planning for resiliency is not just a technical analysis activity but one with real-world implications and consequences for the region’s residents. Climate change and resilience is important to the region’s residents, who raised these issues in response to the TPB’s recent outreach efforts. In addition to addressing public opinion, the TPB is working to understand the potential equity impacts of natural hazard risks and of the actions of transportation agencies.

Public Opinion

Through its “Voices of the Region” effort, the TPB conducted public opinion research on a range of the TPB priorities and policies in fall 2020 through a statistically significant survey and through focus groups that supplemented the survey in 2021. As planning for a resilient region is a COG and the TPB priority, questions about equity, safety, and climate change and resiliency were included in this research.

Residents in the region are concerned about climate change and transportation. The “Voices of the Region” survey found that 84 percent of residents agree that elected officials need to consider the impacts of climate change when planning for transportation in the future, with 72 percent strongly agreeing with the statement. People under 30 years of age especially agreed (92 percent somewhat or strongly agreeing) that elected officials should consider climate change impacts in planning.²³



Figure 3. Heavy snow in 2010.
Source: Blake Patterson/Flickr.

At the end of the survey, respondents could write recommendations for the future of the transportation system, and a large percentage of respondents volunteered the following strategies relevant to climate-resilient transportation:

- Reduce emissions, go climate neutral, reduce our carbon footprint.
 - Adopt “green” options, energy, technology, alternatives.
 - Use renewable energy, such as solar power.
- Improve appeal and use of transit and active transportation modes by providing more shelter and shade.
- Implement more nature-based solutions.
 - Preserve and add natural land, open space, green spaces, and native trees.
 - Install green space on parking garages (replacing parking lots) and subway stations.
 - Install rain gardens and other green infrastructure.
 - “Plant more street trees – safety, shade, air quality, storm-water management, quality of life, connection with the natural world.”
- Shorten and reduce commutes.
 - Encourage employers to establish branch offices near their employees.
 - Encourage telework by investing in digital infrastructure.
- Reduce impervious surfaces; increase water protection and infiltration (absorbable pavement).

²³ ICF. 2021. “Voices of the Region” Survey Final Report.

- Maintain and fix the current transportation infrastructure. “Keep our roads in good shape – both the blacktop and the surrounding greenery.”
- Improve the resilience of the Metrorail system.
 - Flood-proof the Metrorail system.
 - Add Metro sidetracks to improve resilience to disruptions and maintenance.
 - Add redundancy in tunnels and subway lines.

Some respondents directly addressed the issue of transportation resilience to natural hazards. Here are a sampling of quotes (lightly edited for space and clarity):

- “Plan for sea level rise and storm-related flooding.”
- “Design transportation to accommodate extreme weather situations or other events that cause mass movements in transit.”
- “go GREEN! ... It’s a tough adjustment – but massively reducing the need for work-related travel is a game-changer. And in the coming era of constant climate crisis, businesses need employee connections that are flexible and adaptable – anyone may have to relocate at any time due to fire, flood, hurricane, earthquake, plague – the old model of commuting to a central office is obsolete ... And given the climate change crisis, a remote, flexible workforce is the best way to adapt.”
- “To not consider the changing weather patterns (more extremes in weather) is foolhardy. Figuring out what change is needed to live and work in spite of weather extremes needs to be considered. Investments should be made today so that people who are able to work from home can continue to, so that traffic is less congested. Investments for students to have options to learn from home or attend school in person can help provide less congested roads. This all needs to be considered.”

Key Concepts From the TPB Equity Resolution

Our work together will be anti-racist.

Our work together will advance equity in every debate and decision.

Equity will be a foundational principle throughout all TPB work.

Past actions have been exclusionary or had disparate impacts.

Inequitable impacts continue today.

We commit to act to correct such inequities in all our programs and policies.

Equity Considerations

Equity has been an important policy priority for the TPB since its founding. The TPB’s 1998 Vision statement embraced equity as a key principle. Its long-range transportation plan, Visualize 2045, emphasizes the need for multimodal, affordable, and safe mobility options to promote prosperity, accessibility, livability, and sustainability throughout and for all residents in the entire region.

In 2020, the TPB adopted a resolution to “Establish Equity as a Fundamental Value and Integral Part of all Transportation Planning Board’s Work Activities.”²⁴ The resolution includes the following three elements:

- “The TPB and its staff commit that our work together will be anti-racist and will advance equity including every debate we have, and every decision we make as the region’s MPO.”

²⁴ TPB. 2020. Draft Resolution to Establish Equity as a Fundamental Value and Integral Part of all Transportation Planning Board’s Work Activities. https://www.mwco.org/assets/1/28/07222020_-_item_6_-_TPB_Statement_on_Equity.pdf

- “The TPB affirms that equity, as a foundational principle, will be woven throughout the TPB’s analyses, operations, procurement, programs, and priorities to ensure a more prosperous, accessible, livable, sustainable, and equitable future for all residents.”
- “We recognize past actions that have been exclusionary or had disparate negative impacts on people of color and marginalized communities, including institutionalized policies and practices that continue to have inequitable impacts today, and we commit to act to correct such inequities in all our programs and policies.”

Natural hazards impact people and communities differently, and many traditionally marginalized populations may be particularly vulnerable to the impacts, such as:

- **Greater exposure:** Extreme heat impacts are stronger in highly urbanized areas with abundant pavement and little green space, known as the urban heat island effect. The urban heat island effect tends to be highest in neighborhoods with a lot of rental properties and households making lower incomes.
- **Higher sensitivity:** Vulnerable populations can include elders or those with medical conditions that may make them more susceptible to harm during a climate event. For example, these populations are more likely to suffer from heatstroke during a heat wave or experience respiratory issues from smoke during a wildfire.
- **Less adaptive capacity:** Underserved communities may lack resources needed to adapt to climate shocks and stressors, such as air conditioning, air filters, or the ability to easily evacuate and relocate if necessary. A few quotes from the Voices of the Region survey demonstrate that even day-to-day disruptions pose significant hurdles for some of our region’s residents:
 - “Most importantly, providing transportation avenues that help the people that truly need it. More buses and direct routes for those in less affluent areas. Reliable, safe, and as efficient routes as possible for public transportation for those that rely on it. If I have to spend 3 hours each way commuting to work, that’s 6 hours I don’t have to take classes, help my kids with homework, exercise; all the things that more affluent people get with multiple commuting options ...”
 - “I live in a suburb. It is necessary to have a car to get anywhere in a reasonable time. Many jobs do not pay enough to cover the cost of housing, transportation, insurance, taxes, and food. I am concerned for my grandchildren. There are a lot of people who do not make over \$100,000. How do they survive?”
 - “Making it [public transportation] more widely available in less urban areas would be a major step and looking more into making it accessible to people with disabilities especially. Additionally, when things break or fail, have a plan in place for people with disabilities to continue their regular routine rather than having people just shrug at them or have to figure out haphazard fixes.”

To consider equity in its planning activities, the TPB approved a methodology identifying a set of geographically defined places with high concentrations of minority and low-income populations and called them “Equity Emphasis Areas” (EEAs). The TPB’s EEAs have been applied to advance equity considerations within transportation policy, planning, and programming, and in other public sector fields.

In the 2030 Plan’s Climate Risk Vulnerability Analysis (COG CRVA), COG demonstrated potential climate risks to vulnerable populations by overlaying their climate-risk maps with the TPB’s EEAs. The COG CRVA found that EEAs are more heavily burdened by extreme heat, more than 60 percent of

EEAs lie in FEMA floodplains, and more than 10 percent of EEAs will be affected by a 6-foot sea level rise. The TPB and its member jurisdictions may need to work with communities in exposed EEAs to identify specific impacts and how to address community needs.

There are many ways transportation planning for resilience can keep equity considerations in mind, and these can be applied to many of the strategies listed in Section 6 and to the MPO role in Section 7 of this white paper:

- **Enable equitable planning processes:** All components of planning practices can integrate equity to address the concerns of all community members, especially those in underserved communities. These communities disproportionately experience climate and natural hazard-related health impacts; inclusion of their input can help address these historical inequities. The TPB and its member jurisdictions can support equitable planning through development of equity plans and providing meaningful and accessible engagement opportunities. This approach to improving equity is very similar to two strategies proposed in the COG 2030 Plan, which describes the strategies and how member jurisdictions and COG can support the strategies. The TPB could play a similar role as COG identifies for itself, for example:
 - Mitigation Strategy: Enable equitable planning practices. “Continue to identify and share tools, datasets, and resources, such as EEAs and the Environmental Justice Toolkit, to help jurisdictions define what equity means in their local context and engage underserved communities.”
 - Resiliency Strategy: Support engagement of the public on climate risks, with an emphasis on potentially vulnerable populations. “Provide region-wide information identifying vulnerable populations such as transportation EEAs and community level impact data.”
- **Utilize COG’s 2017 Environmental Justice Toolkit:** The toolkit serves as a resource on government measures, practices, and policies that can work toward fair and just treatment and equitable access in the development, application, and enforcement of environmental policies.
- **Conduct an equity analysis of existing resiliency plans:** Analyze how these plans provide opportunities for meaningful public involvement, identify vulnerable populations, and understand the needs and concerns of underrepresented populations. Assess the relative benefits and burdens of proposed programs to determine whether any adverse effects are disproportionately high and identify strategies to mitigate any inequities found. EEA boundaries can be helpful for identifying areas in which the population may be particularly vulnerable to climate impacts and natural hazards.

Some member agencies in the region are already incorporating equity into their transportation planning. For example, the 2030 Plan mentions Montgomery County, Maryland Resilience Ambassador Program, which was established in 2020 to further understand and improve solutions around inequality within the county’s transportation, equity, climate, and energy justice program areas as well as provide COVID-19 pandemic support for the most vulnerable communities. The program aims to increase representation of Black, Indigenous, and People of Color (BIPOC); low-income communities; and immigrants in the county’s programs to better incorporate racial equity and social justice into climate planning processes.

Continued Public Engagement

Ongoing public engagement relating to resiliency to natural hazards will continue to be a priority for ensuring equity in the region. Information about risks will need to be available to all communities so that they can engage in decision-making processes as individuals and with the region's governing bodies. The TPB can support this engagement by:

- Sharing information about best practices and region-specific messaging for effective community outreach strategies to diverse communities.
- Helping member jurisdictions integrate public engagement and equity into their activities, such as:
 - Integrate climate projections, risks, and strategies into existing community outreach programs.
 - Further build partnerships with community groups and leaders to improve communication and engagement strategies.
 - Engage potentially vulnerable communities in assessing their vulnerabilities (social, ecological, economic, public health) to climate impacts and natural hazards.
 - Provide direct assistance (technical and financial) to potentially vulnerable populations.
 - Develop metrics to measure the effectiveness of outreach efforts with diverse communities.

Section 5: Vulnerability Analysis Summary

A vulnerability analysis is literally an analysis of vulnerability, which is “the degree to which a system is susceptible to, or unable to cope with adverse effects of climate change or extreme weather events.”²⁵ Vulnerability analyses examine which elements of the transportation system are exposed to potential natural disaster and climate hazards, how sensitive the system is to potential impacts from those hazards, and the degree to which the system is prepared to adapt to those impacts.

Vulnerability analyses help decision-makers identify opportunities for making the transportation system more resilient to ongoing natural hazards and climate change impacts, and the region’s transportation agencies have been conducting these analyses using several different approaches. This section introduces the reader to key concepts and examples relating to:

- Vulnerability analyses in our region.
- Approaches to conducting vulnerability analyses.
- Hazards considered in climate vulnerability analyses.
- Transportation infrastructure covered by climate vulnerability analyses.
- How transportation infrastructure is vulnerable to climate hazards.
- Potential next steps for vulnerability analysis of the region’s transportation system.

Vulnerability Analysis in Our Region

Agencies throughout the region have been conducting vulnerability analyses of varying natures. Some focus on climate vulnerabilities; others have focused on hazard mitigation. Some analyses look at all the infrastructure in a particular jurisdiction; other analyses have been conducted within a particular agency or focused on a particular type of infrastructure.

The region’s transportation agencies therefore have a wealth of existing analyses and data to draw upon for making decisions to improve resiliency, as shown by the following brief overviews of recent resiliency work in District of Columbia, Maryland, and Virginia.

- In 2019, the District Department of Transportation (DDOT) published its *Climate Change Adaption Plan*, and the overall DC government published *Resilient DC: A Strategy to Thrive in the Face of Change*. DDOT’s plan included a vulnerability analysis that overlaid maps of DDOT’s existing assets with climate hazards such as temperature, precipitation, sea level rise, and storms. By identifying potential impacts from these hazards, DDOT was then able to identify potential adaptation strategies it could take to improve resilience to those hazards.
- Maryland DOT (MDOT) develops annual Climate Change Status Reports to describe its work on adaptation and mitigation. In 2019, the MDOT State Highway Administration (SHA) published its final report – *Integrating Extreme Weather and Climate Risk into MDOT SHA Asset Management and Planning* – about its experience in conducting vulnerability assessments as part of an FHWA pilot program initiated in 2014. To help transportation agencies identify risks to existing and proposed transportation infrastructure, MD SHA developed an interactive online map called “Climate Change Vulnerability Viewer” in 2018 with ongoing updates. This viewer covers Maryland’s portion of the TPB’s planning area, but is limited in the types of risks and infrastructure considered, so there is opportunity to

²⁵ FHWA. 2021. Vulnerability Assessment and Adaptation Framework
https://www.fhwa.dot.gov/environment/sustainability/resilience/adaptation_framework/climate_adaptation.pdf

conduct additional analyses for these areas and the transportation infrastructure within them.

- As part of preparing the Commonwealth of Virginia’s Transportation Plan, VTrans, the Office of Intermodal Planning and Investment (OIP), has been conducting a vulnerability assessment of Virginia’s major roadways, bridges, and culverts. Vulnerability scores are being developed based on exposure to hazards and how essential the asset is to the transportation network. As of spring 2021, the work is ongoing, and the findings will inform development of the plan.

Approaches

The regions’ jurisdictions use several different approaches to conduct assessments of infrastructure vulnerable to natural hazards. The FHWA Vulnerability Assessment and Adaptation Framework²⁶ identifies three methods that planners can use to assess vulnerability:

- Stakeholder input approach.
- Indicator-based desk review approach.
- Engineering-informed assessments.

The stakeholder input approach and indicator-based desk review approach are primarily used for system-level analyses while engineering-informed assessments focus on the asset level. Vulnerability assessments may also use more than one approach when looking at multiple assets. Planners can decide which approaches work best for them in assessing vulnerabilities for their system and helping to identify adaptation strategies later.

STAKEHOLDER INPUT APPROACH

The stakeholder input approach relies on institutional and local knowledge to identify potential vulnerabilities. Stakeholders can include communities served by transit and on-the-ground public agency staff who may have knowledge that is not easily captured in agency records or desk research. Activities to carry out this approach include conducting interviews, holding workshops and meetings, and distributing surveys to the public.

The TPB member agencies played a key role in the research process. A data framework was created where they were asked to provide information on documented resilience activities in their locality or service area. Interviews and a session to discuss the framework questions were also conducted between ICF, the TPB, and the member agencies.

One example of this approach is the Northern Virginia Regional Commission (NVRC), which in 2018 coordinated with other agencies to develop *Resilient Critical Infrastructure: A Roadmap for Northern Virginia*. In their outreach, they found that urban heat islands and intense storm events had impacts on vulnerable populations, such as children and the elderly.²⁷ They also developed findings on

²⁶ FHWA. 2021. Vulnerability Assessment and Adaptation Framework https://www.fhwa.dot.gov/environment/sustainability/resilience/adaptation_framework/climate_adaptation.pdf

²⁷ NVRC. 2018. Resilient Critical Infrastructure: A Roadmap for Northern Virginia. <https://www.novaregion.org/DocumentCenter/View/11933/Resilient-Roadmap-Final-PDF>

secondary impacts, such as flooding and sea level rise leading to brown- and blackouts that affect other critical infrastructure systems.²⁸

INDICATOR-BASED DESK REVIEW APPROACH

The indicator-based desk review approach uses available quantitative data on assets and projected natural hazard risks to serve as indicators and evaluate potential vulnerabilities. Asset data may include location or elevation, while natural hazard risks include temperature and sea level rise. This approach offers a big-picture understanding of vulnerability and allows planners to rank assets by vulnerability.

ENGINEERING-INFORMED ASSESSMENTS

Engineering-informed assessments use a deeper level of asset- or location-specific data and analysis and can evaluate risks to specific transportation assets facing natural hazards. These assessments have an adaptation component as they can help anticipate the effectiveness and return on investment of different strategies. Engineering informed assessments may involve conducting stress tests and climate scenarios, as well as developing a plan to revisit vulnerability to adjust adaptation strategies over time.

HYBRID APPROACHES

Other vulnerability assessments use a combination of the above approaches. The NVRC facilitated a pilot risk assessment that was completed by stakeholders as a desktop exercise. Participants identified types of infrastructure that are vulnerable and identified some specific assets that are at risk. For instance, for the sea level rise and inland flooding scenarios, stakeholders noted that Metrorail lines and stations, regional railroad infrastructure, airports, Capital Bikeshare stations, bridges, tunnels, and roadways are at risk.

Hazards

The metropolitan Washington region already faces a variety of natural hazards to its transportation infrastructure, and these hazards are expected to increase in frequency, duration, and intensity as the climate changes. Climate change hazards, such as extreme temperatures and rising water surface levels, pose a threat to critical transportation infrastructure. As climate hazards intensify, it will be increasingly important to prepare the region's transportation systems for these changing conditions.

Transportation agencies have already experienced damage, service interruptions, and other challenges caused by these hazards. Through vulnerability and risk assessments, agencies have identified extreme heat, extreme winter conditions, flooding, and severe storms as some of the greatest threats to transportation infrastructure. Hazards include:

- Extreme heat
- Extreme winter conditions
- Flooding
 - Flash flooding
 - Stream and river flooding

²⁸ NVRC. 2018. Resilient Critical Infrastructure: A Roadmap for Northern Virginia. <https://www.novaregion.org/DocumentCenter/View/11933/Resilient-Roadmap-Final-PDF>

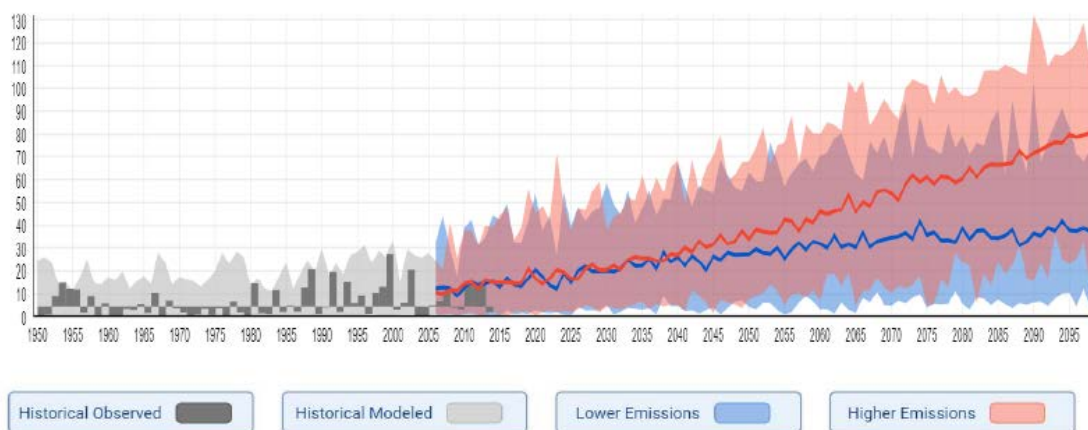
- Coastal flooding
- Lightning and severe storms

The COG regional Climate Risk and Vulnerability Assessment (CRVA) methodology is based on the Global Covenant of Mayors (GCoM) framework. GCoM is a global alliance of cities and local governments that support voluntary action to address climate change and ensure a low-emission, climate-resilient future. Based on the COG CRVA, the most prominent climate hazards facing metropolitan Washington include extreme heat and flash and riverine flooding.²⁹

EXTREME HEAT

Extreme heat poses many dangers to health and safety. High heat days put the region’s population at risk for health emergencies that can lead to death. The risks are especially high for populations with greater exposure to the heat, such as those without air-conditioned homes or jobs and those who travel by walking or biking. The heat also creates safety issues by damaging infrastructure, as discussed below in the section on vulnerabilities of transportation infrastructure.

Extreme heat and heat waves, often measured by the number of “heat emergency days,” or days in which the heat index exceeds 95 degrees Fahrenheit. Heat emergency days are becoming increasingly common in the region as climate change intensifies. For example, the District of Columbia historically averaged 30 heat emergency days per year, but climate projections show this reaching 30-45 days per year by 2050 and 40-75 days per year by the 2080s (See Figure 4).³⁰



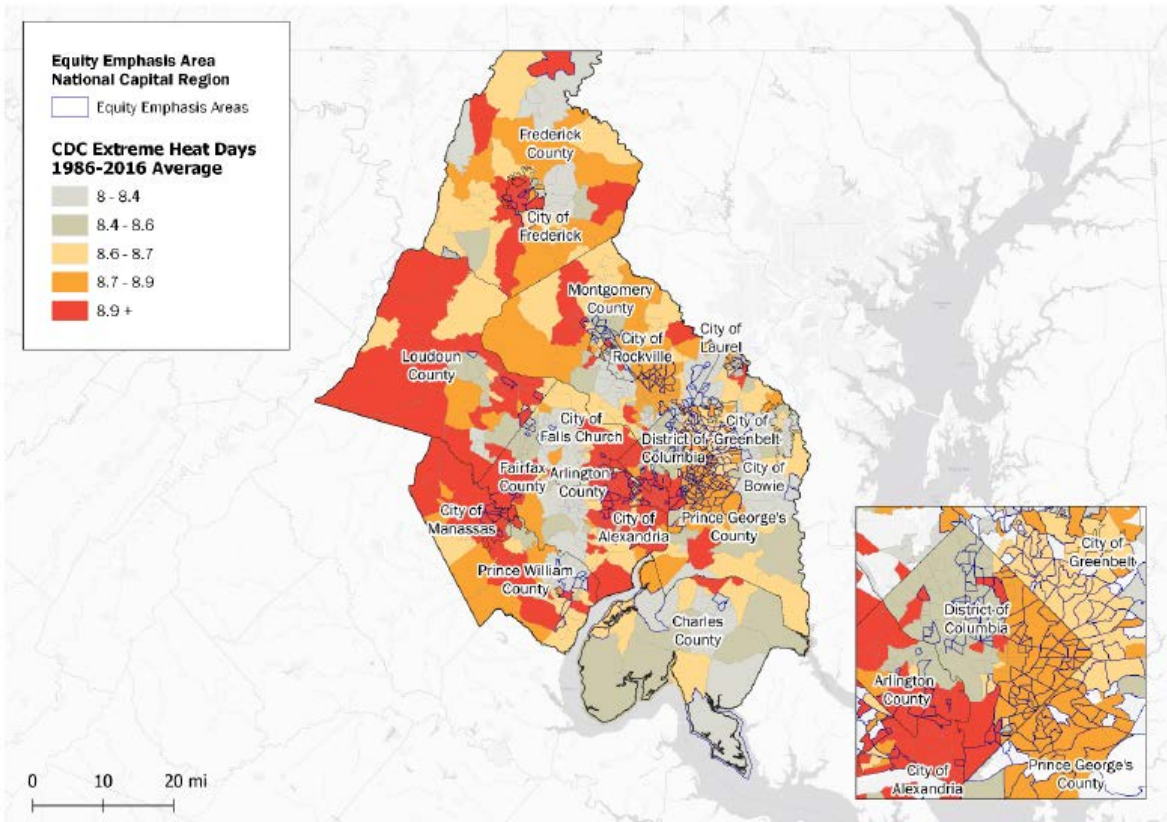
Source: NOAA Climate Explorer

Figure 4. Number of Projected Days Over 95F From 1950 to 2095
Source: COG 2030 CEAP.

COG’s 2030 Climate and Energy Action Plan vulnerability analysis produced the following figures showing the number of extreme heat days across the region and historical and projected heat emergency days in the region (See Figure 5).

²⁹ COG CRVA, p. 61

³⁰ DC Department of Energy and Environment (DOEE). Climate Ready DC.
https://doee.dc.gov/sites/default/files/dc/sites/ddoe/service_content/attachments/CRDC-Report-FINAL-Web.pdf



Source: Centers for Disease Control and Prevention (CDC) National Environmental Public Health Tracking Network Analysis Data Explorer and COG Equity Emphasis Areas

Figure 5. Equity Emphasis Areas and Extreme Heat Days.
Source: COG 2030 CEAP.

EXTREME WINTER CONDITIONS

As the heat extremes worsen, so will the extreme winter weather. Extreme winter events bring down power lines and cause damage to pipes and other infrastructure, which can create further delays and maintenance issues for transportation systems.³¹ Rapid snowmelt can even cause flooding.³²

In recent years, winter storms have shown the vulnerability of the region’s transportation assets. For example, in 2010, over 30 inches of snow fell during a severe winter storm called “Snowmageddon.” Roads and other transportation facilities were obstructed for days or weeks by excessive snow, downed trees, and abandoned vehicles. The storm caused vehicle accidents and widespread loss of electric power.³³



Figure 6. Major Snow event, 2010
Source:

³¹ Commonwealth of Virginia Hazard Mitigation Plan 2018. http://drought.unl.edu/archive/plans/GeneralHazard/state/VA_2018.pdf

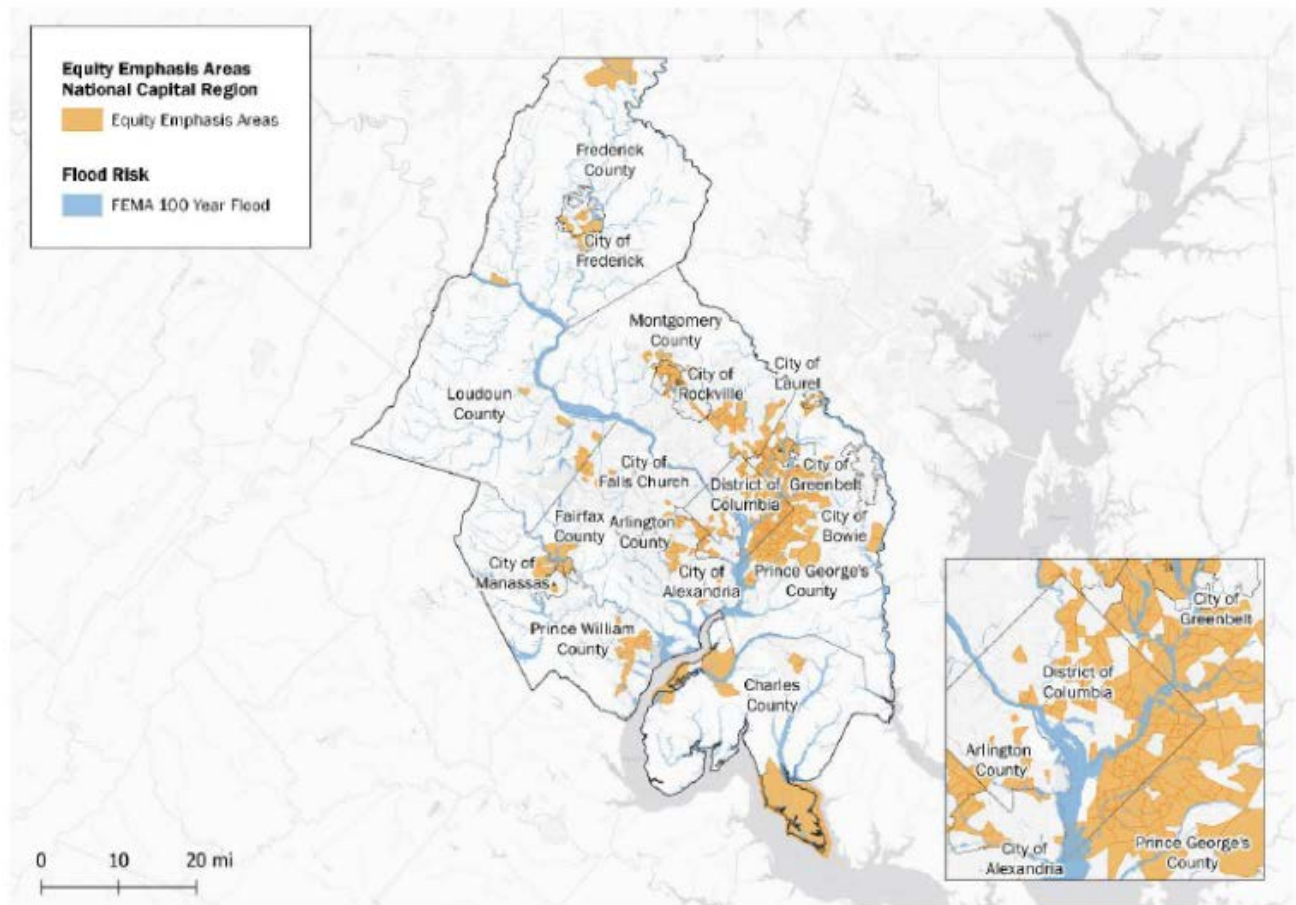
³² Commonwealth of Virginia Hazard Mitigation Plan 2018. https://drought.unl.edu/archive/plans/GeneralHazard/state/VA_2018.pdf

³³ COG. Metropolitan Washington 2030 Climate and Energy Action Plan. 2020. <https://www.mwcog.org/documents/2020/11/18/metropolitan-washington-2030-climate-and-energy-action-plan/>

Extreme winter events, including heavy snow and dangerous wind chills, are projected to increase in frequency and intensity in the region.³⁴ Rising temperatures can create conditions for more extreme winter storms. More storms will occur near 32 degrees Fahrenheit, increasing the risk of ice storms. Ice storms, which occur when more than 0.25 inches of ice accumulates on exposed surfaces, create dangerous conditions for drivers and pedestrians and can lead to road closures, particularly in rural locations.³⁵

FLOODING

As extreme precipitation events become more common and sea levels rise, flooding has already begun to damage transportation infrastructure in the region. Flooding events create dangerous



Source: FEMA and COG Equity Emphasis Areas

Figure 7. Equity Emphasis Areas and FEMA’s 100-Year Floodplains.
Source: COG 2030 CEAP.

conditions for all modes of transportation. See Figure 7 for flood risk in the region overlaid with the region’s TPB’s identified equity emphasis areas, areas with small geographic areas that have concentrations of low-income and/or minority populations based on Census data. Flooding can bring down trees and powerlines, causing route closures. It can cause

³⁴ COG. Metropolitan Washington 2030 Climate and Energy Action Plan. 2020. <https://www.mwcog.org/documents/2020/11/18/metropolitan-washington-2030-climate-and-energy-action-plan/>

³⁵ Charles County. 2018 Hazard Mitigation Plan. 2018. <http://www.charlescountymdhmpu.com/>

extensive property damage. Flooding also causes erosion, threatening the structural integrity of transportation assets such as roads and bridges. It can cause extensive property damage and overwhelm stormwater management systems. Stormwater flooding is especially common in urban areas, where impervious surfaces limit the amount of rainwater that the ground can absorb.

The National Oceanic and Atmospheric Administration (NOAA) projects more frequent heavy precipitation events in the region. By mid-century, a “100-year precipitation event” could become a 25-year event.³⁶ Three primary types of flooding pose a threat to the region: flooding from streams and rivers, coastal flooding, and inland flooding; the region is also susceptible to flash flooding, which can occur as a result of any of the three types of flooding. The Virginia Office of Intermodal Planning and Investment (OIPI) [VTrans Vulnerability Assessment](#) identifies flooding risk of all public roadways and VDOT-maintained structures from three hazard types: sea level rise, storm surge events, and inland flooding.

Flooding from streams and rivers

Flooding from streams and rivers, sometimes called “riverine flooding,” occurs when heavy precipitation and/or snowmelt causes a river’s banks to overflow. This flooding is what is documented in maps of floodplains.

Coastal flooding

Coastal flooding happens during high tides or coastal storms. Coastal storms can bring intense precipitation, storm surges, and high waves, which can damage transportation infrastructure.³⁷ Low-lying areas along our tidal rivers are at greatest risk for coastal flooding. Sea level rise exacerbates the impacts of coastal flooding events. NOAA projects that sea levels could rise by 4 to 8 feet by 2100 in Virginia from 2012 levels.³⁸ Sea levels have already risen 11 inches on both the Potomac and Anacostia River over the past 90 years; this sea level rise is also associated with a 300 percent increase in nuisance flooding along the riverfront, as well as significant shoreline erosion.³⁹ Figure 8 shows the flooding from the 2003 Hurricane Isabel plus projections for where the flooding would reach with higher sea levels. Coastal flooding also poses risks of shoreline erosion, as shown in Charles County’s Hazard Mitigation Plan in Figure 9.

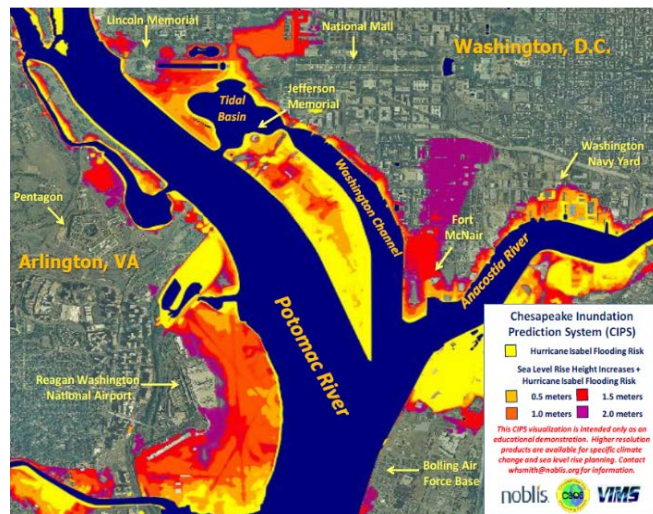


Figure 8. Scenarios for an Isabel-Type Storm Surge With Sea Level Rise.
Source: COG Adaptation Summary.

³⁶ COG. Metropolitan Washington 2030 Climate and Energy Action Plan. 2020. <https://www.mwcog.org/documents/2020/11/18/metropolitan-washington-2030-climate-and-energy-action-plan/>

³⁷ COG. Metropolitan Washington 2030 Climate and Energy Action Plan. 2020. <https://www.mwcog.org/documents/2020/11/18/metropolitan-washington-2030-climate-and-energy-action-plan/>

³⁸ Climate Central. Virginia and the Surging Sea: A Vulnerability Assessment with Projections for Sea Level Rise and Coastal Flood Risk. <http://sealevel.climatecentral.org/uploads/ssrf/VA-Report.pdf>

³⁹ COG. Metropolitan Washington 2030 Climate and Energy Action Plan. 2020. <https://www.mwcog.org/documents/2020/11/18/metropolitan-washington-2030-climate-and-energy-action-plan/>

Inland flooding

When extreme precipitation occurs, flooding can occur in locations where there is no existing body of water. Instead of the flood occurring from a rising body of water, the flooding occurs as water accumulates too quickly to be absorbed into the ground or to be diverted by stormwater infrastructure. Many of the region’s roadways have experienced flooding during significant downpours.

Flash flooding

Flash floods are very dangerous, high-probability, high-consequence events for the metropolitan Washington region.⁴⁰ Flash floods develop over a very short time frame. Flash floods can produce catastrophic forces with little advanced warning, such as walls of water coming down valleys or as storm surges along the coast.

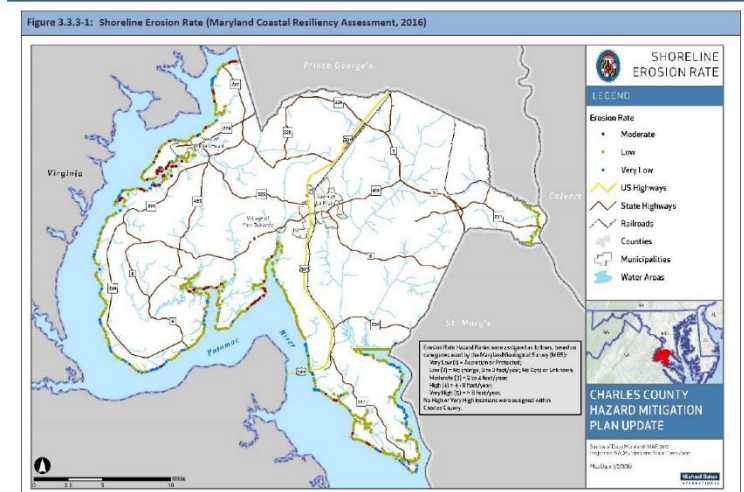


Figure 9. Charles County Shoreline Erosion Rate.
Source: Charles County Hazard Mitigation Plan.

LIGHTNING AND SEVERE STORMS

As temperatures rise, the frequency and intensity of severe storms will continue to increase in the region. Storms can bring down powerlines, causing power outages and obstructing transportation routes. Intense rainfall from thunderstorms can cause flooding.⁴¹

In 2012, a thunderstorm caused major destruction and disruption in the region; winds recorded at more than 85 mph knocked down powerlines and trees, blocking transportation routes.⁴² During that storm, 17 Metro stations experienced power outages.⁴³ Also in 2012, Superstorm Sandy brought flooding and wind that brought down trees and powerlines; as a result, Washington Metropolitan Area Transit Authority (WMATA) paused bus and Metro operations for two days.⁴⁴

Transportation Infrastructure to Assess

⁴⁰ COG. Metropolitan Washington 2030 Climate and Energy Action Plan. 2020. <https://www.mwcog.org/documents/2020/11/18/metropolitan-washington-2030-climate-and-energy-action-plan/>

⁴¹ COG. Metropolitan Washington 2030 Climate and Energy Action Plan. 2020. <https://www.mwcog.org/documents/2020/11/18/metropolitan-washington-2030-climate-and-energy-action-plan/>

⁴² COG. Metropolitan Washington 2030 Climate and Energy Action Plan. 2020. <https://www.mwcog.org/documents/2020/11/18/metropolitan-washington-2030-climate-and-energy-action-plan/>

⁴³ Government of the District of Columbia. Resilient DC: A Strategy to Thrive in the Face of Change. 2018. <https://app.box.com/s/d40hk5ltvcn9fqas1viaje0xbnbsfwga>

⁴⁴ COG. Metropolitan Washington 2030 Climate and Energy Action Plan. 2020. <https://www.mwcog.org/documents/2020/11/18/metropolitan-washington-2030-climate-and-energy-action-plan/>

Different types of transportation infrastructure face different sensitivities to natural hazards. Infrastructure types can include roads and highways, bridges, tunnels, stormwater infrastructure, transit infrastructure, airports, and maritime transportation.

Table 4 shows the types of assets analyzed in the region’s vulnerability assessments and the jurisdictions that looked at them.

Table 4: Infrastructure Identified in Vulnerability Assessments

Vulnerable Infrastructure	Jurisdictions
Roads and highways	DC, MD, VA NVRC, WMATA Charles County, Fairfax County, Frederick County, Montgomery County, Prince George’s County, Prince William County
Bridges	DC, MD, VA NVRC, NCPC Charles County, Fairfax County, Frederick County, Montgomery County, Prince George’s County, Prince William County
Public transit and active transportation infrastructure (e.g., rail, buses, bikes, etc.)	MD NVRC, NCPC, WMATA Charles County, Fairfax County, Frederick County, Montgomery County, Prince George’s County
Airports and maritime infrastructure	MD, VA NVRC Montgomery County
Stormwater infrastructure (e.g., drainage, culverts, etc.)	DC, MD, VA Charles County

Vulnerabilities of Transportation Infrastructure

Once the hazards and infrastructure types are defined, then a vulnerability assessment can determine how those hazards are likely to impact those infrastructure types. This section, organized by infrastructure type, describes how natural hazards impact the region's infrastructure. As of this time, there are no region-specific maps showing the transportation infrastructure vulnerable to climate hazards, but some examples of regional activities to address hazards are included with the descriptions in the following section.

ROADWAYS AND HIGHWAYS

Roads are susceptible to each of the primary climate hazards, as described here.

Extreme heat

Extreme heat can crack concrete roads and make asphalt roads soften. Montgomery County, Maryland, examined transportation vulnerability in a Climate Vulnerability Assessment for its Climate Action Plan and in *Measuring Climate Resilience – A Review of Select Critical Infrastructure Sectors in Montgomery County*.⁴⁵ The plan includes maps showing predicted extreme heat throughout the county overlaid with the locations of roads and other transportation infrastructure.⁴⁶

Extreme winter conditions

Winter weather can cause ice to form on roads, and the freeze/thaw cycle creates potholes and extensive cracking. Snow removal can damage roadway surfaces.⁴⁷

Flooding

Floods interfere with roads in a few ways. In the immediate flood, waters and fallen trees not only block roadways but can wash away or crush travelers. After the flooding subsides, the roadway and its supporting structures may have been eroded and at risk of collapsing. While in various stages of development, providing different levels of detail and analysis focus, the transportation departments of Maryland, Virginia, and District of Columbia vulnerability analyses consider flooding as one of the primary risk factors.

- Charles County, Maryland's 2020 Nuisance and Urban Flood Plan identifies specific roadways that are experiencing nuisance and urban flooding. Charles County mapped all impervious surfaces to identify stormwater management needs; identified 57 nuisance and urban flood locations (most of which were located at roads, bridges, and culverts), and assigned risk rankings based on water levels observed.⁴⁸



Figure 10. A flooded roadway.
Source. Amanda Farber

⁴⁵ Montgomery County, Maryland. 2021. *Measuring Climate Resilience – A Review of Select Critical Infrastructure Sectors in Montgomery County*. https://www.montgomerycountymd.gov/OLO/Resources/Files/2021_Reports/OLOReport2021-5.pdf

⁴⁶ Montgomery County, Maryland. 2021. *Measuring Climate Resilience – A Review of Select Critical Infrastructure Sectors in Montgomery County*. https://www.montgomerycountymd.gov/OLO/Resources/Files/2021_Reports/OLOReport2021-5.pdf

⁴⁷ State of Maryland. Hazard Mitigation Plan. 2016. https://mema.maryland.gov/community/Documents/2016_Maryland_Hazard_Mitigation_Plan_final_2.pdf

⁴⁸ Charles County, Maryland. 2020. Charles County Nuisance and Urban Flood Plan. <https://www.charlescountymd.gov/home/showpublisheddocument?id=6485>

- Frederick County, Maryland’s 2017 Hazard Mitigation Plan identifies roads frequently flooded by high water.⁴⁹
- The 2018 Climate Change Vulnerabilities in the Coastal Mid-Atlantic Region report lists miles of vulnerable road and railways in each state and county in different sea level rise scenarios, specifically mentioning roadways in Prince George’s County, Maryland.⁵⁰
- As of a report published in 2014, Virginia has nearly 1,500 miles of road that are less than 5 feet above the high tide line. At this height, floods exceeding historic records are likely to take place within the next 20 to 30 years.⁵¹
- An interview with agencies in Virginia indicated that City of Alexandria is working on updating flooding curves for roadways.

BRIDGES

Bridges are also one of the most frequently mentioned types of vulnerable infrastructure. Bridges often serve as essential regional connectors, and they are often at high exposure to risks due to their locations along bodies of water. The pavement on bridges is susceptible to many of the same risks that roadways experience, but some risks are greater for bridges.

Extreme heat

High temperatures can cause bridge joints to expand.⁵²

Extreme winter conditions

Like roadways, bridges’ pavement deteriorates with ice and can be damaged by snow removal. Bridges are more vulnerable to winter weather than roads because bridges freeze faster.⁵³

Flooding

Flooding can cause major damage to bridges, such as erosion, which presents a risk to bridge footings.⁵⁴ Higher soil moisture levels can also compromise the structural integrity of bridges.⁵⁵

- The Northern Virginia Hazard Mitigation Plan noted flash flooding as a risk to bridges.

⁴⁹ Frederick County, Maryland. 2017. Hazard Mitigation Plan. <https://www.cityoffrederickmd.gov/DocumentCenter/View/9503/17-23-Concerning-the-Frederick-County-Hazard-Mitigation-Plan?bidId=>

⁵⁰ Middlebury Institute of International Studies at Monterey, Woods Hole Oceanographic Institution. 2018. Climate Change Vulnerabilities in the Coastal Mid-Atlantic Region. <https://www.midatlanticocean.org/wp-content/uploads/2018/04/Climate-Change-Vulnerabilities-in-the-Coastal-Mid-Atlantic-Region.pdf>

⁵¹ Climate Central. 2014. Virginia and the Surging Sea: A Vulnerability Assessment with Projections for Sea Level Rise and Coastal Flood Risk. <http://sealevel.climatecentral.org/uploads/ssrf/VA-Report.pdf>

⁵² COG. 2010. Climate Change and Adaptation Planning Opportunities at the Regional Level

⁵³ Montgomery County Office of Emergency Management and Homeland Security. 2018. Montgomery Hazard Mitigation Plan. <https://www.montgomerycountymd.gov/OEMHS/Resources/Files/HMP2018-FinalPlan-FEMAApproved.pdf>

⁵⁴ COG. 2013. Summary of Potential Climate Change Impacts Vulnerabilities, and Adaptation Strategies in the Metro Washington Region. <https://www.mwco.org/documents/2013/07/01/summary-of-potential-climate-change-impacts-vulnerabilities-and-adaptation-strategies-climate-change/>

⁵⁵ COG. 2010. Climate Change and Adaptation Planning Opportunities at the Regional Level

- MDOT SHA is carrying out a corridor management and drainage improvements project for highway MD 450, portions of which experience frequent flooding during storms.

PUBLIC TRANSIT INFRASTRUCTURE

For bus transit and railway bridges, the hazards include those identified for roadways and bridges. The region’s transit infrastructure also faces additional risks.

Extreme heat

Heat can cause rail tracks to buckle or expand, which may require transit agencies to deploy extreme weather plans, invest in new materials, and activate operational and maintenance actions without disruptions to safety or service.⁵⁶ Heat can also damage road surfaces and cause pavement to soften, which can cause deformities at bus stops.⁵⁷ Additionally, increased heat will increase cooling costs for public transit agencies.



Figure 11. Buckling Caused by Heat Wave on Metro Green Line.
Source: Washington Post in the COG Adaptation Summary.

- *Measuring Climate Resilience – A Review of Select Critical Infrastructure Sectors in Montgomery County.* Montgomery County looked at transportation assets including bus stops, railroads, MARC stations, and Metro stations.⁵⁸ The plan includes maps showing predicted extreme heat throughout the county overlaid with the locations of roads and rail stations.⁵⁹

Extreme winter conditions

Snow can build up on above-ground rail lines, which has led to Metrorail shutdowns during past major winter storm events.⁶⁰ With moderate snow of 3-6 inches, delays occur as Metrorail runs “de-icer” trains between passenger trains.⁶¹ When temperatures drop severely or snowfalls exceed 8 inches, more significant closures can occur because “the electrified third rail can become snow-impacted, aboveground tracks may ice over, and rail yards can become impassable.”⁶²

For buses, even moderate snowfall can require transit operators to reroute some bus lines, such as those that use steep slopes or neighborhood streets that are not high priority for plows.⁶³ In severe

⁵⁶ Montgomery County, Maryland. 2020. Montgomery County Climate Action Plan draft. <https://www.montgomerycountymd.gov/green/Resources/Files/climate/draft-climate-action-plan-printable.pdf>

⁵⁷ COG. Metropolitan Washington 2030 Climate and Energy Action Plan. 2020. <https://www.mwco.org/documents/2020/11/18/metropolitan-washington-2030-climate-and-energy-action-plan/>

⁵⁸ Montgomery County, Maryland. 2021. Measuring Climate Resilience – A Review of Select Critical Infrastructure Sectors in Montgomery County. https://www.montgomerycountymd.gov/OLO/Resources/Files/2021_Reports/OLOReport2021-5.pdf

⁵⁹ Montgomery County, Maryland. 2021. Measuring Climate Resilience – A Review of Select Critical Infrastructure Sectors in Montgomery County. https://www.montgomerycountymd.gov/OLO/Resources/Files/2021_Reports/OLOReport2021-5.pdf

⁶⁰ Washington Post. 2016. D.C. region braces for epic blizzard; Metro to shut down subway, bus lines. https://www.washingtonpost.com/local/dc-region-braces-for-snowstorm-as-it-continues-to-struggle-with-one-inch-from-last-night/2016/01/21/8744619e-c041-11e5-83d4-42e3bceea902_story.html

⁶¹ WMATA. 2021. Metro announces service changes Sunday due to winter storm <https://www.wmata.com/about/news/Jan-31-winter-storm.cfm>

⁶² WMATA. 2021. Rail Snow Service. <https://www.wmata.com/rider-guide/weather/rail.cfm>

⁶³ WMATA. 2021. Bus Snow Service. <https://www.wmata.com/rider-guide/weather/bus/>

snow conditions, routes might only operate on major streets – those that are the focus of regional plowing efforts.

Flooding

In June of 2006, the District of Columbia experienced several days of heavy rain, the equivalent of a 200-year storm, which overwhelmed the sewer system and caused significant flooding of the Federal Triangle area downtown. The flooding shut down federal agencies and several Smithsonian museums, inundating the 9th and 12th Street tunnels under the National Mall, and flooding two Metro stations.^{64, 65} The Federal Triangle flood, which resulted in millions of dollars in damage, demonstrated the potential costly impacts of increasingly frequent and severe rain events.

- The NVRC identified Ronald Reagan National Airport (DCA) in addition to parts of I-95 and Route 1 impacted, I-66 impacted, Parts of Dulles underwater, and Ballston Metro rail station, as vulnerable to inland flooding scenarios.⁶⁶
- Frederick County, Maryland’s Hazard Mitigation Plan identifies critical facilities located in flood zones, including MARC stations.⁶⁷
- The MDOT 2020 Climate Status Report reported that light rail locations suffer progressive erosion and stabilization problems due to rain events and washouts.⁶⁸
- In Maryland, the *Measuring Climate Resilience – A Review of Select Critical Infrastructure Sectors in Montgomery County* used FEMA flood data and an MDOT database of frequently flooded roads to identify a list of “Ride On Bus Stops” impacted by frequently flooded roads.⁶⁹
- The National Academies Press (publisher for The National Academies of Science, Engineering, and Medicine (NASEM)) Maryland Transit Study identified specific tracks and below-ground stations whose entrances may be subject to storm surge and flooding, or whose ventilation shafts would be affected by weather impacts.
- The 2018 *Climate Change Vulnerabilities in the Coastal Mid-Atlantic Region* gives rail data for miles of track vulnerable to flooding and lists miles of vulnerable road and railways in each state and county in different sea level rise scenarios, specifically mentioning Frederick County, Maryland.⁷⁰
- WMATA has Severe Weather Plans and Flood Emergency response Plan that are deployed when an extreme weather event occurs to ensure passenger safety, protect equipment, and respond rapidly to changing conditions

⁶⁴ COG. Metropolitan Washington 2030 Climate and Energy Action Plan. 2020. <https://www.mwcog.org/documents/2020/11/18/metropolitan-washington-2030-climate-and-energy-action-plan/>

⁶⁵ DC Department of Energy and Environment (DOEE). Climate Ready DC. https://doee.dc.gov/sites/default/files/dc/sites/ddoe/service_content/attachments/CRDC-Report-FINAL-Web.pdf

⁶⁶ NVRC, 2017. Utilizing Regional Collaboration to Build Community Resilience in Northern Virginia. <https://www.novaregion.org/DocumentCenter/View/12479/FY-17-Utilizing-Regional-Collaboration-to-Build-Community-Resilience>

⁶⁷ Frederick County, Maryland. 2017. Frederick County Hazard Mitigation Plan. <https://www.cityoffrederickmd.gov/DocumentCenter/View/9503/17-23-Concerning-the-Frederick-County-Hazard-Mitigation-Plan?bidId=>

⁶⁸ Maryland Department of Transportation. 2020. MDOT Climate Status Report – 2020. https://mdot.maryland.gov/OPCP/2020-MCCC_Act_MDOT_Report_12-30-2020.pdf

⁶⁹ Montgomery County, Maryland. 2021. Measuring Climate Resilience – A Review of Select Critical Infrastructure Sectors in Montgomery County. https://www.montgomerycountymd.gov/OLO/Resources/Files/2021_Reports/OLOReport2021-5.pdf

⁷⁰ Middlebury Institute of International Studies at Monterey, Woods Hole Oceanographic Institution. 2018. Climate Change Vulnerabilities in the Coastal Mid-Atlantic Region. <https://www.midatlanticocean.org/wp-content/uploads/2018/04/Climate-Change-Vulnerabilities-in-the-Coastal-Mid-Atlantic-Region.pdf>

Severe storms

High wind events can disrupt the transit system because it makes it dangerous for high-profile vehicles such as buses and rail cars to move. Downed trees and power lines can also lead to hazardous conditions. In 2012, Metro shut down due to hazards related to Superstorm Sandy.⁷¹

ACTIVE TRANSPORTATION INFRASTRUCTURE

Most active transportation infrastructure is susceptible to the same risks experienced by the roadways or bridges that they are on. Active transportation has additional risks posed by the exposure of the people using these modes of transportation—such as to falling tree limbs or flash floods.

Measuring Climate Resilience – A Review of Select Critical Infrastructure Sectors in Montgomery County included bikeways among the other assets reviewed. The assessment used FEMA flood data and an MDOT database of frequently flooded roads to identify a list of bikeways impacted by frequently flooded roads.⁷² The plan includes maps showing predicted extreme heat throughout the county overlaid with the locations of infrastructure, including bikeways.

AIRPORT INFRASTRUCTURE

Extreme heat

Extreme heat can soften pavement, causing issues on runways. High heat could also increase refrigeration needs and costs for goods transportation.

- COG’s 2030 Climate Energy and Action Plan found that extreme heat could affect airports by damaging and softening pavement, affecting aviation runways and plane takeoff.⁷³
- Montgomery County, Maryland’s *Measuring Climate Resilience – A Review of Select Critical Infrastructure Sectors in Montgomery County* assessed impacts to airports and includes maps of predicted extreme heat overlaid with airport locations.⁷⁴

Extreme winter conditions

Extreme winter conditions can disrupt airport operations.

Flooding

Flooding can impact airport facilities similarly as it does roadways, washing out or blocking portions.

- The NVRC 2019 report *Utilizing Regional Collaboration to Build Community Resilience in Northern Virginia* identified types of infrastructure that are vulnerable and identified some specific assets that are at risk. For instance, for the sea level rise and inland flooding

⁷¹ WAMU 2021. Hurricane Sandy Shuts Down D.C. Metro System Through Tuesday Morning https://wamu.org/story/12/10/29/hurricane_sandy_shuts_down_dc_metro_system/

⁷² Montgomery County, Maryland. 2021. *Measuring Climate Resilience – A Review of Select Critical Infrastructure Sectors in Montgomery County*. https://www.montgomerycountymd.gov/OLO/Resources/Files/2021_Reports/OL0Report2021-5.pdf

⁷³ COG. Metropolitan Washington 2030 Climate and Energy Action Plan. 2020. <https://www.mwco.org/documents/2020/11/18/metropolitan-washington-2030-climate-and-energy-action-plan/>

⁷⁴ Montgomery County, Maryland. 2021. *Measuring Climate Resilience – A Review of Select Critical Infrastructure Sectors in Montgomery County*. https://www.montgomerycountymd.gov/OLO/Resources/Files/2021_Reports/OL0Report2021-5.pdf

scenarios, stakeholders noted that airports are included in types of infrastructure at risk and specifically mentioned that Reagan National Airport may be vulnerable to sea level rise and flooding.⁷⁵

- The U.S. Army Corps of Engineers and the COG are conducting a study on coastal flooding issues and potential solutions for sites in Arlington County, the City of Alexandria, Fairfax County, northern Prince William County, and at Reagan National Airport. The study team will assess the implementation of structural, non-structural and nature-based coastal flood risk management solutions at different locations. Potential measures include deployable floodwalls and levees; building retrofits and enhanced evacuation planning; and drainage improvements and living shorelines. The goal is to reduce coastal flood risk to people, properties, critical infrastructure, and important services and resources in the study area, all while considering future climate and sea level change. The final report will be released in March 2024.

Severe storms

High winds also disrupt airport operations.

MARITIME INFRASTRUCTURE

Sea level rise is a significant threat to ports and maritime, or water, transportation infrastructure.⁷⁶ Docks and roadways near ports are vulnerable to flooding, which can disrupt operations. Due to subsidence of coastal land and changes in the flow of the Gulf Stream, Mid-Atlantic ports may experience above-average rates of sea level rise.⁷⁷

STORMWATER INFRASTRUCTURE

Flooding and extreme precipitation are the primary concerns for culverts and other stormwater infrastructure. Frequent intense downpours could overload drainage systems and increase stormwater runoff. Roadways can become impassable, which prevent buses and emergency vehicles from providing critical services. It could also impact Metrorail service by flooding escalators, elevator shafts, and cut off bus, bike, and pedestrian access to and from station entrances, bus loops, and parking lots. Failing culverts affect the performance and safety of roads. In 2001, heavy rainfall in Arlington County washed out a culvert, which created a sinkhole.⁷⁸ Some other identified vulnerabilities include:

- COG conducted a climate change literature review and found that severe storms and sea level rise could result in more combined sewer outflows and power outages, increased runoff, erosion, and sedimentation, and increased strain on and need for infrastructure maintenance.
- In the Nuisance and Urban Flood Plan, Charles County, Maryland identified high-priority stormwater infrastructure. Charles County mapped all impervious surfaces to identify stormwater management needs; identified 57 nuisance and urban flood locations, most of

⁷⁵ NVRC, 2017. Utilizing Regional Collaboration to Build Community Resilience in Northern Virginia. <https://www.novaregion.org/DocumentCenter/View/12479/FY-17-Utilizing-Regional-Collaboration-to-Build-Community-Resilience>

⁷⁶ Middlebury Institute of International Studies at Monterey. Woods Hole Oceanographic. Climate Change Vulnerabilities in the Coastal Mid-Atlantic Region. 2018. <https://www.midatlanticocean.org/wp-content/uploads/2018/04/Climate-Change-Vulnerabilities-in-the-Coastal-Mid-Atlantic-Region.pdf>

⁷⁷ Middlebury Institute of International Studies at Monterey. Woods Hole Oceanographic. Climate Change Vulnerabilities in the Coastal Mid-Atlantic Region. 2018. <https://www.midatlanticocean.org/wp-content/uploads/2018/04/Climate-Change-Vulnerabilities-in-the-Coastal-Mid-Atlantic-Region.pdf>

⁷⁸ Northern Virginia Regional Commission. Northern Virginia Hazard Mitigation Plan Update. 2017. <https://www.alexandriava.gov/uploadedFiles/fire/info/NOVAHazardMitigationPlan.pdf>

which were located at roads, bridges, and culverts; and assigned risk rankings based on water levels observed.⁷⁹

- Charles County, Maryland and Frederick County, Maryland have identified vulnerable culverts and priority repairs/replacements.⁸⁰
- The NVRC found that flooding and sea level rise would exceed the capacity of aging stormwater infrastructure systems.⁸¹
- Alexandria’s Risk Assessment and Management Plan (RAMP) combines updated climate projections with new capacity studies to identify system gaps. The RAMP maps critical community facilities in all sectors, to support vulnerability and risk assessments. (Source: Water Resource Technical Committee Presentation, January 2021)

OTHER

Other transportation infrastructure types include buildings and facilities or other structures. The following agencies have identified other assets facing natural hazards:

- MDOT Climate Status report identifies transportation interdependent facilities and vulnerabilities across these systems, like electric grid, telecom, water supply, stormwater management systems.⁸²
- Montgomery County, Maryland mentions systems that transportation depends upon, such as communications and information technology and energy. The county recognizes in its plans that mass power outages can affect operation of county facilities and utility companies.⁸³
- Virginia DOT buildings are included in Virginia Hazard Mitigation Plan’s (HMP) list of critical facilities.⁸⁴ The HMP looks at the vulnerability of each critical facility to each natural hazard. Thirteen airfields are included in the list of mapped critical facilities.

Further Analysis

The region’s transportation agencies are at various levels of completion (from not started to state-wide mapping) in terms of conducting vulnerability assessments. A common first step is to overlay the hazards with the types of infrastructure. MDOT has completed a statewide effort that focuses on significant flooding and sea level rise, but additional analysis of other risks and additional infrastructure from a regional perspective would be beneficial. Several agencies throughout the region have begun such mapping efforts, but regional maps that cover all hazards and infrastructure types are not available yet.

⁷⁹ Charles County, Maryland. 2020. Charles County Nuisance and Urban Flood Plan. <https://www.charlescountymd.gov/home/showpublisheddocument?id=6485>

⁸⁰ Charles County, Maryland. 2020. Charles County Nuisance and Urban Flood Plan. <https://www.charlescountymd.gov/home/showpublisheddocument?id=6485>

⁸¹ NVRC, 2017. Utilizing Regional Collaboration to Build Community Resilience in Northern Virginia. <https://www.novaregion.org/DocumentCenter/View/12479/FY-17-Utilizing-Regional-Collaboration-to-Build-Community-Resilience>

⁸² Maryland Department of Transportation. 2020. MDOT Climate Status Report – 2020. https://mdot.maryland.gov/OPCP/2020-MCCC_Act_MDOT_Report_12-30-2020.pdf

⁸³ Montgomery County. 2021. Hazard Mitigation Plan. <https://www.montgomerycountymd.gov/OEMHS/Resources/Files/HMP2018-FinalPlan-FEMAApproved.pdf>

⁸⁴ Commonwealth of Virginia. 2018. Hazard Mitigation Plan. http://drought.unl.edu/archive/plans/GeneralHazard/state/VA_2018.pdf

Such overlay maps can provide lists of vulnerable infrastructure, but given the vast amount of infrastructure that has the potential for exposure, a recommended next step is to focus resources and planning efforts on identifying exposed infrastructure that is most important regionally. This list could help the region and its jurisdictions prioritize how to spend its resilience efforts.

Section 6: Strategies for Resilience

Although the region’s transportation infrastructure is subject to climate change vulnerabilities and other natural hazards, our leaders are identifying and implementing a range of strategies for improving the resilience of our transportation system. Resilience strategies improve our transportation agencies’ “ability to the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.”⁸⁵ In the context of climate change and this study, the strategies address disruptions related to natural hazards that have always occurred but that are increasing in frequency, duration, and intensity.

The strategies can be grouped into the following buckets:

- Provide overall strategic direction guiding government actions.
- Modify the government organizational structure and coordination.
- Conduct research and studies to identify more specific strategies.
- Modify the process for selecting and developing transportation projects.
- Improve resilience of the existing transportation infrastructure.

Strategic Direction

Elected officials, political appointees, or agency executives provide overall strategic direction to the government using legislation, regulation, and policy directives.

- **Legislation.**
 - The District of Columbia in 2016 passed legislation establishing the Commission on Climate Change and Resiliency. The commission is responsible for identifying best practices in resiliency, conducting vulnerability assessments for critical infrastructure and systems, and making recommendations for legislative or regulatory changes needed to reduce vulnerabilities, and other duties.
 - Another example is the Maryland Commission on Climate Change. Codified into law in 2015, the commission provides resilience and mitigation advice to the General Assembly and the governor on strategies to adapt to climate change.
 - In 2014, Maryland HB615 established the Maryland Coast Smart Council in the Department of Natural Resources for the purposes of adopting specific Coast Smart siting and design criteria to address impacts associated with sea level rise and coastal flooding on future capital projects.
 - In Maryland, SB 227 requires the Department of the Environment to update certain stormwater management regulations at least once every 5 years to incorporate certain updated precipitation data
 - In 2020, Virginia HB1313 formalized the role of a chief resilience officer, who serves as the main coordinator of resilience and adaptation initiatives.
- **Regulations** are usually developed to add specificity to legislation.
- **Policies** establish that the government will aim do things a certain way in all its actions. Policies to improve resilience could include a policy to minimize disruption to existing trees and green space, which help with both mitigation and adaptation to climate change.
- **Guidance** provides recommendations on specific actions or steps to help governments and developers achieve certain resilience goals.
 - MDOT refers to the Smart Growth for Coastal and Waterfront Communities (2009) guidebook that was developed in partnership between the Environmental Protection

⁸⁵ Federal Highway Administration. December 2014. “FHWA Order 5520.” Available at: <https://www.fhwa.dot.gov/legsregs/directives/orders/5520.cfm#par6>

Agency and the NOAA. The guidebook builds on smart growth principles with 10 development guidelines for coastal and waterfront communities that address resilience and climate change challenges of coastal areas. The MDOT Department of Planning has a requirement that if coastal Maryland communities cannot meet the guidance in the guidebook, they have to receive a waiver to be involved in future investments.⁸⁶

- With the Maryland Commission on climate change, MDOT is developing an adaptation framework that provides actions that can support adaptation resiliency goals. Specific guidance will be provided, such as guidelines for updating bridges to certain engineering codes, but there is not a regulatory requirement. The framework is anticipated to be completed in 2022.

As part of the OIPI VTrans Vulnerability Assessment, flooding risk was identified as one of 10 macro trends in the state. OIPI defines macro trends as an emerging pattern of change likely to impact state government and require a response. This was highlighted in Chapter 6 of the [VTrans Draft Policy Guide](#) that contains the draft policy to develop and monitor the risk and opportunity register.

Organizational Structure

Within government agencies, staff, departments, and workflows can be adjusted to enable a greater focus or improved coordination to improve resiliency.

- **New departments or staff.** When agency executives establish a new office or staff person dedicated to a particular topic, it signals that the topic is a major priority by devoting that resource to the topic.
- **Coordination among departments or agencies.** Achieving a resilient transportation system will require coordination among many agencies and disciplines within the agencies. For example, the people who maintain and operate the existing infrastructure will have data and knowledge that is important to people who are planning long-term projects for the system.
 - Maryland established the Maryland Resiliency partnership, which included SHA and Maryland Transit Administration (MTA), to meet periodically to identify resiliency strategies.⁸⁷ Mitigation Action Worksheets were used to evaluate, prioritize, and rank strategies.
 - WMATA's Severe Weather Plans and Flood Emergency response Plan, provide guidance for the Director of the Office of Emergency Management (OEM), and other staff members during a severe weather event.

Plans, Research, and Studies

Improving the resilience of the transportation system requires new approaches that differ from those used in the past. Transportation investments are often very expensive and take many years to complete. Research and studies help transportation planners identify what changes to make to the existing process for developing projects. These research studies take many approaches:

⁸⁶ Maryland DOT Interview. April 5, 2021.

⁸⁷ Charles County, 2020. Climate Resilience Action Strategy. Available at: [https://go.boarddocs.com/md/chrisco/Board.nsf/files/BRPHA247795D/\\$file/Charles%20County%20Draft%20Resilience%20Report_7.15.2020.pdf](https://go.boarddocs.com/md/chrisco/Board.nsf/files/BRPHA247795D/$file/Charles%20County%20Draft%20Resilience%20Report_7.15.2020.pdf)

- **Vulnerability analyses and risk assessments**, as described in Section 5, COG conducted a CRVA in 2019 as part of its development of the 2030 Climate and Energy Action Plan.⁸⁸ The CRVA assessed the likelihood and consequences of various climate hazards as relating to various sectors, including the transportation sector.
- **Conduct an equity analysis as part of any resiliency or adaptation plans.** Does the adaptation plan include input from EEA residents and other traditionally underrepresented populations? Did the plan’s research investigate how impacts differ for different communities or population groups? Are the benefits and burdens of the proposed plan equitably distributed? COG’s Environmental Justice Toolkit provides helpful tips and approaches for answering these and related questions, and the TPB’s EEA boundaries can be helpful for identifying areas in which the population may be particularly vulnerable to natural hazards.
- **Strategic plans and Action plans** that identify strategies that will improve resilience or help adapt to climate change. Many jurisdictions already have hazard mitigation plans in place; these plans do not typically have a focus on transportation but could incorporate more transportation elements. Other agencies have chosen to create separate plans relating to climate change adaptation.
 - In June 2021, the Metro Board of Directors adopted a sustainability vision and principles and zero emission vehicle goals demonstrating Metro's commitment to provide a sustainable transportation system to the region. One of the principles indicate that WMATA commits to: Build, operate, and maintain a resilient transportation system to improve livability, the environment, equity, and access to opportunity.
 - DDOT’s 2019 Climate Change Adaptation Plan included a vulnerability assessment that ranked how vulnerable different impacts would make transportation assets based on climate indicators and identified strategies to adapt to changing temperature, precipitation, sea level rise, and storms.⁸⁹ Strategies included specific infrastructure improvements, considerations for climate change in planning and design phases for future projects, and analyses to evaluate conditions and climate-related impacts.
 - MDOT’s 2020 Climate Change Adaptation Strategies for a Resilient Transportation System outlines steps to achieve a resilient system: explore climate hazards, assess vulnerability and risks, investigate options, prioritize actions, and act.⁹⁰
 - In October 2020, Virginia released the Virginia Coastal Resilience Master Plan setting out the goals, objectives, guiding principles, and key actions the Commonwealth will pursue to enhance costal resilience, with a focus on protecting key assets, developing cost-effective strategies, conserving and enhancing natural flood controls, and ensuring equity for underserved communities.⁹¹
 - The OIPI VTrans Draft Policy Guide notes strategic actions being developed to address long-term risks and opportunities.
 - Charles County will be using their Climate Resilience Action Strategy as the foundation of the Climate Resilience Plan.

⁸⁸ COG. Metropolitan Washington 2030 Climate and Energy Action Plan. 2020. <https://www.mwco.org/documents/2020/11/18/metropolitan-washington-2030-climate-and-energy-action-plan/>

⁸⁹ District Department of Transportation. 2019. DDOT Climate Change Adaptation Plan. https://osse.dc.gov/sites/default/files/dc/sites/ddot/publication/attachments/ddot_climate_adaptation_plan.pdf

⁹⁰ Maryland Department of Transportation. 2020. Climate Change Adaptation Strategies for a Resilient Transportation System. https://baltometro.org/sites/default/files/bmc_documents/committee/presentations/tc/TC200407pres_Climate-Change%20Adaptation.pdf

⁹¹ Virginia Office of Governor Ralph S. Northam. 2020. Virginia Coastal Resilience Master Planning Framework. <https://www.governor.virginia.gov/media/governorvirginiagov/governor-of-virginia/pdf/Virginia-Coastal-Resilience-Master-Planning-Framework-October-2020.pdf>

- **Gathering available data** in user-friendly ways to inform decision makers. TPB member agencies are exploring the use of technology, geospatial, and engineering tools to help estimate climate-related risks, vulnerabilities, and costs.
 - Virginia and Maryland are part of a pooled fund solicitation with other states for the NOAA Atlas 14 data to aid in climate resiliency.
 - Virginia has completed a sketch-planning level analysis tool identifying impacts of flooding risk on different areas, facilities and population groups. Access the tool online at: <https://vtrans.org/interactvtrans/map-explorer>
- **Analyzing data** in new ways to answer decision-makers' questions relating to resilience.

Development of Transportation Projects

Resiliency strategies can apply at any stage in developing transportation projects. Although the project development process differs across jurisdictions and project types, the major elements involve:

- **Developing project selection criteria.** Agencies can use their goals and objectives to develop criteria that will help them prioritize and select from the many potential projects. Project selection criteria relating to resilience include:
 - Awarding additional points to projects that address known natural hazard risks.
 - Deducting points from projects that are in a high-hazard location and do not have risk-mitigation elements.
- **Addressing known deficiencies.** Transportation planners look for deficiencies in the existing system and propose projects that address those deficiencies. Traditionally, these deficiencies related to congestion or safety goals, but now resiliency goals can also be included.
 - Alexandria, VA, experiences recurrent flooding along the Potomac riverfront; in response, the city is constructing elevated walkways to help with mitigation and maintain pedestrian options.
 - Maryland's 2016 Hazard Mitigation Plan identified the need to re-profile and reconstruct roads in low-lying areas that are prone to flooding.
 - Frederick County's Hazard Mitigation Plan identifies structural corrective action plans (paving/elevation programs) for the county's frequently flooded roadways. Frederick County has developed a map layer of frequently flooded roadways and shares that information with citizens through the county's at-a-glance mapping site.
- **Screening projects for exposure to natural hazards.** Project locations can be overlaid with maps of natural hazard risks, such as flooding. For projects that are in high-risk locations, the agency can either decide to stop investing in that location or to require the project be designed to accommodate the risk.
 - The OIPI [VTrans Vulnerability Assessment](#) is a tool that identifies the vulnerability of Virginia's transportation system that are vulnerable to flooding risks.
- **Project funding.** Agencies can set aside a portion of their funds for projects that address climate risk. Charles County recently created the Resilience Authority of Charles County that is a quasi-governmental entity with non-profit status to funnel resilience projects through. The Authority will focus on drainage projects initially, but the intent is to expand the types of resilience projects as more funding sources are identified for the Authority.
 - MDOT said in an interview that Maryland SHA incorporates resiliency into their goals, which transportation officials consider when vetting projects to approve funding for.

- **Project design and engineering** can prepare for climate risks and natural hazards. VDOT has updated its bridge design practices to account for potential climate impacts. Other agencies have increased the use of erosion control methods and green infrastructure.
 - In 2012, Maryland enacted the initiative “Coast Smart” construction, which directs all state agencies to consider the risk of coastal flooding and sea level rise in the design of state structures to minimize impacts.
- **Environmental reviews** ensure that the transportation agencies fully understand the potential environmental impacts of the proposed projects and require that they accept and respond to public feedback on the project. Although the federal government has been inconsistent about whether the environmental review should include climate considerations, states and localities may decide to include climate risks in their reviews.

Resilience for Existing Infrastructure

Much of the region’s transportation system is already in existence, but resiliency can be improved without waiting for major reconstruction. Resiliency strategies can also be applied to retrofit existing infrastructure, to improve resiliency via the management and operations of the system, and to improve resiliency as part of programs to manage transportation assets. Given that about 80 percent of transportation funding is required to maintain the existing system, many transportation needs compete for the remaining funding. Therefore, funds for stand-alone resiliency projects are limited. To the extent possible, resiliency strategies should be integrated into all aspects of transportation planning, engineering, design and construction. As the relevance and awareness of planning for resiliency continues to increase, agencies in the region will need to identify federal and state funding opportunities, such as the Federal Emergency Management Administration (FEMA) Transit Security Grant Program, BRIC Program, Hazard Mitigation Assistance Grant Program and The Maryland CoastSmart Communities Grant.

- **Asset management programs** work to keep the transportation infrastructure in working order, including clearing and maintaining storm drains.
 - Maryland’s 2016 Hazard Mitigation Plan identified the need to investigate and install evacuation and detour message signs along flood-prone highways.
 - Frederick County’s Hazard Mitigation Plan sets a goal for annual maintenance of all county-owned bridges and culverts. Early warning and educational signage and barricades will be purchased for the identified high-traffic-volume roadways with historically documented high water hazards. The division also maintains a list of roads frequently flooded by high water on the county website.
- **System management and operations** have direct-response duties when a natural hazard disrupts the transportation system. These departments work to ensure that roadways (starting with emergency routes and major roads) are cleared of debris and downed wires.
 - Frederick County’s Hazard Mitigation Plan describes a plan to purchase early warning and educational signage and barricades for high-traffic-volume roadways that were identified as having a documented record of hazardous water. The division also maintains a list of roads frequently flooded by high water on the county website.

Green Infrastructure

“The range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspire stormwater and reduce flows to sewer systems or to surface waters.”

Section 502 of the U.S. Clean Water Act

- **Retrofitting existing infrastructure.** Sometimes existing infrastructure can be made more resilient without the upgrade needing to be a major capital investment.
 - Maryland’s 2016 Hazard Mitigation Plan identified the need to install trash racks upstream of critical bridges to preserve structures and to retrofit or drainage on frequently flooded roads.
 - Frederick County’s Hazard Mitigation Plan describes specific roadway improvements planned/ongoing, such as retrofitting drainage on major roads that frequently flood.

Section 7: MPO Role

As the MPO responsible for transportation planning across the metropolitan Washington region, the TPB plays a key role in transportation planning and convening member agencies to collaborate on important issues for the region’s mobility, environment, and quality of life. The TPB plans for the region’s future, develops consensus on priorities and approaches, and ensures that the MPO’s transportation planning activities meet all federal requirements.

This TPB Resiliency Study, and the products and activities associated with the study, promote the implementation of several of the COG 2030 Climate and Action Plan action items shown in Figure 11, including: PL-2, PL-3, PL-4, and inform RI-4 and RI-5.

Figure 11. COG 2030 Climate and Action Plan, Priority Collaborative Actions

Climate Action Area	Action ID	Priority Collaborative Action
Planning	PL - 2	Support Capacity Building for Climate Resilience Planning
	PL - 3	Develop Integrated Approach to Climate Resilience Planning
	PL - 4	Update Local and Regional Plans to Address Climate Risks
Equity	EQ - 3	Support Engagement of the Public on Climate Risks, with a Particular Emphasis on Potentially Vulnerable Populations
	EQ - 4	Support Equitable Secure Energy Access
Resilient Infrastructure	RI - 1	Support Establishment of Resilience Hubs
	RI - 2	Improve the Resilience of Critical Infrastructure
	RI - 3	Implement Measures to Equitably Address Urban Heat Island
	RI - 4	Enhance Green Infrastructure Networks
	RI - 5	Implement Measures to Reduce Flood Risk

The TPB can play the following roles in helping improve the resilience of the region’s transportation system:

1. Information sharing and professional development.
2. Collaboration around regional priorities and policies.
3. Integrating resiliency considerations into existing TPB activities.

These recommendations are supported by feedback collected through outreach interviews with the TPB member jurisdictions as part of this study.

To ensure that the TPB assistance is equitable, TPB can prioritize the agencies and jurisdictions with fewer resources. For example, some jurisdictions may not have the resources or time to apply to grant programs.

Information Sharing and Professional Development

The TPB-member jurisdictions vary significantly in their responsibilities and their organizational capacity to handle resilience efforts; some member agencies oversee the building of roads, some member agencies operate transit services, and some member agencies have entire transportation

departments. The TPB-member agencies expressed a need to better engage staff in their agencies and other stakeholder organizations who do not see resiliency as a responsibility. The TPB could support all member agencies with professional development materials that are focused on metropolitan Washington and the needs of the TPB member jurisdictions that could be attended/viewed by the TPB member agency staff who may not typically see resiliency as their responsibility. This information could include national and/or regional best practices on resilience-related topics.

These knowledge-sharing opportunities could expand upon the topics discussed in this white paper to include:

- **Climate change risks** to the region’s transportation system, and the benefits of action.
- The role of equity and environmental justice in planning for resiliency, such as how to apply the TPB’s EEA data and COG’s Environmental Justice Toolkit to resilience work.
- **The public’s perceptions** and priorities relating to climate risks and resiliency, such as through the information gathered via the TPB public opinion surveys and focus groups.
- **Key activities underway in the region**, connecting within and across agencies and jurisdictions.
- **Funding sources/opportunities** for resiliency projects and retrofits (e.g., bridge and stream restoration).
- Resiliency for **systems that transportation relies upon** (e.g., electric grid, telecommunications, cybersecurity, water/stormwater).
- **Co-benefits** of resiliency, such as how Complete Streets and Vision Zero policies are related to resiliency.
- **Performance measures** to assess the resiliency of the system and to understand whether the region is improving its resiliency.
- **Descriptions of capital projects** that would improve resiliency. This can help the project sponsors identify projects that would increase resiliency while still meeting their priority needs.
- **Evaluations of projects**. The region’s agencies are spending a lot of money on transportation investments. To protect these investments, the TPB could offer trainings on evaluating the resiliency of major projects.
- **Multimodal systems** as a resiliency strategy. When the public transit is more resilient, it helps the roadway system be more resilient. the TPB could help departments of transportation expand their focus beyond the roadway system.
- **Vehicle Miles Traveled (VMT) reduction** strategies as a tool for improving resiliency. Reducing VMT helps the region reduce its reliance on vehicular traffic that may be susceptible to disruptions, but it also helps reduce the potential climate impacts that we may face.

Avenues for sharing this information include:

- **Trainings and webinars**. Trainings and webinars could be offered virtually or in person, and include the TPB-member agency staff that might not typically attend the TPB meetings, but who may work in areas where resiliency could be more strongly incorporated into agency operations. These trainings and webinars could target co-benefits of resilient infrastructure and support bridging silos between staff who identify as working in resilience and those who do not typically identify their work as being focused on resiliency. For the TPB-member agency field staff who could not attend in real time due to work demands, recordings could be available. The TPB-member agencies emphasized that these trainings would be

especially helpful in learning about and responding to federal government requirements or authorization bills.

- **Peer exchanges.** Similar to trainings and webinars, peer exchanges could bring together representatives of the TPB-member agencies for more in-depth conversations and information-sharing and allow agencies to learn from each other through presentations on each participating agency’s practices related to the resiliency topic, such as resilience performance measures or prioritizing resiliency in project selection.
- **Guides and publications.** The TPB could provide support for jurisdictions by developing resources about resiliency that could help counties incorporate policies and practices into their planning documents and engineering operations that would be consistent with other jurisdictions. The TPB-member agencies reported that this would be especially helpful for jurisdictions that do not directly manage some of the infrastructure construction or operations within their jurisdiction, so that they can still support the regional resiliency efforts in these areas even though it might not make sense for them to develop their own separate policies and goals. Resources may include guidebooks, case studies, or reports based on presentations from webinars or peer exchanges.

Collaboration Around Regional Priorities and Policies

The TPB plays an essential role convening the region’s stakeholders around regional priorities, and with this project, the TPB has started convening efforts relating to resiliency. This project’s convenings began as a way to gather and share information, but they could evolve to develop regional collaboration on solutions. Here are some examples of how the TPB’s information sharing activities could lead to regional collaboration:

- **Making the case for competitive grant applications.** Collaboration can help agencies/projects be more competitive for funding opportunities relating to resiliency. Many grant programs include criteria to show an active partnership among multiple agencies or jurisdictions.
- **Improving efficiency by pooling resources.** Coalitions working together can help streamline the process and lead to efficiencies by pooling efforts across multiple agencies. Several of the region’s agencies do not have the available staff to lead resiliency efforts, but they could have capacity to support a coalition of agencies.
- **Systems thinking** to look within and between different transportation modes and across different jurisdictions in the region, including finding critical points of failure, or handling multiple interacting crises and cascading failures.

The TPB can also build resiliency into existing collaborative efforts such as Region Forward and the Transportation and Climate Initiative.

Integrating Resiliency Into Existing TPB Activities and Research

The TPB, as the region’s MPO, has many existing duties to comply with federal requirements and with the planning support needs of the region’s transportation stakeholders. This project has begun responding to the federal requirements and regional needs relating to resiliency, and resiliency can continue to appear as a theme across the TPB’s work.

- Reviving the familiarity with the **TPB Green Streets Policy**.⁹² This policy came up in many discussions over the course of this project, and connecting it to resiliency efforts could build momentum for the strategy. The policy encourages the region’s agencies to adopt their own green streets policies and includes the following definitions:
 - “Green Streets are an alternative to conventional street drainage systems designed to more closely mimic the natural hydrology of a particular site by infiltrating all or a portion of local rainfall events. A green street uses trees, landscaping, and related environmental site design features to capture and filter stormwater runoff within the right of way, while cooling and enhancing the appearance of the street.”
 - Green Streets Policy is “a directive at the local, state, regional, or federal level that requires the use of green streets techniques to manage stormwater runoff from transportation facilities in a manner appropriate to the function and context of the relevant facility.”
- Resiliency strategies can be a topic of discussion at the **TPB’s existing meetings**, including of the TPB Technical Committee, subcommittees, the Citizens Advisory Committee, and the Access for All Advisory Committee. If the TPB does not have its own existing work to share, then participants at these meetings could be invited to share the work of their agency, and the TPB staff could facilitate a conversation around how to support those efforts.
- When the TPB conducts **major studies**, such as scenario planning efforts or updates to the travel demand model, the scope could include resiliency considerations to understand how climate impacts might alter future conditions in the region.
- The **Transportation Land-Use Connections Program** offers opportunities for resiliency strategies related to the preservation of open space and other land use issues. For example, several agencies are working to raise the elevations of frequently-flooded roadways, but this raises the question of what happens if the surrounding land is underwater.
- The **Metropolitan Area Transportation Operations Coordination Program** offers opportunities to improve coordination for addressing near-term natural hazards but also to put systems in place to prepare for the future. For example, as technology becomes more prevalent to monitor the transportation system and its performance, this technology could include sensors to provide trend data or real-time notification of flooding or heat extremes.
- The TPB provides its jurisdiction with some **data and tools** but has no single clearinghouse or website at which jurisdictions can find the data. The TPB could expand its Regional Transportation Data Clearinghouse to include multiple datasets, or even to support the uploading of data from its stakeholder jurisdictions. The region also faces challenges in that many of the national datasets divide the region, with Virginia being part of southern datasets and DC and Maryland being part of mid-Atlantic datasets.
- COG recently completed a **vulnerability assessment** for the region. The TPB could work with COG to update the assessment to provide a greater focus on transportation impacts and strategies. By building off of COG’s existing work, the TPB could provide a vulnerability assessment for the region at a lower level of effort than if they undertook the project from scratch.
- The TPB provides evaluations of the performance of the long-range plans, and these evaluations can include measures relating to resiliency.
 - Exposure to Localized Transportation Pollution can decrease a community’s ability to recover from natural hazards, and EEA communities may be particularly vulnerable.

⁹² TPB R10-2014 Resolution Approving the Green Streets Policy for the National Capital Region. Available at <https://www.mwcog.org/documents/2014/02/19/tpb-r10-2014--resolution-approving-the-green-streets-policy-for-the-national-capital-region/>

- Percent Green Land Cover and measures of open space can help the region understand their current ability to use natural lands to protect against natural hazards by absorbing stormwater and reducing heat.
- Infrastructure Exposed to Flooding can measure the extent to which the region's infrastructure is exposed and, therefore, at risk.
- Number of Projects in the Plan that Incorporate Best Practices to Improve Resiliency can help the region measure whether we are making progress on improving resiliency. By including such a question on project submission forms, it can encourage project sponsors to consider resiliency as they develop the project.

Conclusion

Metropolitan Washington faces many natural hazards that may be worsening with climate change, and the region's transportation agencies are preparing the transportation system to be resilient to these changes. The resilience strategies discussed in this paper and others underway are improving "the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions."⁹³

This paper provides only a high-level overview of past and current work to improve transportation resiliency, such as the three recent or ongoing studies out of COG and the TPB.

1. COG's 2030 Climate and Energy Action Plan contains voluntary actions relating to both mitigation and adaptation/resilience. As a COG product, the 2030 Plan provides a cross-sector approach with only high-level information relating to transportation resilience.
2. The TPB Resiliency Study: Adaptation Planning and Coordination takes a deeper dive into preparing the region for transportation resilience. This study looks at resilience to natural hazards that have always occurred in the region as well as the increase in intensity, frequency, and duration of natural hazards due to climate change. This white paper is a product of the TPB Resiliency Study.
3. The TPB Climate Change Study of 2021 is evaluating scenarios of strategies for reducing GHG emissions from the transportation sector.

The TPB will continue working with the region's transportation agencies to coordinate on planning for a more resilient transportation system. These efforts help comply with federal planning requirements, but they also respond to expectations expressed in public opinion surveys and to regional priorities for improving equity.

⁹³ United States Department of Transportation (USDOT) Federal Highway Administration (FHWA), December 2014. "FHWA Order 5520." Available at: <https://www.fhwa.dot.gov/legsregs/directives/orders/5520.cfm#par6>

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