THE NEED FOR RESILIENCE: PREPARING AMERICA'S TRANSPORTATION INFRASTRUCTURE FOR CLIMATE CHANGE

HEARING

BEFORE THE

SUBCOMMITTEE ON INVESTIGATIONS AND OVERSIGHT

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

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C O N T E N T S

May 21, 2019

THE NEED FOR RESILIENCE: PREPARING AMERICA'S TRANSPORTATION INFRASTRUCTURE FOR CLIMATE CHANGE

TUESDAY, MAY 21, 2019

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON INVESTIGATIONS AND OVERSIGHT,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to notice, at 10:02 a.m., in room 2318 of the Rayburn House Office Building, Hon. Mikie Sherrill [Chairwoman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON INVESTIGATIONS AND OVERSIGHT
U.S. HOUSE OF REPRESENTATIVES

HEARING CHARTER

The Need for Resilience:
Preparing America's Transportation Infrastructure for Climate Change

Tuesday, May 21, 2019
10:00 a.m.
2318 Rayburn House Office Building

PURPOSE

On Tuesday, May 21, 2019, the Subcommittee on Investigations and Oversight will hold a hearing to examine the threat to transportation assets posed by climate change; assess the current state of federal research on transportation infrastructure climate resilience; and explore strategies by which the federal research enterprise can complement state and local efforts on transportation climate resilience more effectively.

WITNESSES

- **Ms. Susanne DesRoches (Duh-ROWSH)**, Deputy Director for Infrastructure and Energy, Office of the New York City Mayor.

- **Mr. Gregory D. Winfree (WIN-free)**, Director, Texas A&M Transportation Institute (TTI).

- **Mr. Jason Averill (AV-ur-ill),** Chief, Materials and Structural Systems Division, Engineering Laboratory, National Institute of Standards and Technology.

- **Mr. Scott Reeve (REE-vuh),** President, Composite Advantage.

KEY QUESTIONS

- How do climate impacts threaten transportation infrastructure?
- What are the risks to public investment when we fail to plan for climate considerations?
- What is the federal research enterprise currently doing to support increased climate resilience in transportation infrastructure?
- What are state and local governments doing to strengthen the climate resilience in transportation?
- How can the federal research enterprise help cities, states, planning organizations and codes and standard bodies accommodate climate considerations more effectively?

BACKGROUND

Defining Climate Resiliency

The American Society of Civil Engineers defines resilience as "the infrastructure system's capability to prevent or protect against significant multi-hazard threats and incidents," as well as its ability "to quickly recover and reconstitute critical services with minimum consequences for public safety and health, the economy, and national security."[1] For the purposes of this hearing discussion, the Committee defines climate resilience in transportation infrastructure to include how assets are able to avoid and minimize destruction, degradation and service interruptions when they encounter climate change impacts like extreme weather and flooding (that is, the ability to sustain), and the ability for assets to be restored to service more quickly and at lower cost when they are damaged or destroyed (that is, the ability to recover). Sometimes the former concept is referred to as robustness or reliability.

The Impacts of Climate Change on Transportation Infrastructure

As a result of greenhouse gases accumulating in the atmosphere, global average temperatures are about 1.8° F (1° C) higher today than in 1880.[2] The effects of this rapid change are numerous. The rising incidence of extreme weather patterns are degrading, destroying or limiting access to our roads, bridges, tunnels, ports, airports and railways - punctuated by devastating weather events such as Hurricane Sandy. While climate conditions are already changing rapidly in the 21st century, most transportation infrastructure in the U.S. was designed and built with an assumption of a static, 20th century environment. Particularly because transportation assets are designed for long life spans that will extend well past mid-century and potentially even beyond 2100, it is important for transportation planners to accommodate a changing climate as they invest taxpayer dollars in new projects and project enhancements.

The symptoms affecting transportation infrastructure most directly and immediately are outlined below. Different regions have varying degrees of vulnerability to different aspects of climate change, and the impact on transportation infrastructure will vary accordingly.

- **Sea Level Rise and Storm Surge**: Since 1880, average global sea levels have increased ~9 inches.[3] The National Climate Assessment of 2018 projects an additional 1-4 feet by 2100 under a moderate greenhouse gas emissions scenario, but as many as 8 feet is possible.[4] As a result, coastal infrastructure is exposed to a far greater "baseline" risk of flooding, with particularly acute consequences when storm surges push seawater inland. NOAA has found nuisance flooding occurs 300-900% more frequently than 50 years

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[1] American Society of Civil Engineers, "What Makes A Grade?" 2019, accessed here: https://www.infrastructurereportcard.org/making-the-grade/what-makes-a-grade/.
[2] Intergovernmental Panel on Climate Change, "Global Warming of 1.5°C," October 2018, accessed here: https://www.ipcc.ch/sr15/.
[3] Fourth National Climate Assessment, "Chapter 12: Transportation," November 2018, accessed here: https://nca2018.globalchange.gov/chapter/12/.
[4] *Id.*

ago.[5] Bridges, ports, airports, and more than 60,000 miles of coastal roadways are at risk from sea level rise and storm surge; more than 7,500 miles of roadway on the East Coast alone – along with critical rail and bridge assets – are susceptible to high-tide flooding.[6]

- **Extreme Weather Events:** Climate change increases the frequency and severity of hurricanes and tropical storms, which in turn increases the vulnerability of coastal transportation assets to flooding. Climate-driven volatility is also leading to more frequent and severe non-coastal weather events, such as hail storms and extreme rains, which can drive inland flooding.[7] More aggressive climate models estimate that 4,600 inland bridges are vulnerable to increased precipitation levels by 2050, while a greater likelihood of mudslides and landslides threatens both coastal and inland roadways.[8]

- **Extreme Temperatures:** Railroad tracks experience thermal expansion during extreme heat that can lead to buckling and warping under rail traffic, requiring rail operators to slow or temporarily stop trains during heat waves.[9] Bridge construction projects have required modifications as a result of warping steel from extreme temperatures during construction. In air travel, hotter air is less dense, and it therefore becomes harder for aircraft to achieve the loft needed to take off safely. Extreme summer heat waves have already caused an increase in flight delays and cancellations in the Southwest.[10]

- **Effects on building materials.** Shifts in temperature and rainfall amounts are altering regional freeze-thaw cycles, affecting the durability of infrastructure building materials such as asphalt and concrete.[11] More frequent freeze-thaw episodes and extreme heat waves lead to more potholes in roadways and reduce the service life of concrete and steel bridges.[12] In addition, the metals and concrete traditionally used in construction corrode when exposed to sea water. As more coastal assets are exposed to storm surge and flooding, some tunnels, bridges, and rail assets will see accelerated degradation.

Federal Participation in Transportation Planning

States are the primary decision-makers on all transportation infrastructure choices, including how and whether to accommodate changing environmental conditions like coastal flooding. However, the federal government has an interest in supporting transportation climate resilience in order to protect public safety, minimize disruptions to its investments in transportation assets via grants made to states and planning organizations, and reduce the financial burden of future transportation disaster relief. The federal investment in transportation infrastructure nationwide

[5] ClimateWatch, "Climate Change: Global Sea Level," August 2018, accessed here: https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level.
[6] Fourth National Climate Assessment, "Chapter 12: Transportation," November 2018, accessed here: https://nca2018.globalchange.gov/chapter/12/.
[7] *Id.*
[8] *Id.*
[9] *Id.*
[10] *Id.*
[11] *Id.*
[12] Federal Highway Administration, "Planning for Systems Management & Operations as part of Climate Change Adaptation," February 2017, accessed here: https://ops.fhwa.dot.gov/publications/fhwahop13030/chap3.htm.

is substantial. The Highway Trust Fund, administered through the DOT Federal Highway Administration (FHWA), represents the lion's share of federal spending on surface transportation generally. The Highway Trust Fund's projected outlays for FY2021 are $58 billion, with an estimated $41 billion coming from federal gas tax revenues and the balance presumably sourced from the Treasury's general fund.[13]

Federal policy generally does not require state and local governments to incorporate climate resilience into their transportation planning in order to receive federal assistance.[14] Other sectors have made it compulsory to consider climate predictions at certain stages of infrastructure planning. For example, the National Defense Authorization Act of 2019 requires the Department of Defense to construct all buildings at least two feet above the base flood elevation.[15] Similarly, the National Flood Insurance Program requires communities to adopt adequate floodplain management measures before it will make flood insurance available for residential and commercial buildings in that region.

By contrast, climate considerations are accommodated in the transportation sector when states and municipalities prioritize their own expenditures. Under the FAST Act, states may choose to obligate DOT grant funding for protection of transportation assets against extreme events and to enhance resilience generally.[16] There are also a number of relatively modest competitive grant programs within DOT and other agencies that are dedicated to helping communities minimize the impacts of future floods and other disasters. For example, the Federal Emergency Management Agency (FEMA) hosts the Hazard Mitigation Grant Program and Pre-Disaster Mitigation grants programs.

Climate resilience and other "smart growth" considerations are also incorporated in transportation planning and restoration via industry-based codes and standards. Codes and standards organizations develop technical guides and make them available to states and local jurisdictions, product manufacturers, and project developers, who then elect whether to adopt the model codes as compulsory. For example, the American Society of Civil Engineers (ASCE) develops standards for construction of roads and bridges, the "Green Book" from the American Association of State Highway and Transportation Officials (AASHTO) dictates geometric design of highways and streets, and ASTM International establishes standards for the durability of cement and concrete. The decision to follow various codes and standards can have implications for issues such as how much it costs to finance an asset, and whether the engineers that design the asset can procure liability insurance.

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[13] Congressional Research Service, "Funding and Financing Highways and Public Transportation," October 2018, accessed here: https://crsreports.congress.gov/product/pdf/R/R45350.
[14] Kevin DeGood, "Testimony Before the House Transportation and Infrastructure Committee," February 2019, accessed here: https://transportation.house.gov/imo/media/doc/DeGood%20Testimony.pdf.
[15] John S. McCain National Defense Authorization Act for Fiscal Year 2019, Public Law 115-232, August 2018, accessed here: https://www.congress.gov/115/bills/hr5515/BILLS-115hr5515enr.pdf.
[16] Fixing America's Surface Transportation Act (FAST Act), Public Law 114-94, December 2015, accessed here: https://www.congress.gov/114/plaws/publ94/PLAW-114publ94.pdf.

Federal Participation in Asset Restoration

The federal government has an important role in restoring communities who are affected by extreme weather, flooding or other disasters. Federal spending on disaster relief has surged in recent years, largely due to more frequent natural disasters: the United States averaged 6 weather-related disaster events with a cost of at least $1 billion annually between 1980 and October 2018, but it experienced fifteen such events in 2016, sixteen such events in 2017, and 11 such events through October 2018.[17] U.S. DOT spent $10 billion on disaster relief between FY 2005 and FY 2014, of which 94% came from the agency's own budget and only 6% originated with FEMA.[18]

Federal policies that require climate considerations to inform planning in disaster relief and infrastructure restoration are relatively minimal. For example, when FEMA funds are used to rebuild an asset destroyed in a flood or other disaster, it must be rebuilt as it was, even if its vulnerability to future flooding is well understood.

Federal Research and Information Sharing on Transportation Infrastructure Climate Resilience

The federal research enterprise can support climate resilience in transportation in three general ways today:

- Developing and sharing climate predictions and mapping of future conditions;
- Supporting research on advanced materials that can better tolerate changing climate conditions; and
- Providing technical assistance to states and planning organizations, including vulnerability assessments and adaptation studies.

Relevant Department of Transportation (DOT) Research Activities

DOT does not have a coordinated institutional framework dedicated to climate resilience research, planning and education. Annual dedicated funding for climate resilience appears to be no more than several million dollars across the Department, although exact funding amounts are difficult to calculate due to a lack of precise categorization.[19]

U.S. DOT does support relevant research activities across its various program offices, including the Office of the Assistant Secretary for Research and Technology (OST-R) in the Office of the Secretary and within each of the major modal operating administrations (highways, transit, rail and aviation). Each office has a relatively broad set of research priorities, within which climate resilience is only one consideration. These programs provide modest support for materials research, primarily through the pavement and materials research and development program led

[17] Congressional Research Service, "The Disaster Relief Fund: Overview and Issues," February 2019, accessed here: https://crsreports.congress.gov/product/pdf/R/R45484.
[18] Pew Charitable Trusts, "Federal Disaster Assistance Goes Beyond FEMA," September 2017, accessed here: https://www.pewtrusts.org/-/media/assets/2017/09/federal-disaster-goes-beyond-fema_final.pdf.
[19] Government Accountability Office, "Climate Change: Analysis of Reported Federal Funding," April 2018, accessed here: https://www.gao.gov/assets/700/691572.pdf.

by the FHWA.[20] The University Transportation Centers (UTC) program, administered by OST-R but funded by FHWA, has made a handful of grants to universities specifically dedicated to research on sustainability and resilience in transportation.

DOT programs also work with cities and states to develop targeted vulnerability and adaptation studies focused on specified locations. DOT's primary effort in this regard is FHWA's Sustainable Transportation program, which encourages sustainability and resilience planning in the maintenance of road and highway systems.[21] The Sustainable Transportation program has partnered with state and local DOTs in five rounds of pilot programs to develop state and local capabilities regarding a range of transportation resilience planning activities.[22] The Federal Aviation Administration (FAA) also oversees an Airport Sustainability program that provides grants to airports to encourage long-term sustainability planning on the part of airport operators.[23]

DOT helps support the development of technical information and best practices by AASHTO, a nonpartisan association of the highway and transportation departments of all 50 states. DOT and AASHTO jointly operate a Center for Environmental Excellence that provides a range of programs related to environmental issues in transportation policy, including a Resilient and Sustainable Transportation Systems Technical Assistance Program.[24] DOT funds are also used to support the Transportation Research Board (TRB) at the National Academies. TRB plays an important role in convening technical experts, evaluating and sharing information about many transportation issues, including resilience solutions, and providing advice to federal, state and local decision-makers via its policy studies.

Relevant NIST Research Activities

NIST supports transportation climate resilience through materials research. The Materials and Structural Systems Division (MSSD) leads NIST efforts to study the weathering and aging of materials and structures in order to both predict their service life with accuracy and understand how to protect structures from natural hazards.[25] As an example, the Accelerated Weathering Laboratory under MSSD uses a device called SPHERE to expose various materials to UV light under controlled conditions in order to develop performance models for their service life. MSSD's research and the reference materials they develop are used by private codes and standards bodies to improve their own test standards. MSSD also leads NIST's efforts on making communities more resilient. Its Community Resilience Planning Guide is a set of technical tools

[20] Federal Highway Administration, "Pavement and Materials," November 2018, accessed here: https://highways.dot.gov/infrastructure/pavements-and-materials/pavement-and-materials#materials.
[21] Federal Highway Administration, "Sustainable Transportation," August 2018, accessed here: https://www.fhwa.dot.gov/environment/sustainability/.
[22] Federal Highway Administration, "Resilience Pilots," March 2019, accessed here: https://www.fhwa.dot.gov/environment/sustainability/resilience/pilots/.
[23] Federal Aviation Administration, "Airport Sustainability," April 2019, accessed here: https://www.faa.gov/airports/environmental/sustainability/.
[24] Center for Environmental Excellence by AASHTO, "Resilient and Sustainable Transportation Systems Technical Assistance Program," 2019, accessed here: https://environment.transportation.org/center/rsts/.
[25] National Institute of Standards and Technology, "Materials and Structural Systems Division," https://www.nist.gov/el/materials-and-structural-systems-division-73100.

that communities can use to assess their vulnerability to extreme weather risk and inform science-based investment decisions. The guide contains a chapter dedicated to bolstering the resilience of transportation systems.[26]

NIST's Applied Chemicals and Materials Division (ACMD) in Boulder, Colorado evaluates measurement standards to complete lifetime models and predictions for various materials.[27] ACMD work on pressurizing devices, fracture and fatigue of materials has broad applications across all manner of building materials, including steel, concrete, and advanced composites.

[26] National Institute of Standards and Technology, "Community Resilience Planning Guide for Buildings and Infrastructure Systems," May 2016, accessed here: https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1190v2.pdf.

[27] National Institute of Standards and Technology, "Applied Chemicals and Materials Division," accessed here: https://www.nist.gov/mml/acmd.

Chairwoman SHERRILL. This hearing will come to order.

Without objection, the Chair is authorized to declare recess at any time.

Good morning, and welcome to today's hearing of the Investigations and Oversight Subcommittee. I am pleased once again to welcome Ranking Member Norman of South Carolina and all of my colleagues on both sides of the aisle.

Today, we are discussing a subject that directly touches all of our lives almost daily. America's transportation infrastructure is vital to the Nation's well-being. And in cities, suburbs, and small towns across the country, Americans rely on the roads, highways, bridges, tunnels, trains, airports, and ports of our transportation system to live their lives and to support their families.

But climate change poses an unprecedented threat to our transportation infrastructure. Sea-level rise and coastal flooding place 60,000 miles of roads and bridges in coastal floodplains at greater risk. Rail infrastructure and airports are also vulnerable to more frequent extreme heatwaves and increased flooding. And the impacts of climate change for transportation infrastructure will only intensify over time.

This issue hits home in New Jersey, because we've seen the impacts of extreme weather up close. In 2012, Hurricane Sandy flooded the Hudson Tunnel, the only tunnel that provides passenger rail access between New Jersey and New York City. We have been living with the consequences ever since, as the concrete and metal in the tunnel, the 100-year-old tunnel, continue to deteriorate due to the effects of age and seawater. I toured the tunnel earlier this month with some of my colleagues in Congress and saw the degradation firsthand.

If the Hudson Tunnel must eventually be shut down for repairs, the economic effects for the region and the Nation will be catastrophic. Many of my constituents commute to work and school every day through that tunnel. We need to understand that climate change makes storms like Hurricane Sandy more likely and that our transportation infrastructure is exposed.

We also need to take climate reality into account when planning for the future. In the Northeast, we have a solution called the Gateway Program that would build a second rail tunnel to handle passenger rail traffic while the current tunnel is being repaired. Gateway is vital to the region's future. We must ensure that the Gateway tunnel gets built as soon as possible, and we must make sure it is built to enhance the overall climate resilience of the region's transportation system.

Other transportation assets in my region are similarly vulnerable to climate impacts. Using the Surging Seas analysis from Princeton University, we can see the impacts of sea-level rise for coastal transportation infrastructure in northern New Jersey. The expected sea-level rise in that area is 3 to 6 feet, and under a 6-foot scenario, Newark Airport is virtually underwater, and the roads, bridges, and rail infrastructure all along the coastline are inundated, as you can see. A 2017 report commissioned by Amtrak identified the same kind of flooding vulnerabilities along the system's coastal routes in the Northeast Corridor.

This hearing is an opportunity to look forward, rather than backward, and to focus on solutions. I hope that the hearing helps us to answer questions about the role that the Federal Government should play in understanding and enhancing transportation climate resilience, and we need to understand what the Federal Government is doing well and not so well. We need to listen to cities and municipal planners when they tell us the challenges they face, and we need to help them share their lessons learned with other communities around the country. We also need to think creatively about how to mobilize our Nation's research enterprise, from Federal agencies to academia. The stakes are too high for anything less.

I'm very pleased to welcome the distinguished witnesses appearing here today, and we thank you for appearing before the Subcommittee and look forward to your testimony.

[The prepared statement of Chairwoman Sherrill follows:]

Good morning, and welcome to today's hearing of the Investigations and Oversight Subcommittee. I am pleased once again to welcome Ranking Member Norman of South Carolina and all of my colleagues on both sides of the aisle.

Today we are discussing a subject that touches all of our lives almost daily. America's transportation infrastructure is vital to the nation's wellbeing. In cities, suburbs and small towns across the country, Americans rely on the roads, highways, bridges, tunnels, trains, airports and ports of our transportation system to live their lives and support their families

But climate change poses an unprecedented threat to our transportation infrastructure. Sea level rise and coastal flooding place 60,000 miles of roads and bridges in coastal floodplains at greater risk. Rail infrastructure is vulnerable to more frequent extreme heat waves. Increased precipitation and inland flooding threaten the structural integrity of thousands of bridges. Airports are exposed to a spectrum of flooding and extreme heat risks. And the impacts of climate change for transportation infrastructure will only intensify over time.

This issue hits home in New Jersey, because we have seen the impacts of extreme weather up close. In 2012, Hurricane Sandy flooded the Hudson Tunnel - the only tunnel that provides passenger rail access between New Jersey and New York City. We have been living with the consequences ever since, as the concrete and metal in the Tunnel continue to deteriorate due to the effects of seawater. I toured the Tunnel earlier this month with some of my colleagues in Congress and saw the degradation first hand.

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This hearing is an opportunity to look forward, rather than backward, and to focus on solutions. I hope that the hearing helps us to answer questions about the role that the federal government should play in understanding and enhancing transportation climate resilience. We need to understand what the federal government is doing well and not so well. We need to listen to cities and municipal planners

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Chairwoman SHERRILL. The Chair now recognizes Mr. Norman for an opening statement.

Mr. NORMAN. Thank you, Chairwoman Sherrill, for convening this meeting, and thank each one of the witnesses for taking the time to come.

In case you're wondering, the rose on my lapel is for the 100-year women's right to vote. I was there at the time. I was about 4 years old, and I was responsible for passing it, so thank you all for recognizing that.

We are here today to examine how natural disasters and extreme weather events pose risks to transportation infrastructure and to assess the research and development targeted at improving the resilience of America's transportation infrastructure.

Reliable and strong infrastructure is critically important to my home State of South Carolina. In the past 5 years alone, South Carolina has been impacted by a 1,000-year flood and back-to-back hurricanes. In South Carolina we're also concerned about the impact that increased flooding frequently has on our communities.

To address our State's specific concerns, the Governor created the South Carolina Floodwater Commission. This commission is tasked with identifying short-term and long-term solutions to mitigate the impact of extreme weather, with one task force specifically focused on infrastructure resilience.

I welcome the chance to consider the issue of infrastructure resilience and highlight the role the Federal Government can play in ensuring that State and local communities all have the resources necessary to make the best decision for their infrastructure planning.

Further, I'm looking forward to learning more about technologies and innovations that can improve the resilience of America's transportation infrastructure systems and assets, from advanced composite materials to additive manufacturing with cement and concrete.

We will also hear about some of the ambitious initiatives being undertaken at the Federal, State, and local levels of government to incorporate resilience considerations into the planning, design, and construction of America's transportation infrastructure, both now and in the future.

In recent years, much of the country's transportation infrastructure has started to show its age. Across the country, from coastal communities to land-locked States, roads are in disrepair, bridges are collapsing, and tunnels are crumbling. Fortunately, great work is being done at the Federal, State, and local levels of government, within industry, and among academia to improve transportation infrastructure resilience.

Composite materials, like those manufactured by Composite Advantage and other members of the American Composites Manufacturers Association (ACMA), are already being used to rebuild and

repair our crumbling infrastructure and corroding assets. This is a great example of American innovation rising to meet the challenges facing our Nation.

The National Institute of Standards and Technology (NIST) is also working hard to help improve the resilience of American communities. From research into advanced materials and enhancing traditional materials like concrete and cement, to the development of tools, standards, and guidelines, NIST has been working diligently to improve the way transportation infrastructure decisions are made, once again putting its extreme brain power to work for the American people.

State agencies like the Texas A&M Transportation Institute are making positive strides to improve transportation infrastructure resilience. And municipal authorities like the New York City Mayor's office are also involved in this important work.

It is encouraging to see representatives from each of these organizations here today, as the work they are doing will undoubtedly benefit officials throughout the country as they plan and prepare to build resilient considerations into their transportation infrastructure decisions.

I look forward to a productive and insightful discussion with our distinguished witnesses about the risks that extreme weather events and natural disasters pose to the American transportation infrastructure, research, and activities aimed at operationalizing and incorporating resilient considerations into the planning, design, and construction of infrastructure systems and assets, and innovating in exciting ways that we can improve the resilience of America's transportation infrastructure, both now and in the future.

My line of work is development. We're contractors, and this has extreme importance to me, particularly as it relates to the new products.

Thank you, Madam Chair, and I yield back.

[The prepared statement of Mr. Norman follows:]

Thank you, Chairwoman Sherrill, for convening this important hearing, and thank you to the witnesses for your testimony this morning.

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Thank you, Madam Chair. I yield back.

Chairwoman SHERRILL. Thank you, Representative Norman.

And if there are Members who wish to submit additional opening statements, your statement will be added to the record at this point.

[The prepared statement of Chairwoman Johnson follows:]

Thank you Madam Chair, and I would like to join you in welcoming our witnesses this morning.

In the 116th Congress, the Science Committee will be examining both the science of climate change and its impact on our society. Transportation infrastructure is critical to our national economy and our way of life, but it is vulnerable to climate change. If we do not prepare our transportation systems effectively, the damage will be enormous.

As a senior Member of the Transportation and Infrastructure Committee, I am very familiar with the challenges facing our transportation infrastructure. And it has become increasingly clear to me that climate change will be one of the most consequential and complex challenges. Climate implications exist for every type of transportation asset: highways and roads, bridges, railroads, airports, tunnels, ports and more. Every region of America is being affected: north and south; urban and rural; coastal and inland. The time has come to use the scientific tools at our disposal to adapt our transportation infrastructure in order to avoid the worst effects of a changing climate.

Elevating the use of science in policymaking is a priority for this Committee, and the issue of transportation resilience is a perfect example of why that is so important. Transportation assets are designed and built to operate over extremely long timespans - multiple decades and sometimes as long as 100 years. As a result, today's transportation planning decisions are not only about us - they will affect our great-grandchildren. If transportation planning does not incorporate climate resilience into its calculations, the vulnerabilities of our transportation infrastructure will become a permanent feature of American life. We must work to ensure that the most advanced climate research findings are integrated into transportation planning frameworks.

I also want to highlight the importance of mobilizing the nation's research enterprise to promote transportation climate resilience. At a federal level, this means encouraging the Department of Transportation and NIST to carry out research on how a changing climate threatens transportation assets. It also means prioritizing climate resilience research through federal grant programs such as DOT's University Transportation Centers program, which is a longstanding area of interest for the Committee. The UTC program supports cutting-edge transportation research at academic institutions around the country. UTCs like the one led by Mr. Winfree at Texas A&M are conducting some of the most innovative transportation research in the world. We want to make sure that the fruits of their labors, and the efforts of other forward-looking universities, professional societies and engineers, are being shared effectively with cities and states around the country.

Preparing America's transportation infrastructure for the impacts of climate change is one of the major economic challenges facing our country, and there is much to be done.

Thank you, and I yield back to Chairwoman Sherrill.

Chairwoman SHERRILL. At this time, I would like to introduce our four witnesses. Ms. Susanne DesRoches is the Deputy Director of Infrastructure and Energy at the New York City Mayor's Office of Resiliency and Office of Sustainability.

Mr. Gregory Winfree is the Agency Director for the Texas A&M Transportation Institute and former Assistant Secretary of the U.S. Department of Transportation.

Mr. Jason Averill is the Chief of the Materials and Structural Systems Division of the Engineering Laboratory at the National Institute of Standards and Technology or NIST.

And our final witness, Mr. Scott Reeve, is the President of Composite Advantage. Today, Mr. Reeve is speaking on behalf of the American Composites Manufacturers Association of which his company is a member.

As our witnesses should know, you will each have 5 minutes for your spoken testimony. Your written testimony will be included in the record for the hearing. When you all have completed your spoken testimony, we will begin with questions, and each Member will have 5 minutes to question the panel.

We will start with Ms. DesRoches.

TESTIMONY OF SUSANNE DESROCHES, DEPUTY DIRECTOR FOR INFRASTRUCTURE AND ENERGY, NEW YORK CITY MAYOR'S OFFICE OF RESILIENCY AND OFFICE OF SUSTAINABILITY

Ms. DESROCHES. Good morning. My name is Susanne DesRoches, and I'm the Deputy Director for Infrastructure and Energy in the New York City Mayor's Office of Resiliency. On behalf of the Mayor and the city of New York, I would like to thank Chair Sherrill and Ranking Member Norman for the opportunity to speak today.

Nearly 7 years ago Hurricane Sandy hit New York City with unprecedented force, tragically killing 44 New Yorkers. Over 2 million residents were without power, some for weeks. Fuel shortages persisted for over a month. Subway and rail tunnels were closed for days. Our airports were closed to passenger and freight traffic, and our ports sustained considerable damage. Sandy caused $16 billion in damages to our region's transportation network, which is vital to our regional and national economy.

Our national transportation system faces climate-related risks. The Fourth National Climate Assessment released last year, of

which I co-authored the transportation chapter, found that impacts of climate change threaten the very existence of a reliable, safe, and efficient U.S. transportation system. Critical port, rail, and highway infrastructure are vulnerable to sea-level rise across the country in places like Houston, Texas; Long Beach, California; and Mobile, Alabama. Thirteen of the Nation's 47 largest airports have a runway within reach of moderate-to-high storm surge today. Inland flooding threatens up to 4,600 bridges across the U.S. by 2050. Climate change risks are not just flooding-related. Transportation will be impacted by rising temperatures through bridge stress, increased delays, buckled rails, and roadways and compromised worker safety.

New York City's regional transportation network is a large legacy—complex legacy system that is particularly vulnerable to the coming risks of climate change. Already, 12 percent of our roadway network is at risk. By 2100, 20 percent of lower Manhattan streets could be subject to tidal flooding daily.

Our transportation network is more resilient than before Sandy. Regional transportation agencies have implemented resiliency measures for our subways, trains, airports, ports, and tunnels. In New York City we are raising some of our most flood-prone streets and making them more resilient through elevated traffic signal controllers. We are ensuring multi-stakeholder coordination through our Climate Change Adaptation Task Force established over 10 years ago to address infrastructure interdependencies and the risk of a changing climate.

City government is building stronger, more resilient facilities and infrastructure using forward-looking climate data from the New York City climate resiliency design guidelines. Last, we are partnering with FEMA (Federal Emergency Management Agency) to develop future flood hazard mapping products, the first of their kind in the Nation.

Much has been done but much work remains. Congress can play an important role to ensuring the long-term resiliency of the cities and of our Nation's transportation network in three main ways. First, we encourage Congress to pass legislation that requires the use of forward-looking climate data in all Federal investments—infrastructure investments. Guidance to reach this goal were first articulated in Executive Order 13690 from 2015 on floodplain management, which was revoked in 2017. Making this guidance law would reestablish this important standard and make it permanent. Taking this one step further, Congress should require that all infrastructure projects using Federal dollars use forward-looking climate data.

Second, the city commends Congress' passing of the *Disaster Recovery Reform Act of 2018*, which allocates 6 percent of a community's disaster expenses from the previous year to invest in pre-disaster mitigation. We urge Congress to expand this program, further enabling Federal disaster aid to support resiliency investments before disaster strikes.

Finally, we urge Congress to increase funding for freight and public transit infrastructure. One critical infrastructure is the long-overdue rail link between New York and New Jersey referred to as the Gateway tunnel. This project would vastly strengthen this vul-

nerable transportation line that links the entire Northeast Corridor.

In conclusion, Congress has the opportunity to rethink how Federal Government supports the transportation needs of cities and communities across the country and to ensure that resilient investments made today provide value for all Americans for generations to come.

Thank you for the opportunity to testify today, and I'm happy to answer any questions.

[The prepared statement of Ms. DesRoches follows:]

THE CITY OF NEW YORK
OFFICE OF THE MAYOR
NEW YORK, NY 10007

THE US HOUSE OF REPRESENTATIVES
COMMITTEE ON SPACE, SCIENCE, & TECHNOLOGY
SUBCOMMITTEE ON INVESTIGATIONS AND OVERSIGHT

Testimony of Susanne DesRoches, Deputy Director for Infrastructure and Energy, New York City Mayor's Office of Resiliency.

Tuesday, May 21, 2019

I. INTRODUCTION

Good morning. My name is Susanne DesRoches and I am the Deputy Director for Infrastructure and Energy for the New York City Mayor's Office of Resiliency. On behalf of the Mayor and the City of New York, I would like to thank Chair Sherrill and Ranking Member Norman for the opportunity to speak today about the City's challenges, accomplishments, and opportunities to build a more resilient transportation network that will benefit New Yorkers and the nation's economy as a whole.

Nearly seven years ago, Hurricane Sandy hit New York City with unprecedented force, tragically killing 44 New Yorkers,[1] and causing over $19 billion in damages and lost economic activity. Neighborhoods were devastated: 88,700 buildings were flooded; 23,400 businesses were impacted; and our region's infrastructure was seriously disrupted.[2] Over 2,000,000 residents were without power for weeks and fuel shortages persisted for over a month.[3] Cross river subway and rail tunnels vital to the movement of people and goods were closed for days. Our airports were closed to passenger and freight traffic, and our ports sustained substantial damage to physical infrastructure as well as goods stored at their facilities. In short, Sandy highlighted New York City's vulnerability to climate change and rising seas and underscores the urgency of the actions we've taken since then to build a stronger, more resilient city. Sandy also vividly emphasized how vital our regional transportation network is to the functioning of a healthy regional and national economy.

In this testimony, I will provide a broad summary of national transportation challenges associated with climate change and discuss New York City's specific vulnerabilities. I will also outline the actions that New York City is taking to improve the resiliency of our transportation

1 https://www1.nyc.gov/site/cdbgdr/about/About%20Hurricane%20Sandy.page
2 http://www.nyc.gov/html/sirr/downloads/pdf/final_report/Ch_1_SandyImpacts_FINAL_singles.pdf
3 ibid

systems and offer suggestions on how Congress and our federal partners can continue to support cities as we prepare for the challenges of climate change.

A. Findings of the Fourth National Climate Assessment

The Fourth National Climate Assessment was released on November 23, 2018.[4] National Climate Assessments are mandated by the Global Change Research Act of 1990,[5] and assess the impacts of climate change on the United States. I am a co-author of the transportation chapter of this report, along with professionals from the transportation industry, the US Department of Transportation, and academic and engineering experts.

In this assessment, we found that the impacts of climate change—such as heavy precipitation, coastal flooding—threaten the existence of "a reliable, safe, and efficient U.S. transportation system." The impacts of climate change are already being felt; and will continue to be felt throughout our country and economy.

For instance, by 2100, certain states along the eastern seaboard will experience over 625 million vehicle hours of delay annually due to high tide flooding if roadway networks are not prepared for the impacts of sea level rise.[6] Climate impacts will affect all of our transportation, freight, and transit networks, including air, rail, road, and marine. Climate change impacts on transportation infrastructure will also disproportionately burden vulnerable populations.

Importantly, the assessment found that cities and states are taking action mainly through conducting vulnerability assessments specific to transportation infrastructure. These assessments assist decision makers in identifying and prioritizing ways to mitigate risk through resiliency projects and operational strategies. The National Climate Assessment shows that these vulnerabilities are not limited to one geographic region. The Assessment found many examples of climate vulnerability, including:

- Critical roadways, rail lines, ports, and pipelines bringing fuel and goods to market in transportation hubs such as Mobile, AL, Long Beach, CA, and Houston and Galveston, TX will be at risk with 30 inches of sea level rise.
- 13 of the nation's 47 largest airports have at least one runway with an elevation within the reach of moderate to high storm surge today.
- The Upper Mississippi and Missouri river basins have seen two 300-500 year floods within the past 20 years, posing hazards to bridge structures and the navigability of rivers.

New York City understands that we are not alone as we face climate-related challenges, and we rely on documents such as the National Climate Assessment to reassess our strategies for mitigating our risk and to learn from our peers.

[4] https://nca2018.globalchange.gov/
[5] https://www.globalchange.gov/about/legal-mandate
[6] https://nca2018.globalchange.gov/chapter/12/#fig-12-3

II. NEW YORK CITY WILL EXPERIENCE TRANSPORTATION NETWORK DISRUPTIONS DUE TO THE EFFECTS OF CLIMATE CHANGE

For more than a decade, New York City has been at the forefront of climate science-informed policy, leveraging the expertise of the New York City Panel on Climate Change (NPCC), an independent panel of academic and NASA scientists formed by the City of New York in 2008, and whose members are appointed by the Mayor. This body provides scientific projections for the region and assists the City's policymakers in understanding and planning for the climate change risks of today and the threats of the future.

The Panel's fourth and latest assessment, released in March 2019, makes it clear that the city will face new and worsening challenges from a range of climate hazards. These include increasing frequency of heat waves that will impact vulnerable populations and up to six or more feet of sea level rise by the end of the century, which will reshape our shoreline and subject transportation corridors to daily flooding.[7] Extreme rainstorms will become more common, necessitating improvements to drainage infrastructure commensurate to these changes. A summary of New York City's climate change projections is provided in Exhibit 1.

The City of New York maintains 6,000 miles of roadways and 794 bridges and tunnels which provide key access corridors for vehicles, transit, and freight.[8] Since 2006, we have installed over 1,200 miles of bike lanes,[9] and are expanding the Western Hemisphere's largest bike-sharing system from 12,000 to 40,000 bikes.[10] Many transportation networks within the city, however, are not operated by City agencies. The Metropolitan Transportation Authority (MTA) is a New York State agency responsible for the operation of subways and buses within New York City and two regional rail networks. The Port Authority of New York and New Jersey (PANYNJ) operates the region's major airports and ports, bridges and tunnels between New York City and New Jersey, as well as the PATH light rail system. NJ Transit operates regional rail to and from New Jersey, and Amtrak maintains and operates rail infrastructure connecting New York City, New Jersey, Connecticut, and long distance rail (see exhibit 1 for an overview of transportation networks in the City). Exhibit 2 provides an overview of transportation networks within New York City. Given that the effects of climate change do not recognize the fact that many different stakeholders operate different parts of the transportation network, it is in the de Blasio Administration's interest to ensure a multi stakeholder response.

No part of New York City's transportation network was spared from the effects of Hurricane Sandy. Starting the day before Sandy hit, most public transportation agencies initiated an orderly shutdown of their systems to protect critical infrastructure and vehicles and to ensure public safety. Due to concerns about high winds and flooding, the Port Authority, MTA, and the City closed major bridges and tunnel crossings, with the exception of the Lincoln Tunnel, the entrances to which were deemed to be high enough above the Hudson River to be at low risk of flooding. Meanwhile, airlines flew their planes out of harm's way, sheltering them at airports out of Sandy's path.

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[7] https://nyaspubs.onlinelibrary.wiley.com/doi/10.1111/nyas.14008
[8] https://www1.nyc.gov/html/dot/html/about/about.shtml
[9] https://www1.nyc.gov/html/dot/downloads/pdf/cycling-in-the-city.pdf
[10] https://www1.nyc.gov/office-of-the-mayor/news/576-18/mayor-de-blasio-dramatic-expansion-citi-bike#/0

Once Sandy arrived, its storm surge severely impacted many elements of the transportation system, including subway, railroad, and vehicular tunnels. Vehicular tunnels that were closed due to severe storm damage included the City's Battery Park Underpass and West Street Underpass, the MTA's Queens Midtown and Hugh L. Carey (formerly Brooklyn- Battery) Tunnels, and the Port Authority's Holland Tunnel. Also inundated were all six of the subway tunnels connecting Brooklyn to Manhattan, the Steinway Tunnel that carries the 7 train from Queens to Manhattan, and the G train tunnel between Queens and Brooklyn. The Port Authority's PATH tunnels under the Hudson River also were flooded, with water entering via entrances on both the New York and New Jersey sides, as were Amtrak and the MTA's railroad tunnels under the East River and the Hudson River. Many subway stations and rail yards were flooded, and floodwaters damaged rail viaducts in Queens. Maritime transportation was disrupted due to damage to landings and docks. The Port Authority's airports flooded from storm surge, but waters did not reach critical terminal infrastructure.

After Sandy passed through New York City, days-long power outages severely affected the ability to dewater tunnels and restore service to the transportation systems. Given that many tunnels were inundated with salt water for days, lingering damage caused electrical malfunctions for months and years after the storm. As commuters attempted to return to work three days after the storm, the subway and other transportation systems were still out of service. This caused significant congestion on surface roadways. For example, when Hurricane Sandy disabled subway connections across the East River, over 40,000 additional daily bus trips and another 40,000 private vehicle trips were made over New York City's cross-river bridge network in the weeks after the storm, stressing the ability for the roadway network to absorb excess capacity.[11] Commuters experienced this congestion and also faced severe fuel shortages that would last for weeks. These factors limited the ability for the regional transportation network to support recovery actions and transportation in the wake of the disaster.

Facing these challenges, City officials partnered with the MTA and Port Authority to place bus bridges into service where subway service was not available, impose carpool requirements on bridge crossings, and put in place temporary ferry routes. This emergency operational plan helped New York get moving again even with severely limited transportation options.

Service gradually returned to normal with the City, transportation agencies, and utilities working around the clock to remove debris, dewater tunnels, and restore electric service. Ferries and marine transportation took between two days and a week to restore, while airports were open three days after the storm. Most subway service was restored a week after Sandy, and vehicular tunnels were in service 10 days after the storm. Two weeks after the storm, most, but not all, transportation systems were up and running again. All told, Sandy resulted in almost $16 billion in documented costs to regional transportation agencies.[12]

Hurricanes are not the only extreme weather event to have already caused significant impacts to New York City. Extreme rainfall is also a risk, as evidenced on August 8, 2007 when nearly 4" of rain fell within two hours during morning rush hour. The intensity of the rain was too great for the existing drainage, and flash flooding occurred across the metropolitan region, ultimately

[11] https://www1.nyc.gov/site/sirr/report/report.page
[12] https://www.fhwa.dot.gov/environment/sustainability/resilience/publications/hurricane_sandy/index.cfm

disrupting the trips of 2.5 million transit customers. Major disruptions were felt on 19 segments of the subway system, service on the lines of both Metro North and Long Island Railroad was suspended, and there were significant disruptions to bus services citywide as highways, roads, and underpasses flooded.[13] These two hours of rain caused so much damage that the President declared a national emergency in Brooklyn and Queens where the damage was most severe, qualifying these boroughs for federal disaster assistance.

The greatest future risk to the city's transportation network is storm surge—a risk that, as Sandy illustrated, is significant even today primarily because so many critical pieces of transit infrastructure are located within the 100-year floodplain, the area that has a one percent or greater chance of flooding in any given year. This is true of many other coastal communities across the United States, as found in the National Climate Assessment. The 100-year floodplain in New York City already includes approximately 12 percent of the roadway network, all of the major tunnel portals other than the Lincoln Tunnel, portions of both airports, a variety of commuter rail assets, our heliports, and a number of subway entrances and vent structures, principally in Lower Manhattan. Going forward, the risks associated with storm surge will grow more severe, as rising sea levels increase the impact of those surges and turn minor surges into major events. A map of New York City's anticipated floodplain in 2050 is provided in Exhibit 3. By 2100, 20 percent of Lower Manhattan's streets could be subject to daily tidal inundation.[14]

Extreme rainfall events are also increasing, and will continue to cause costly disruptions to our transportation system. Other risks that will affect our transportation network include high winds and heat waves. An assessment of all these risks and regional vulnerabilities is included in Exhibit 2.

III. NEW YORK CITY HAS IMPROVED THE RESILIENCY OF OUR TRANSPORTATION NETWORK

The region is dependent upon the functionality of its transportation systems. After Sandy, the City of New York and its partners took significant actions to repair damaged transportation infrastructure and improve the resiliency of the network. For example, the MTA worked to "Fix and Fortify" its system of subways, buses, regional rail lines, bridges, and tunnels, while the Port Authority embarked on an ambitious resiliency capital program, upgrading temporary measures into permanent protections using forward-looking climate data.

A. The de Blasio Administration is investing in resilient roadway and ferry networks

In the days after Sandy, underground and aboveground rail transportation networks, as well as roadway tunnels, were disabled. This changed traffic patterns on New York City streets and sidewalks, many of which lacked signalization due to power outages, and led the City to impose mandatory high occupancy vehicle restrictions on East River Bridges, which reduced strain on the transportation network and boosted its efficiency. In the months and years after Sandy, City of New York's transportation department needed to reconstruct 60 lane miles and resurface 500

[13] http://web.mta.info/mta/pdf/storm_report_2007.pdf
[14] https://www.nycedc.com/project/lower-manhattan-coastal-resiliency

lane miles of roadway,[15] as well as perform significant repairs on two tunnels in lower Manhattan. The City continues to invest in its resiliency strategy, including raising traffic signal controllers in flood prone areas, protecting vulnerable moveable bridge machinery, raising streets and street ends in neighborhoods with chronic flooding problems, and siting more than 4,500 street-side rain gardens and green space to date.[16]

Ours is a city of islands, and ferries are an important part of our transportation system. Ferries serve residents of our some of our most vulnerable neighborhoods such as the Rockaways in Queens, Soundview in the Bronx, and several parts of south Brooklyn, and provide important redundancy in the event of severe weather events. In addition, over 22 million people rely on the Staten Island Ferry every year,[17] which provides a critical transportation link to the only borough without a direct rail connection to other boroughs. The Staten Island Ferry Terminals were badly damaged in Sandy, and the ferry system received $191 million from the Federal Transit Administration's Hurricane Sandy Competitive Resilience Program to purchase new vessels capable of operating during large scale evacuations and to complete storm hardening projects at both the St. George and the Whitehall ferry terminals.[18]

B. The City convenes critical stakeholders to leverage a citywide adaptation knowledge base

As noted above, the City has fairly limited control over other parts of the regional transportation network, given the complex web of operators and jurisdictions inherent in a connected region encompassing three states and dozens of counties and municipalities.

To coordinate resiliency actions between these important yet distinct agencies, the City first convened the New York City Climate Change Adaptation Task Force in 2008. The City acknowledges that the functionality of the regional transportation effort depends upon the cooperation of transportation agencies and operators of services upon which the transportation industry depends, including liquid fuels, electric power, communications, and water/wastewater providers. Both before and after Hurricane Sandy, the City worked with task force members to understand local climate change projections, and used those projections to assess and prioritizes climate risks to infrastructure assets. This knowledge base was critical to Sandy recovery, and today allows the City to identify potential failure points in advance of major events, and determine what actions or coordination among stakeholders can mitigate certain risks. It also has inspired internal policy at agencies. For example, the Port Authority's Climate Resilience Design Guidelines incorporate climate change projections into an engineering standard used in the design of the transportation authority's capital projects.[19] The task force continues to meet regularly and share information and best practices, as required by Local Law 42 of 2012.[20]

[15] https://www1.nyc.gov/site/sirr/report/report.page
[16] https://www1.nyc.gov/html/dep/pdf/green_infrastructure/gi-annual-report-2018.pdf
[17] https://www1.nyc.gov/html/dot/html/about/about.shtml
[18] https://www1.nyc.gov/html/dot/html/pr2014/pr14-usdot.shtml
[19] https://www.panynj.gov/business-opportunities/pdf/discipline-guidelines/climate-resilience.pdf
[20] https://legistar.council.nyc.gov/LegislationDetail.aspx?ID=1107144&GUID=EB5DD6B3-D9D2-4C02-AD0F-61FF1A91BA88&Options=ID%7CText%7C&Search=834-A

C. The City is using forward-looking data in the design of City capital construction projects

In the face of climate change and extreme weather, New York City has taken bold action to overhaul how we plan and design our built environment. Every City facility including police stations, schools, senior centers, and public housing built today needs to be ready to serve New Yorkers for decades to come. To ensure that our capital assets are resilient to extreme weather and a changing climate, the de Blasio Administration has developed guidelines to include forward-looking climate change data in the design of all city government capital projects. In March of this year, we released version 3.0 of our Climate Resiliency Design Guidelines after several years of testing and analysis (see Exhibit 4).

The Guidelines provide designers and engineers with step-by-step instructions and tools to incorporate sea level rise, heat, and rainfall projections into the design and construction of capital projects. Examples of design guidelines for heat and sea level rise are included in Exhibit 5. The City engaged the scientific, engineering, and architectural communities to ensure that this innovative product is ready for use. Each time the City invests public dollars in the buildings and infrastructure that New Yorkers rely on, we have an opportunity to invest that money in facilities that are going to be resilient to a changing climate. As an example, climate informed design standards could allow inland roads to absorb more rainwater and elevate coastal streets above the elevation of high tides and sea level rise to the extent possible. Resilient ferry terminals are able to withstand waves and winds, ensuring that soon after a storm ends the life of the city can continue again. With the Guidelines, we are ready to take the necessary steps to go beyond existing design standards and begin building today for the climate we will have tomorrow.

D. The City is leading on regional emergency management and hazard mitigation

Planning for disaster is a crucial part of our resiliency plan, and the City coordinates closely with the region's major transportation providers. The New York City Emergency Management agency recently released its latest Hazard Mitigation Plan (HMP), which continues to make the City eligible for post-disaster mitigation funding from FEMA, including Hazard Mitigation Grant Program (HMGP) and the new Pre-Disaster Mitigation (PDM) funding. Beyond the regulatory requirement to complete an HMP, the City intends for the plan to serve as a risk communication tool to the general public, with information on risks and ongoing/completed mitigation actions across a range of natural and climate hazards. The HMP was completed in conjunction with the region's two largest transportation providers, the PANYNJ and the MTA.

Emergency Management chairs the New York City Urban Area Working Group, made up of New York City, Nassau and Suffolk counties in Long Island, Westchester County, Yonkers, and the Port Authority of New York and New Jersey. The Working Group is instrumental in linking and coordinating regional activities, including joint training and exercises, public education and outreach, and the development of response protocols. The agency is also active in the nationwide group, Big City Emergency Managers, a network of 16 large cities, including New York City, Seattle, Los Angeles, Houston, Miami, Chicago and others, that meet semi-annually to discuss issues of mutual concern.

E. The City is partnering with FEMA on forward-looking flood mapping products

Planners and developers across city government and private sector entities require sophisticated tools to plan for current and projected flooding risks and other climate change impacts. In 2016, as part of the resolution of the City's appeal of the Preliminary Flood Insurance Rate Maps, FEMA and the City agreed to develop innovative future flood hazard product(s) to better enable ongoing resilient planning, design, and land use strategies in New York City. The new future flood hazard product(s) will inform adaptation strategies for reducing flood risk to property and the environment today and in the future, as well as design standards and regulation for construction and development, notably building codes, zoning ordinances and land use regulation. In this regard, the future flood hazard product(s) will allow city planners, engineers, architects and contractors to ensure that their buildings and infrastructure are designed to withstand future climate stresses.

IV. SUGGESTIONS FOR HOW CONGRESS CAN SUPPORT CITIES

Congress can play an important role to ensuring the long term resiliency of our nation's transportation network. I will now outline three specific recommendations to enhance and protect transportation infrastructure and plan for the impacts of climate change.

1. Use forward looking climate data to inform policy and program design

We cannot continue to look to past weather conditions to plan for the future. Building code and engineering standards as written today assume that the past 30, 50, or 100 years of weather gives us insight into what the next century of weather will look like. Historic data alone is no longer a reliable proxy for future conditions. We have climate change projections of ever-increasing confidence available today, and those projections offer new practical applications. New York City recognizes the imperative of using forward-looking weather projections to supplement historic weather data, and that's why we've issued the Climate Resiliency Design Guidelines to change how the City designs and builds its infrastructure and buildings. The Guidelines identify the changes to existing design standards that we need to take in New York City, such as: identifying where design flood elevations need to be higher; assessing how much larger stormwater retention systems need to be to manage extreme rain; and identifying which materials and mechanical systems need to be upgraded to better withstand extreme heat.

The City is not alone in this effort. The MTA and PANYNJ have implemented similar resilient design guidelines to ensure that their transportation infrastructure is able to withstand the stresses of climate change and shocks of extreme weather. This is increasingly true of other cities and agencies across the country. The City of New York's efforts used existing Federal guidance on preventive maintenance and resilient design, including:

- Federal Highway Administration Order 5520 (2014) "*Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events,*" which advises on the use of risk-informed decision making and adaptive learning.
- Executive Order 13690 from 2015 established guidance on how the use of forward-looking sea level rise data in federal capital investments to improve the nation's resiliency Though rescinded in 2017, this EO established an important standard for using

forward-looking data that provided an important foundation for the development of the City's resilient design policy.

We encourage Congress to pass legislation that requires the use of forward-looking climate change data. One near-term example would be for Congress to re-establish EO 13690 and make it law. Using forward-looking data increases the resilience of our built environment, ensuring that assets built today serve Americans for decades to come, do not require additional maintenance costs, and are able to withstand the extremes of climate change. All Federal investments in our country's transportation infrastructure should be designed to a resilient standard using forward-looking climate data.

2. Enable federal disaster aid programs to help cities make resiliency investments before disasters strike

We urge the federal government to take an increasingly proactive role to ensure that transportation infrastructure be prepared ahead of natural disasters. In January 2019, the National Institute of Building Sciences published its *Natural Hazard Mitigation Saves: 2018 Interim Report*, and found a national benefit of $11 dollars for every $1 invested. Every dollar we invest in stronger, more resilient transportation infrastructure offers significant returns to not just our city and region, but to the country. The City commends Congress' passing of the Disaster Recovery Reform Act of 2018, particularly Section 1234 on National Public Infrastructure Pre-Disaster Hazard Mitigation, which creates an annual fund with a 6 percent set aside from disaster expenses in the previous year "to allow for a greater investment in mitigation before a disaster." We urge Congress to expand this program, increasing the amount of money set aside for pre-disaster mitigation project scoping so as to better capitalize on the benefits of proactive hazard mitigation.

It is important to acknowledge that extreme weather events are only one of the threats to our infrastructure. The chronic stresses to the built environment caused by higher temperatures, rising seas, and the increasing intensity of rain pose an equally great challenge and cost to the City as one-time natural disasters. However, these are not addressed or funded in the same way. Pre-disaster funding also needs to be provided to specifically address chronic stressors of factors like temperature extremes in addition to the major shocks of events like hurricanes.

We recommend that Congress and our federal partners fund and collaborate on studies that continue to refine and characterize specific climate risks for cities, in order to appropriately target mitigation activities and operational response planning, specifically funding conceptual planning studies to scope large-scale, cost-effective mitigation projects and the operational response activities associated with these projects.

Finally, we are also looking to Congress to help rationalize the distinct ways federal agencies calculate benefit-cost ratios, since each agency has its own methodology. These methodologies should be streamlined and standardized to support faster recovery and mitigation investments. Furthermore, benefit-cost ratios are biased by higher property values, placing lower-income communities at a disadvantage when comparing mitigation projects. We urge Congress to address these issues.

3. Fund investments in resilient transportation infrastructure

We urge Congress to increase federal funding for transportation to address existing infrastructure challenges that will be worsened by climate change. There is evidence of ongoing underinvestment in parts of the US transportation system, and it is vitally important for Congress to directed funding towards new construction and asset management to provide the robust, resilient systems that support the nation's economy. Specifically, we urge Congress to increase funding for the public transit, bicycle, and pedestrian infrastructure and services that move tens of millions of Americans daily. These add vital resiliency to the nation's mobility systems.

We urge Congress to make the visionary transportation infrastructure investments that shape our nation and bolster our economy, like those made by this body for generations, such as the Federal Highway Act of 1956 and the Rail Passenger Service Act of 1970. These kinds of investments are the backbone of our national economy and have substantially contributed to American prosperity and global competitiveness. The need for new investment in our transportation system is great, and the call to make those investments resilient is loud and clear.

In the New York City region, one critical infrastructure project is the long overdue rail tunnel between New York and New Jersey, referred to as the Gateway Tunnel, which would vastly strengthen this crucial and vulnerable transportation line serving not just the city but the entire Northeast Corridor. The Portal Bridge and two-track North River Tunnel have been in service for 108 years and need significant improvements in order to remain in service. Sandy pushed billions of gallons of saltwater into the tunnels, degrading existing signals, benchwalls, and electrical equipment and significantly reducing the reliability of the tunnels. In order to repair the existing tunnels, they must be taken out of service for an extended period of time. Without significant repairs, the tunnels could fail, which the Regional Plan Association estimates would cost the economy $16 billion and reduce home values by $22 billion region-wide.

Taking one tunnel out of service would reduce the existing 24-train per hour capacity by up to 75 percent, given the need to run bidirectional trains on a single track. Building the Gateway Tunnel will relieve this pressure and allow Amtrak to repair the existing North River tunnels. Once repaired, a four-track northeast corridor would greatly improve the capacity, resiliency, and redundancy of the transportation network in the Northeast.[21]

All of this infrastructure, whether new or renovated, must be designed to withstand the decades of climate change that are projected, so that necessary improvements that we make to our transportation systems today continue to benefit Americans even as sea levels rise and extreme weather becomes more severe.

V. CONCLUSION

Enhancing and protecting transportation infrastructure is necessary to the future of New York City and the surrounding region. This Congress has the opportunity to rethink how the federal

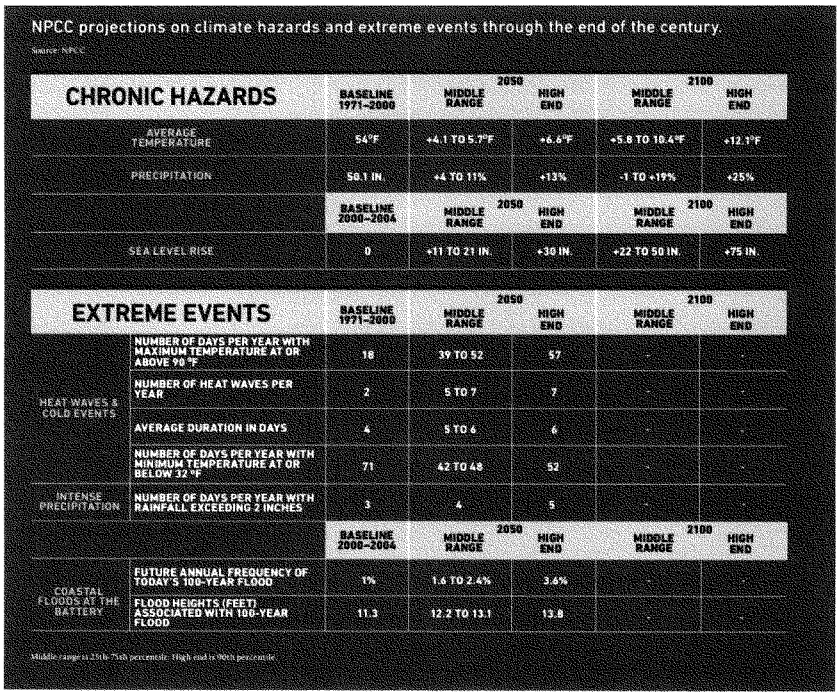
[21] https://www.fra.dot.gov/Elib/Document/16762

government supports the transportation infrastructure needs of cities and communities across the country, and to ensure that resilient investments made today provide value to New Yorkers and all Americans for generations to come.

Thank you for the opportunity to testify today and I am happy to answer any questions.

Exhibit 1. New York City's climate projections.

For more than a decade, New York City has been at the forefront of science-informed climate policy, leveraging the expertise of the New York City Panel on Climate Change (NPCC), an independent panel of academic and private-sector experts formed by the City of New York and whose members are appointed by the Mayor. This body, which is unprecedented among American cities, provides downscaled scientific projections for the region and assists New York City's policymakers in understanding and planning for the climate change risks of today and the threats of the future. Source: OneNYC 2050.[22]



NPCC projections on climate hazards and extreme events through the end of the century.

Source: NPCC

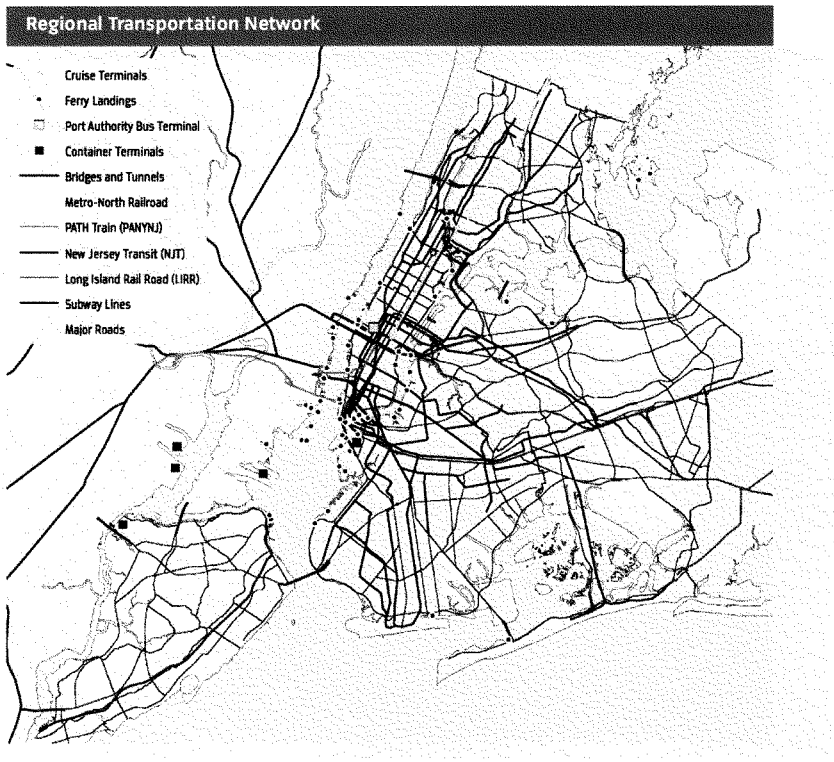
CHRONIC HAZARDS		BASELINE 1971–2000	2050 MIDDLE RANGE	2050 HIGH END	2100 MIDDLE RANGE	2100 HIGH END
AVERAGE TEMPERATURE		54°F	+4.1 TO 5.7°F	+6.6°F	+5.8 TO 10.4°F	+12.1°F
PRECIPITATION		50.1 IN.	+4 TO 11%	+13%	-1 TO +19%	+25%
		BASELINE 2000–2004	2050 MIDDLE RANGE	2050 HIGH END	2100 MIDDLE RANGE	2100 HIGH END
SEA LEVEL RISE		0	+11 TO 21 IN.	+30 IN.	+22 TO 50 IN.	+75 IN.

EXTREME EVENTS		BASELINE 1971–2000	2050 MIDDLE RANGE	2050 HIGH END	2100 MIDDLE RANGE	2100 HIGH END
HEAT WAVES & COLD EVENTS	NUMBER OF DAYS PER YEAR WITH MAXIMUM TEMPERATURE AT OR ABOVE 90 °F	18	39 TO 52	57	-	-
	NUMBER OF HEAT WAVES PER YEAR	2	5 TO 7	7	-	-
	AVERAGE DURATION IN DAYS	4	5 TO 6	6	-	-
	NUMBER OF DAYS PER YEAR WITH MINIMUM TEMPERATURE AT OR BELOW 32 °F	71	42 TO 48	52	-	-
INTENSE PRECIPITATION	NUMBER OF DAYS PER YEAR WITH RAINFALL EXCEEDING 2 INCHES	3	4	5	-	-
		BASELINE 2000–2004	2050 MIDDLE RANGE	2050 HIGH END	2100 MIDDLE RANGE	2100 HIGH END
COASTAL FLOODS AT THE BATTERY	FUTURE ANNUAL FREQUENCY OF TODAY'S 100-YEAR FLOOD	1%	1.6 TO 2.4%	3.6%	-	-
	FLOOD HEIGHTS (FEET) ASSOCIATED WITH 100-YEAR FLOOD	11.3	12.2 TO 13.1	13.8	-	-

Middle range is 25th-75th percentile. High end is 90th percentile.

[22] https://onenyc.cityofnewyork.us/wp-content/uploads/2019/05/OneNYC-2050-A-Livable-Climate.pdf

Exhibit 2. NYC Transportation Network (does not include all elements of the network, including local roads, bus routes, Amtrak, and freight networks). Source: SIRR 2013.[23]



[23] https://www1.nyc.gov/assets/sirr/downloads/pdf/Ch_10_Transportation_FINAL_singles.pdf

Exhibit 3. Anticipated 100 year (1% or greater annual chance of flooding) flood map of New York City in 2050. Source: NYC Flood Hazard Mapper.[24]

[24] https://www1.nyc.gov/site/planning/data-maps/flood-hazard-mapper.page

Exhibit 4. NYC Climate Resiliency Design Guidelines. Available at: https://www1.nyc.gov/assets/orr/pdf/NYC_Climate_Resiliency_Design_Guidelines_v3-0.pdf

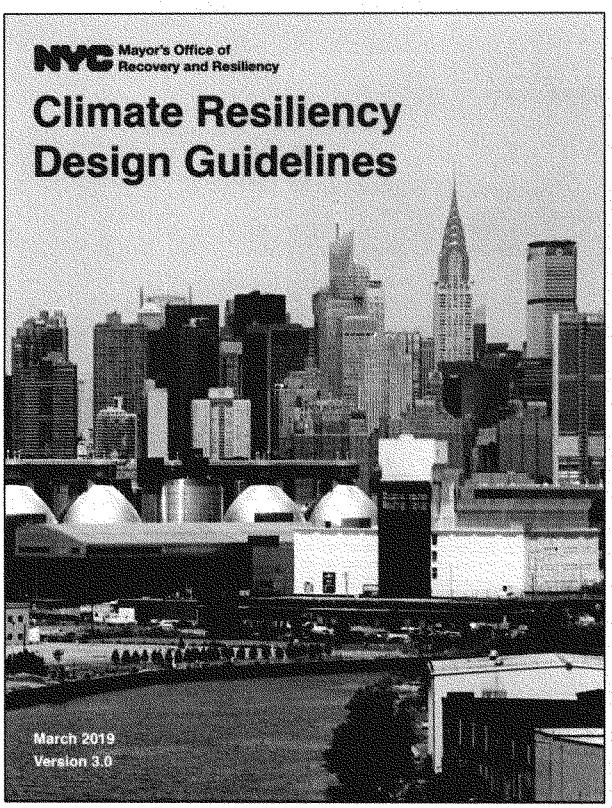


Exhibit 5. Forward looking design guidance for extreme heat and sea level rise. Source: NYC Climate Resiliency Design Guidelines.[25]

Exhibit 5a. Extreme Heat. The table below provides design criteria for future average temperatures, incidents of extreme heat events projected to different time periods across the 21st century, and guidance on future 1% Dry Bulb temperature and Cooling Degree Days for the NYC area. These design criteria can be applied when designing heating and cooling systems and building envelopes.

Table 2 – Current and projected extreme heat events and design criteria[27]

	Extreme heat events			*Design criteria*	
End of useful life	**# of heat waves per year**	**# days at or above 90°F**	**Annual average temperature**	**1% Dry Bulb temperature**	**Cooling Degree Days** *(base = 65°F)*
Current (1971-2000)	2	18	54°F	91°F	1,149
2020s (through to 2039)	4	33	57.2°F	--	--
2050s (2040-2069)	7	57	60.6°F	98°F	2,149
2080s (2070-2099)	9	87	64.3°F	--	--

Note: Due to HVAC system typical useful life of around 25 years, only design criteria projections for the 2050s are shown. Projections for the 2020s are not shown because it is anticipated that enough of a safety margin is employed already in current systems to withstand the temperature rise expected through the 2020s. The NPCC is developing projections of 1% Wet Bulb temperatures, which are expected to increase. This design criteria will be added in a later version of the Guidelines.

[25] https://www1.nyc.gov/assets/orr/pdf/NYC_Climate_Resiliency_Design_Guidelines_v3-0.pdf

Exhibit 5b. Sea level rise. Table and schematic below show the process for selecting a sea level rise adjusted Design Flood Elevation that is consistent with the useful life of the asset.

Table 3 - Determine the sea level rise-adjusted design flood elevation (DFE)[55]

End of Useful Life	Base Flood Elevation (BFE)[56] in NAVD 88	+ Freeboard[57]	+ Sea Level Rise Adjustment[58]	= Design Flood Elevation (DFE) in NAVD 88
Critical* Facilities				
2020s (through to 2039)	FEMA 1% (PFIRM)	24"	6"	= FEMA 1% + 30"
2050s (2040-2069)	FEMA 1% (PFIRM)	24"	16"	= FEMA 1% + 40"
2080s (2070-2099)	FEMA 1% (PFIRM)	24"	28"	= FEMA 1% + 52"
2100+	FEMA 1% (PFIRM)	24"	36"	= FEMA 1% + 60"
Non-critical Facilities				
2020s (through to 2039)	FEMA 1% (PFIRM)	12"	6"	= FEMA 1% + 18"
2050s (2040-2069)	FEMA 1% (PFIRM)	12"	16"	= FEMA 1% + 28"
2080s (2070-2099)	FEMA 1% (PFIRM)	12"	28"	= FEMA 1% + 40"
2100+	FEMA 1% (PFIRM)	12"	36"	= FEMA 1% + 48"

Additional analysis should be conducted to incorporate wave action and wave run-up in DFE calculations especially in areas that are located within the FEMA's 1% annual chance Limit of Moderate Wave Action (LiMWA) zone. Wave run-up is the maximum vertical extent of wave uprush above surge.

*Facilities defined as critical

The criticality definitions below are for use in the application of the Guidelines only. All items identified as critical in NYC Building Code Appendix G are critical in these Guidelines; however, this list includes additional facilities that are not listed in Appendix G.[59] If a facility is not listed here, it is considered non-critical for the purposes of these Guidelines.

- Hospitals and health care facilities;
- Fire, rescue, ambulance, and police stations, as well as emergency vehicle garages;
- Jails, correctional facilities and detention facilities;
- Facilities used in emergency response, including emergency shelters, emergency preparedness, communication, operation centers, communication towers, electrical substations, back-up generators, fuel or water storage tanks, power generating stations and other public utility facilities;
- Critical aviation facilities such as control towers, air traffic control centers and hangars for aircraft used in emergency response;
- Major food distribution centers (with an annual expected volume of greater than 170,000,000 pounds);[60]
- Buildings and other structures that manufacture, process, handle, store, dispose, or use toxic or explosive substances where the quantity of the material exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released;[61]
- Infrastructure in transportation, telecommunications, or power networks including bridges, tunnels (vehicular and rail), traffic signals, (and other right of way elements including street lights and utilities), power transmission facilities, substations, circuit breaker houses, city gate stations, arterial roadways, telecommunications central offices, switching facilities, etc.;
- Ventilation buildings and fan plants;
- Operations centers;
- Pumping stations (sanitary and stormwater);
- Train and transit maintenance yards and shops;
- Wastewater treatment plants;
- Water supply infrastructure;
- Combined-sewer overflow (CSO) retention tanks;
- Fueling stations;
- Waste transfer stations; and
- Facilities where residents have limited mobility or ability, including care facilities and nursing homes.

Susanne E. DesRoches

Susanne DesRoches is the Deputy Director, Infrastructure and Energy at the New York City Mayor's Office of Resiliency and Mayor's Office of Sustainability. In this role, she is responsible for the City's energy policy and regulatory affairs at the local, state and federal level and directs the City's efforts to adapt regional infrastructure systems to climate change. Susanne leads the NYC Climate Change Adaptation Task Force, which works to identify climate risks and coordinate adaptation strategies, and oversees the development of the NYC Climate Resiliency Design Guidelines. She is a chapter author for the fourth National Climate Assessment.

Susanne was previously the Chief of Resilience and Sustainability for the Engineering Department at the Port Authority of New York & New Jersey. She holds a Bachelor of Industrial Design from Pratt Institute and an MPA in Environmental Science and Policy from Columbia University. Susanne is on the faculty of Columbia University's Earth Institute and School of Professional studies.

Chairwoman SHERRILL. Well, thank you. And thank you so much for your timeliness. That was almost exactly 5 minutes. That was perfect.

And next we'll hear from Mr. Winfree.

TESTIMONY OF GREGORY D. WINFREE,
DIRECTOR, TEXAS A&M TRANSPORTATION INSTITUTE

Mr. WINFREE. Good morning, Chairwoman Sherrill, Ranking Member Norman, and Members of the Subcommittee and staff. Thank you for inviting me to testify regarding transportation infrastructure resilience and transportation research. My name is Greg Winfree, and I'm the Agency Director of the Texas A&M Transportation Institute, also known as TTI. Prior to joining TTI in 2016, I served as the Assistant Secretary on the U.S. Department of Transportation's Office of the Assistant Secretary for Research and Technology.

Established in 1950 and a member of the Texas A&M University system, TTI is a State agency and largest and most comprehensive university-affiliated transportation research center in the United States. TTI has conducted work in all 50 States and 51 countries. Our system Chancellor John Sharp was appointed by Texas Governor Greg Abbott to lead the Rebuild Texas Commission formed to help rebuild our State's infrastructure damaged by Hurricane Harvey in 2017.

Between 1980 and 2017, the U.S. was hit by 227 weather-related disasters that caused more than $1 billion in losses. Ninety-eight of those happened in the State of Texas. More than one-third or 91 of those disasters struck between 2010 and 2017 with nearly half striking Texas directly. Hurricane Harvey was the costliest in history leaving behind $190 billion in damage. Robust research efforts must put—must be put into place to change the traditional ways in which we design, build, and maintain our infrastructure, so I'd like to share a few examples of TTI research outcomes that plan for and mitigate these devastating occurrences.

Additional projects like these are critical to transforming our infrastructure to deal with this new paradigm of extreme weather. In 2005, Hurricanes Katrina and Rita identified the critical need for safety—safely evacuating large numbers of coastal residents. Through TTI's University Transportation Center funding, UTC, researchers developed a Bluetooth travel-time monitoring system that was implemented in 2010 to track real-time traffic flow on evacuation routes. Today, the system is installed on over 1,000 center-line miles of Texas highways.

In 2017, TTI led a national symposium on the barriers and opportunities for infrastructure renewal. Members of the Presidential Administration and other high-level State and Federal officials, as well as private-sector stakeholders, were in attendance, including Congressman Bill Shuster, then Chairman of the U.S. House Transportation and Infrastructure Committee. One of the critical needs identified was transportation infrastructure resilience.

In 2018, TTI developed the first-of-its-kind flood warning system that warns motorists in real time about locations where roadway flooding is likely to occur in the Houston area using data from 170 existing county-maintained flood sensors. Residents can view the

warnings through the TranStar traffic management system website or mobile app.

As a country, we've historically responded to weather disasters in a reactive way, turning to established rehabilitation and repair practices to return service to pre-disaster levels. As demands on our infrastructure systems grow and the population and funding to meet these demands lag behind, that strategy is no longer sustainable. Instead, we must focus more on preparation and planning. This new mindset requires a different approach to making our existing and new infrastructure more resilient.

While U.S. DOT (Department of Transportation) research has made strides in this effort particularly at the Federal Highway Administration, sufficient program-based resources and capabilities focused on transportation resilience are not currently in place. More innovative research-based and data-driven solutions are required to make significant progress in learning how to build and maintain our infrastructure to last longer and withstand extreme weather events. Sample research needs include: Multidisciplinary research initiatives that involve not only the traditional approach of engineers and transportation planners but climatologists, hydrologists, and a host of other disciplines that don't normally work together.

Examination of multiple data sets, including data collected on roadway flooding, GPS, and LIDAR (light detection and ranging), roadway elevation, climate, FEMA, and storm surge, just to name a few. These varying and often complex sets of data need to be put into a more useful and consistent format such as a data clearinghouse.

More robust software models are needed to evaluate the impacts on infrastructure service life given an extreme weather event. The variety of resiliency studies and best practices developed by individual DOTs and the Federal Highway Administration in areas such as vulnerability assessment, asset management, and risk management should be shared and duplicated throughout the country. Performance measures for resiliency must be developed, and their correlation with other DOT priorities such as, safety and infrastructure condition, must be better understood so that scarce resources can be allocated most effectively.

And, in closing, the UTC program is currently actively involved in transportation resilience research. Of the 35 UTCs awarded in the most recent competition authorized by the *Fixing America's Surface Transportation (FAST) Act*, seven list resilience as being a major focus of their programs in research, education, and technology transfer. As previously discussed, TTI's UTCs have made significant contributions to the state of practice in this area. This valuable program is contributing to the body of knowledge in transportation resilience, and this should continue as long as the topic falls within U.S. DOT and congressional priorities.

Any severe weather event poses risk to our transportation system but also to our economy and our very existence. We can't prevent major weather disasters, but by investing resources into research that focuses on resiliency long before the disaster strikes, we will be far better able to weather whatever happens and whatever comes our way.

So thank you for your time and attention. I will be happy to answer any questions you may have.

[The prepared statement of Mr. Winfree follows:]

U.S House of Representatives Committee on Science, Space and Technology
Subcommittee on Investigations and Oversight

The Need for Resilience: Preparing America's Transportation Infrastructure for Climate Change

Testimony of

The Honorable Gregory D. Winfree
Agency Director
Texas A&M Transportation Institute

Tuesday May 21, 2019

Chairwoman Sherrill, Ranking Member Norman, and Members of the Subcommittee, thank you for inviting me to testify before the Subcommittee regarding transportation infrastructure resilience. My name is Greg Winfree and I am the Agency Director of the Texas A&M Transportation Institute (TTI). Established in 1950 and part of the Texas A&M University System, TTI is a state agency and the largest and most comprehensive higher education-affiliated transportation research center in the United States. TTI has conducted work in all 50 states and in 51 countries.

The Texas A&M University System is one of the largest systems of higher education in the nation, with a budget of $4.7 billion. Through a statewide network of 11 universities and seven state agencies, the Texas A&M System educates more than 153,000 students and makes more than 22 million additional educational contacts through service and outreach programs each year. System-wide, research and development expenditures exceeded $996 million in FY 2017 and helped drive the state's economy.

Prior to joining TTI in 2016, I served as the Assistant Secretary of the U.S. Department of Transportation's (USDOT) Office of the Assistant Secretary for Research and Technology. In this role I was responsible for a $450 million budget and oversaw more than 1,000 scientific, data analysis and administrative staff members who support USDOT's multi-modal transportation initiatives. The program offices under my purview included: the John A. Volpe National Transportation Systems Center; the Research, Development and Technology Coordination Office (which administers the University Transportation Centers Program); the Bureau of Transportation Statistics; the Positioning, Navigation, Timing and Spectrum Management Office; the Intelligent Transportation Systems Joint Program Office; and the Transportation Safety Institute.

Between 1980 and 2017, the U.S. was hit by 227 weather disasters that caused more than $1 billion in losses; 98 of those happened in Texas. More than one third (91) of those disasters struck between 2010 and 2017, with nearly half (43) striking Texas directly. Harvey, the last

major storm to hit Texas in 2017, was the costliest in history, leaving behind $190 billion in damage.

Hurricane Harvey shut down the Port of Houston for eight days, forcing ships to wait offshore or divert to other U.S. ports and choking off the region's oil and gas supply. Railroad operations came to a halt, requiring extensive inspection and repairs on hundreds of miles of track. Persistent floods from 50 inches of rain weakened infrastructure foundations, collapsing entire roadway sections, compromising response times for emergency crews and stranding countless people.

We have historically responded to severe weather events in a reactive way, turning to established rehabilitation and repair practices to return service to pre-disaster levels. As our population and its demands on our infrastructure system grow, while funding to meet those demands lags behind, that strategy no longer makes sense. Instead, we should focus more on preparation and planning. That effort requires that we adopt new paradigms to make our infrastructure more resilient.

TTI and Transportation Resilience

With the multiple extreme weather events in recent years, TTI has been involved in several significant efforts and initiatives to mitigate these devastating occurrences.

A collaborative effort of Texas A&M and TTI, the 138,000 square-foot Center for Infrastructure Renewal (CIR) is a state-of-the-art research center that is a leading source for developing transformative infrastructure solutions. The center, which was funded by the Texas Legislature in 2015, provides the facilities and the multidisciplinary research environments for attracting significant cross-industry and government agency participation, as well as educating the 21st century workforce needed to build and operate this new infrastructure. The research conducted at the CIR improves the safety, security, longevity, efficiency, performance, resiliency, financial feasibility and sustainability of state and national infrastructure in nine critical infrastructure sectors, including transportation systems. The Center's 12 laboratories focus on the development of transformative infrastructure solutions, innovating new materials, technologies and processes to create solutions that last longer, have lower costs and can be built in less time.

In 2005, Hurricanes Katrina and Rita created many disturbing realities for Gulf Coast states, including the need for safely evacuating large numbers of coastal residents. Through TTI's University Transportation Center funding (the UTC Program will be discussed in greater detail later in this document), TTI researchers developed a Bluetooth travel-time monitoring system that was implemented in 2010 to monitor traffic flow on evacuation routes to enable transportation officials to make better decisions during evacuation scenarios. The system is installed on over 1,000 centerline miles of Texas highways, including hurricane evacuation routes.

In 2008, TTI participated in a taskforce formed by the Governor of Texas to mitigate hurricane evacuation issues that arose during Hurricane Rita. The evacuation resembled a parking lot, as residents along the coast converged on Houston escape routes, where half of all city residents were trying to flee at the same time. Running out of fuel and drinking water and enduring 100 degree temperatures, motorists were stalled for hours, with the typically 3-hour drive to San Antonio or Dallas taking 20+ hours. The taskforce helped develop new hurricane response strategies and contra-flow plans, organized and announced evacuation routes by zip code, and tailored education-outreach materials about hurricane preparedness.

In September 2017, TTI led a National Symposium on the Barriers and Opportunities for Infrastructure Renewal. Members of the Trump Administration and other high-level state and federal officials, as well as private-sector stakeholders, were in attendance, including Congressman Bill Shuster, then Chairman of the U.S. House Transportation and Infrastructure Committee. Transportation resilience was one of the critical needs identified in the discussion.

In 2017, TTI pavements and materials experts led accelerated construction workshops throughout the state to assist the Texas Department of Transportation (TxDOT) personnel in Hurricane Harvey rebuilding efforts. TTI researchers also analyzed pavements that were under as much as seven feet of water for as long as 14 days. These roads exhibited structural anomalies such as air bubbles and domes that were examined and rehabilitated as needed to ensure they were safe for travel.

In 2018, TTI developed a first-of-its-kind flood warning system that warns motorists in real time about locations where roadway flooding is likely to occur using data from 170 existing flood sensors maintained by the Harris County Flood Control District. Residents are able to view the warning areas by accessing the TranStar traffic management system website or through the mobile app. Houston media also relay the warnings on their radio and television broadcasts and information is communicated via social media.

A recent TTI research effort funded by the Federal Highway Administration (FHWA) and administered by TxDOT used the Houston region as a laboratory to explore and improve transportation resilience. Among the recommendations were the use of thicker pavement structures, adequate drainage and elevated roadways.

TTI is also using Mobile LiDAR (a surveying sensor that uses pulsed laser light) to collect vast amounts of geometric data at highway speeds for DOTs. This is used to assess performance of roadway ditches to ensure they are deep and steep enough to help mitigate roadway flooding. While it might sound trivial, roadsides have been in place as long as roadways and have received much less maintenance. The easiest way to improve pavement structure and performance is to keep water from entering the pavement substructure. This work helps roadway managers accomplish this.

USDOT, state DOTs and Transportation Resilience

One of the topics that I was asked to address in this testimony is the capabilities of the DOT research enterprise to enhance resilience in transportation. While I am not aware of any research programs at any of the USDOT modal agencies that are specifically dedicated to transportation resilience, I do know of efforts to address this issue in FHWA's established general research programs. Some examples are:

- **An FHWA-sponsored Sustainable Pavements Technical Working Group is developing a "Pavement Resilience Guidebook."** TTI is participating in this comprehensive effort. One of the objectives is to determine the impact of climate change on pavement systems and how resilience can be considered in their design, construction and maintenance. Preliminary information has been developed that:
    - identifies climate impacts (higher average temperature, more freeze thaw events, higher precipitation, etc.);
    - identifies pavement vulnerabilities (pavement distress, accelerated aging, etc.);
    - adapts materials (harder binders, use of polymers, etc.); and
    - adapts design (change design parameters such as concrete pavement joint design, etc.).
- **The FHWA TechBrief: Climate Change Adaptation for Pavements, August 2015 (FHWA-HIF-15-015):**
  https://www.fhwa.dot.gov/pavement/sustainability/hif15015.pdf
  This Tech Brief provides an overview of climate change and pavement-specific impacts, and addresses specific hard-surfaced pavement adaptation strategies that could be implemented now and in the future. The recommendations of the TechBrief include:
    - Increased monitoring of key pavement performance parameters, searching for trends to determine when design, materials, construction, or preservation efforts should be changed.
    - In pavement design, the use of predictive climate models in place of historical climate data, and the use of design strategies that allow flexibility in responding to future adaptation needs.
    - Investigating the use of more robust paving materials and designs that perform better in more extreme temperature, precipitation, and flooding scenarios.
    - Adjusting construction seasons and temperature limitations as needed while concurrently reviewing worker safety and comfort requirements.
    - Understanding that pavement systems can be severely damaged by extreme weather events, but that resilience efforts should focus more on embankment height/construction considerations and relocation of roads rather than fortifying pavement structures against these events. Fortification should be a last resort option where no feasible relocation exists.

- **FHWA Building Resilient Transportation Brochure, January 2019:** https://www.fhwa.dot.gov/environment/sustainability/resilience/publications/brt_brochure2019.pdf
    - FHWA has partnered with state DOTs, Metropolitan Planning Organizations (MPOs) and others across the country to assess vulnerabilities and analyze opportunities to improve resilience. Projects vary in scope and emphasis and include: state-wide vulnerability assessments, analyses of engineering options for improving resilience of specific road segments, analysis of opportunities to protect assets by mimicking nature, incorporating climate risks into asset management, and deploying and monitoring adaptation solutions.
    - FHWA is developing resources, including a white paper, case studies, and a handbook, on options and real world examples for integrating resilience into the transportation planning process.

On the state DOT level, the 2015 Fixing America's Surface Transportation (FAST) Act (Pub. L. No. 114-94) requires state transportation agencies to address resiliency in their transportation planning processes and develop a Transportation Asset Management Plan (TAMP) that integrates climate change and extreme weather event resilience approaches into transportation asset management. How transportation agencies address these requirements is generally left up to the individual agencies.

Although a few transportation agencies (specifically the Arizona Department of Transportation, California Department of Transportation, and Colorado Department of Transportation) have begun incorporating climate change and extreme weather event information into plan development and asset management, most state departments of transportation (DOTs) currently emphasize planning for disaster response and recovery.

In a TxDOT research report developed by TTI and entitled, "Developing a Resilient Texas Transportation System," issued in November 2018, several strategies are recommended that would improve the resiliency of Texas's transportation system. Examples include:

- Build/rebuild assets to withstand anticipated environmental conditions (e.g., using moisture-resistant pavement layers such as pavement sublayers stabilized with asphalt and cement, and using materials to withstand higher numbers of very hot days).
- Adapt existing assets to mitigate the impacts of extreme weather events (e.g., improving drainage and reinforcing embankments).
- Adopt dynamic or seasonal restrictions for trucks during times of high heat to minimize or prevent pavement damage.
- Site new facilities outside floodplains or reconstruct at-risk highways using design standards/guidelines considering more conservative flood frequency events (i.e., 500-year flood occurrences as opposed to 100-year flood occurrences) or greater for lower-classification roadways. This would result in these roadways and bridges having higher

than usual profiles, more substantial drainage systems, and possibly longer bridge lengths to handle extreme flooding events.

- Increase system redundancy. For example, designate two or more roadways to provide emergency evacuation routes during extreme weather events. This may result in significant reconstruction of such designated facilities (e.g., adding emergency evacuation lanes or raising the profile of the roadways) to provide travelers with more than one option for evacuation during extreme weather events. Redundancy can also be provided by other modes of transportation, including transit modes.
- Implement more frequent maintenance schedules (e.g., cleaning culverts more frequently).

The American Association of State Highway and Transportation Officials (AASHTO) is actively involved in helping its members (which consist of state DOTs nationwide) to address transportation resiliency issues. Some of these initiatives include pooled-fund programs addressing the effects of extreme weather and strategies for mitigation and adaptation; case studies of lessons learned from state DOTs who have experienced extreme weather events; and a Center for Environmental Excellence that is currently conducting resiliency research. In fact, four of the most recent projects awarded in April 2019 address transportation resilience, in response to research priority statements developed by the AASHTO Committee on Transportation System Security and Resilience.

UTCs and Transportation Resilience

The University Transportation Centers (UTC) Program began in 1987 when it was included in the Surface Transportation and Uniform Relocation Assistance Act of 1987. The legislation authorized a competition for 10 regional centers nationwide. Since then, the UTC Program has been reauthorized in every transportation bill. Over time, the program expanded to include multiple tiers and even designated (or "earmarked") UTCs. However, since the passage of the Moving Ahead for Progress in the 21st Century Act (MAP-21) all UTCs in the program have been competitively awarded. The current structure of the program as authorized in the Fixing America's Surface Transportation Act (the FAST Act) consists of three tiers: five National UTCs, 10 Regional UTCs and 20 Tier 1 UTCs. Additionally, there is a competition currently underway funded through the appropriations process that will award two additional national UTCs in the areas of infrastructure and congestion reduction. These two new centers will be the first UTCs to be funded outside of the transportation reauthorization process.

Prior to the passage of MAP-21, individual UTCs developed their research programs according to themes they proposed in the competition process, or according to specific topics mandated when the UTC was designated in the bill. For competitively awarded UTCs, proposals were required to discuss how their proposed theme and programs would support USDOT's priorities.

Since the UTC program has been competitively awarded following the passage of the last two reauthorization bills, the tier structure seems to have stabilized, as has the proposal process. In both cases, UTCs were required to select one of USDOT's priority focus areas on which to

concentrate, as opposed to self-determining a theme and demonstrating how it fit USDOT's priorities. MAP-21 directed the USDOT Secretary to determine the focus areas for the competition, and the FAST Act named the focus areas specifically. In both cases, transportation resilience, while not specifically called out as a focus area, was included as an item in the scope of one or more focus areas.

In the MAP-21 competition, resilience could be included within the "State of Good Repair" and/or "Environmental Sustainability" focus areas, and in the FAST Act Competition resilience was specifically called out as a topic area within the "Preserving the Existing Transportation System" focus area. It could also be included in the focus areas of "Preserving the Environment" and "Improving the Durability and Extending the Life of Transportation Infrastructure."

Because the UTCs throughout the history of the program have either self-determined their themes, responded to congressionally directed themes (in the case of designated UTCs), or selected one of the USDOT-determined focus areas, UTCs have always had the capability to choose to conduct transportation resilience research. And some have – a review of current UTCs shows that seven of the 35 selected in the most recent competition have an emphasis on resiliency as part of their programs. Those UTCs, their lead institutions and links to their websites are as follows:

- The Transportation Infrastructure Durability Center (TIDC)., University of Maine, https://www.tidc-utc.org/about-us/#rt1
- Center for Advanced Infrastructure and Transportation (CAIT), Rutgers https://cait.rutgers.edu/about/
- The Center for Integrated Asset Management for Multi-Modal Transportation Infrastructure Systems (CIAMTIS), Pennsylvania State University, https://r3utc.psu.edu/research/thrust-areas/
- The Transportation Consortium of South Central States (Tran-SET), Louisiana State University, http://transet.lsu.edu/about-us/
- Inspecting and Preserving Infrastructure through Robotic Exploration (INSPIRE), Missouri University of Science and Technology, https://inspire-utc.mst.edu/
- C2SMART: Connected Cities with Smart transportation, New York University, http://c2smart.engineering.nyu.edu/research-areas/
- Center for Safety Equity in Transportation (CSET), University of Alaska, Fairbanks, http://cset.uaf.edu/3779/#t3748-target

In the current competition for the two new National UTCs, it would be reasonable to assume that the national center focusing on infrastructure would include a resilience component, as the comprehensive approach expected of a national center should address that topic. This approach should include not just recovery from extreme events but the "hardening" of infrastructure assets to better withstand them. Policy and planning should be considered as well as traditional civil engineering transportation infrastructure research. In fact, TTI's current proposal for the national infrastructure center includes all of these elements, with resilience as one of its fundamental research pillars.

Research recommendations

There are many opportunities for research topics in the field of transportation resiliency. Resilience requires a multidisciplinary approach that should involve not only pavement and structural engineers and transportation planners, but climatologists, hydrologists, community champions and a host of other disciplines that don't normally work together. Specific research topic recommendations include:

- Multiple data sets of varying levels of complexity – including roadway flood data, GPS and LiDAR data, roadway elevation data, climate data, FEMA data and storm surge data – just to name a few, need to be analyzed and put into a useful, more accessible form, such as a data clearinghouse. DOTs or MPOs don't have the resources or funding to manage all of the data sets themselves.
- We currently don't have good tools to anticipate the impact of an extreme weather event. More robust software systems are needed to calibrate existing models to more accurately calculate anticipated flooding events on infrastructure, for example, and to evaluate the resulting damage.
- Current efforts are focused on the flooding impacts on infrastructure damage to roadways, while the traffic operations impacts are not considered. The operational impacts of devastating weather events are even more costly, such as road closures and their effects on traffic congestion on lower arterial streets as well as the resulting economic effects.
- There have been a variety of resiliency studies and best practices developed by individual DOTs in areas such as vulnerability assessments, storm surge modeling, asset management, and risk management. Efforts should be made to identify these state best practices and replicate them throughout the country.
- Robust models to evaluate the impact on pavement service life given a flooding event need to be developed and monitored to search for trends that develop over periods of time to better understand the link between climate metrics and pavement performance. Research could determine the best ways to address any necessary changes in materials, design, construction and maintenance.
- Culvert management systems (similar to existing pavement management systems) need to be developed.
- Designers and engineers rely on manuals, AASHTO and Federal guidance, and other established procedures. Resilient design practices need to be developed and incorporated into these resources.

A recent National Cooperative Highway Research Program publication **Resilience in Transportation Planning, Engineering, Management, Policy, and Administration: A Synthesis of Highway Practice,** published in 2018, conducted a comprehensive literature review, a survey of state DOTs and case examples to document resilience efforts. The authors found that research is needed in the following areas:

- Performance measures need to be developed for resilience. Research can determine measures for resilience and the benefits expected from resilience investments. How do agencies measure success in this area?
- The relationship between risk assessment, management and resilience is not well understood. How should agencies balance the need for resilience with varying levels of risk?
- How does resilience correlate with other priorities, such as safety, infrastructure condition and operations? These have clear performance metrics and established monetary and other benefits linked to them. No such correlations exist for resilience, and this makes it difficult for agencies to justify spending limited resources on resilience benefits as opposed to others.

Any extreme weather event poses severe risks to our transportation system, but also to our economy and our very existence. Increasingly frequent and severe storms leave behind devastation with massive financial costs associated with loss of service, repair and recovery. Other costs, like those that result from permanent rips in the fabric of communities, can never be recovered.

We can't prevent major weather disasters. But by investing resources into better planning and engineering, and focusing on resilience long before disaster strikes, we will be far better able to weather whatever comes our way.

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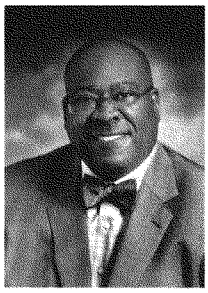


Gregory D. Winfree
Agency Director
Texas A&M Transportation Institute

Short Biography

Mr. Gregory D. Winfree was appointed Agency Director of the Texas A&M Transportation Institute (TTI) on December 15, 2016. TTI is a state agency and the largest and most comprehensive higher education-affiliated transportation research institute in the United States. He is also an Adjunct Professor at the Texas A&M University School of Law.

Winfree joined the U.S. Department of Transportation's Office of the Assistant Secretary for Research and Technology in March 2010 as Chief Counsel and was later sworn in as the Assistant Secretary in January 2014. During his tenure, Winfree also served as Deputy Administrator and Administrator of a predecessor agency, the Research and Innovative Technology Administration (RITA).

As Assistant Secretary, he was the senior executive responsible for a $450 million budget and oversaw more than 1,000 scientific, data analysis and administrative staff members who support USDOT's multi-modal transportation initiatives. The program offices under his purview included: the John A. Volpe National Transportation Systems Center; the Research, Development and Technology Coordination Office; the Bureau of Transportation Statistics; the Positioning, Navigation, Timing and Spectrum Management Office; the Intelligent Transportation Systems Joint Program Office; and the Transportation Safety Institute.

Prior to his USDOT appointments, Mr. Winfree served as Corporate Counsel for several Fortune 500 corporations for 17 years that operated in a number of technical industries, including:

- Natural resources and metals (Freeport-McMoran Copper & Gold, Phoenix, AZ);
- Pharmaceuticals (Wyeth Pharmaceuticals, Collegeville, PA); and
- Chemicals and polymers (Union Carbide Corporation, Danbury CT).

Education

- J.D., Georgetown University, Washington, D.C., 1989
- Sc.B., St. John's University, Jamaica, NY, 1986

Chairwoman SHERRILL. Thank you.
Mr. Averill?

**TESTIMONY OF JASON D. AVERILL,
CHIEF OF THE MATERIALS AND STRUCTURAL
SYSTEMS DIVISION, NIST**

Mr. AVERILL. Chairwoman Sherrill, Ranking Member Norman, and Members of the Subcommittee, I'm Jason Averill, Chief of the Materials and Structural Systems Division at the Department of Commerce's National Institute of Standards and Technology or NIST. NIST works at the frontiers of measurement science to address complex measurement challenges on every scale. In my division, we focus our efforts from the chemical properties of cement to buildings to the resilience of whole communities.

Thank you for the opportunity to appear before you today to discuss NIST's programs focused on the resilience of transportation infrastructure.

The 2017 U.S. hurricane season and the 2018 wildfires remind us that natural, technological, and human-caused hazards take a high toll on communities. The impacts can last long after the event. To help address these impacts, NIST manages a multifaceted Community Resilience program as part of our broader disaster resilience work. Principal among these efforts is support for science-based resilience planning. Effective planning can improve a community's quality-of-life, economic well-being, its ability to recover rapidly, and to build back better.

To support community planning, we produced the NIST Community Resilience Planning Guide that provides a practical and flexible approach to help all communities improve their resilience by setting priorities and allocating resources to manage risks for their prevailing hazards. Using this guide can help communities to integrate resilience goals into their comprehensive economic development, zoning, and other local planning activities.

In addition, the NIST community resilience Economic Decision Guide, or EDG, provides a standard economic methodology for evaluating investment decisions. The EDG quantifies the costs and benefits for the variety of resilience options that a community may be considering. To supplement the NIST Community Resilience research program, NIST has designated a Center of Excellence devoted to community resilience. The Center for Risk-Based Community Resilience Planning will accelerate the development of systems-level models and associated data to support community resilience decisionmaking.

In addition, NIST is committed to working with our Federal partners to transfer research results to products and end-users. For example, cities have partnered with NIST, EPA (Environmental Protection Agency), and used FEMA tools to develop proactive and integrated plans that address their local issues.

Another critical part of community resilience is looking at infrastructure and building materials. Concrete is a widely used building material playing a principal role in transportation infrastructure such as bridges and roadways by providing strength, durability, and resiliency. These material properties can be linked to the performance of a key component of concrete, cement. NIST of-

fers more than 20 types of cement Standard Reference Materials that help to ensure quality cement products in the integrity of structures around the globe.

Looking toward the future, NIST is exploring exciting new opportunities in construction that additive manufacturing, AM, with cement-based materials offers. Metrology and standards used for traditional concrete construction are not suitable for AM, and NIST is doing research with our industry partners to assess the potential of various material systems for this area.

NIST is also working on an advanced composite road-mapping effort that is focused on infrastructure. The resulting roadmap has the potential to lead NIST, other government agencies, and the industry toward wider acceptance and use of advanced composites for more resilient infrastructure.

Following select disaster events, NIST conducts disaster and failure studies where engineers and scientists seek to learn from and prevent similar disasters in the future. Studies previously conducted by NIST have led to significant changes in building codes, standards, and practices to enhance the health and safety of the American public. NIST is currently investigating the effects of Hurricane Maria in Puerto Rico to better understand how the buildings and infrastructure performed and how we can improve that performance in the future.

NIST has a long history of addressing industry needs through measurement science. Resilient infrastructure, particularly transportation, is the backbone of U.S. economic competitiveness, and NIST is proud to collaborate with industry, academia, and government agencies to meet critical national needs.

I'll be pleased to answer any questions you may have.

[The prepared statement of Mr. Averill follows:]

51

Testimony of

Jason D. Averill
Division Chief
Materials and Structural Systems Division
Engineering Laboratory
National Institute of Standards and Technology
United States Department of Commerce

Before the

Committee on Science, Space, and Technology
Subcommittee on Investigations and Oversight
United States House of Representatives

The Need for Resilience: Preparing America's Transportation Infrastructure for Climate Change

May 21, 2019

Introduction

Chairwoman Sherrill, Ranking Member Norman, and Members of the Subcommittee, I am Jason Averill, Chief of the Materials and Structural Systems Division at the Department of Commerce's National Institute of Standards and Technology (NIST). The NIST laboratory programs work at the frontiers of measurement science to ensure that the U.S. system of measurements is firmly grounded in sound scientific and technical principles. With the unique facilities at the NIST laboratories, we address complex measurement challenges on every scale, from the chemical kinetics of cement hydration, to buildings, and the resilience of whole communities. Thank you for the opportunity to appear before you today to discuss NIST's role in, and programs focused on, resilience of transportation infrastructure.

NIST and Community Resilience

Recent events, including the 2017 U.S. hurricane season and the 2018 wildfire season, remind us that natural, technological, and human-caused hazards take a high toll on communities, and that the impacts can last long after the event. To help address these impacts, NIST manages a multi-faceted Community Resilience Program, a part of our broader disaster resilience work, assisting communities and stakeholders on issues related to buildings, social functions, and the interdependencies of physical infrastructure systems, including the transportation network.

Principal among these efforts is support for science-based resilience planning. Effective planning can improve a community's quality of life, economic well-being, its ability to recover rapidly, and build back better. To support community planning, NIST produced the NIST Community Resilience Planning Guide for Buildings and Infrastructure Systems (Guide),[1] that provides a practical and flexible approach to help all communities improve their resilience by setting priorities and allocating resources to manage risks for their prevailing hazards. Using the Guide can help communities to integrate consistent resilience goals into their comprehensive, economic development, zoning, mitigation, and other local planning activities that impact buildings, public utilities, transportation, and other infrastructure systems.

The Guide's six-step process helps communities to think through and plan for their social and economic needs, their particular hazard risks, and recovery of the built environment by:

- setting performance goals for vital social functions—healthcare, education, and public safety—and supporting buildings and infrastructure systems—transportation, energy, communications, and water and wastewater;
- recognizing that the community's social and economic needs and functions should drive goal-setting for how the built environment performs; and
- providing a comprehensive method to align community priorities and resources with resilience goals.

In addition, the NIST Community Resilience Economic Decision Guide for Buildings and Infrastructure Systems (EDG)[2] provides a standard economic methodology for evaluating

[1] https://www.nist.gov/topics/community-resilience/planning-guide
[2] https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1197.pdf

investment decisions aimed at improving the ability of communities to adapt to, withstand, and quickly recover from disruptive events. The Economic Decision Guide, designed for use in conjunction with the Guide, offers an easy-to-follow approach that describes the costs and benefits for the variety of resilience options that a community may be considering.

The Economic Decision Guide frames the economic decision process by identifying and comparing the present and future streams of costs and benefits of resilience investments to the status-quo. Benefits are quantified through cost savings and damage loss avoidance. Other topics include non-market values, uncertainty, co-benefits related to resilience investments, and positive and negative externalities - costs or benefits that impact a third party - for a given strategy. NIST has also published the "EDGe$" Tool,[3] a powerful, software-based technique for selecting cost-effective, infrastructure-based community resilience projects based on the Economic Decision Guide.

NIST-funded *Center for Risk-Based Community Resilience Planning*

In order to supplement the NIST Community Resilience Research Program, NIST has designated a NIST Center of Excellence devoted to community resilience. The *Center for Risk-Based Community Resilience Planning*[4] (Center) was awarded to a 12-university partnership led by Colorado State University in February 2015.[5] The Center will accelerate the development of system-level models and associated data and databases to support community resilience decision-making. The Center's multi-disciplinary team includes experts in engineering, economics, data and computing, and social sciences. Their research will support development of metrics and tools that will help decision-makers decide how to best invest resources intended to lessen the impact of hazards on buildings and infrastructure systems, and how to recover rapidly and minimize community disruption.

The centerpiece of the Center's effort is IN-CORE—the Interdependent Networked-Community Resilience Modeling Environment. Built on an open-source platform, the computer model and associated software and databases will incorporate a risk-based approach to decision-making that will provide a quantitative and science-based approach to community resilience assessment and support a business case for enhancing disaster resilience at the community level.[6]

[3] https://www.nist.gov/news-events/news/2018/01/new-nist-edge-tool-can-help-communities-select-cost-effective-resilience

[4] https://www.nist.gov/coe/community-resilience-center-excellence

[5] The partners in the Center of Excellence include Colorado State University, University of Illinois at Champagne Urbana, University of Oklahoma, Rice University, Oregon State University, Texas A&M University, University of South Alabama, University of Colorado Boulder, California Polytechnic at Pomona, University of Washington, University of Kansas, and Iowa State University

[6] More information on the Center can be found at http://resilience.colostate.edu/

Working with U.S. Communities

NIST is committed to working with our federal partners to transfer research results and products to end-users.[7] For example, Nashua, New Hampshire, faces a variety of potential hazards, including riverine flooding. Nashua regularly experiences flooding due to an overwhelmed stormwater infrastructure and impervious cover such as roadways, parking lots, rooftops, and sidewalks.

Partnering with NIST, the Environmental Protection Agency, and using Federal Emergency Management Agency (FEMA) tools, Nashua is developing a proactive and integrated plan that addresses shocks and stressors ranging from natural disasters to adverse socio-economic trends. Through Resilient Nashua, the City is engaging with a broad and diverse set of community stakeholders. Nashua is using the six-step planning process in NIST's Guide to assist in its initiative. Nashua has developed its performance goals and is in the process of using FEMA tools to determine the anticipated performance of its buildings.

Nashua has identified five resilience focus areas: (1) aging infrastructure; (2) climate change and adaptation; (3) services for an increasingly diversified population; (4) resiliency as a culture; and (5) community health. In 2019, the City's resilience planning efforts will culminate in an updated Hazard Mitigation Plan and a first-time Community Resilience Strategy. The document will contain required FEMA hazard mitigation components and also present a strategy for community resilience-oriented preparedness, continuity of operations, and social programs.

NIST Concrete Research and Infrastructure

Concrete is the most widely used building material in the world, playing a principal role in transportation infrastructure such as bridges and roadways by providing strength, durability, and resiliency. NIST has been doing research to support the concrete industry for over 60 years.

The strength and reliability of buildings, bridges and roadways can be linked to the performance of a key component of concrete: cement—a fine powder of limestone, clay, sand and gypsum. When mixed with water, it creates a paste that can bind sand and rock together and harden into concrete. Manufacturers strive for uniformly reliable cement, relying on standard test methods developed and validated through the American Society for Testing and Materials (ASTM) International.

To support the development, usability, accuracy, and precision of consensus standards, NIST offers more than 20 types of cement standard reference materials (SRM®). The standard test methods supported by NIST SRMs ensure quality cement products and the integrity of structures around the globe. For example, SRM 46h, the Portland Cement Fineness Standard, is essential to the calibration of fineness testing equipment according to ASTM Standard Methods. SRM 2492, the Bingham Paste Mixture for Rheological Measurements, provides a well-characterized mixture to calibrate rheometers for measuring the rheological, or flow, properties of concrete. Well-characterized rheological properties are crucial to ensuring the ability to pump concrete on

[7] For more information about success stories from communities using the Guide, see https://www.nist.gov/topics/community-resilience/nist-community-resilience-planning-guide-success-stories.

job sites. SRM 1881b, Portland Cement Blended with Fly Ash, is used to validate chemical and instrumental methods of analysis of cements and materials of similar matrix for elemental content. Fly ash is a byproduct of burning coal for power generation. Previously considered a waste byproduct, research indicates that fly ash can be used to create improved cement that requires less water to mix into concrete, sets faster, flows more easily through pumps, and creates a stronger and less permeable concrete. The fly ash cement SRM is an example of how NIST continues to respond to the evolving needs of the $1 trillion global cement industry.

Additive Manufacturing with Cement and Concrete

Additive Manufacturing (AM) with cement-based materials is an emerging technology that offers exciting new opportunities in the construction industry. Robotic arms have been used to automate casting of concrete into formwork, and computer-controlled gantry cranes have been adapted to dispense material in a layer-by-layer method. Rapid construction enabled by AM techniques has many possible applications and benefits, including rapidly constructed shelters for communities after natural disasters (i.e., automated military construction with local materials), reduced transportation costs by on-site printing of bridge components, taller wind towers to access higher energy winds, more cost-effective design strategies through precise control of materials, and new methods to repair concrete in hard-to-reach areas.

AM with cement-based materials represents a paradigm shift in the approach to concrete specification and quality control and assurance. Metrology and standards used for traditional concrete construction are not suitable for AM, as precise measurements of a material's rheology before and during construction are required. NIST is conducting a combination of experimental measurements, numerical simulations, and machine learning (ML) techniques to assess the potential of various material systems for AM. Artifacts will be constructed using two AM robots: one bench-scale robot for paste and one construction-scale robot for grout. Non-destructive testing techniques will be used to assess a structure's build quality by detecting defects such as cold joints. In addition, numerical simulations of paste and mortar flow will provide insight into the stresses experienced by the material during the AM and will inform rheology experimental protocols. Finally, to aid in material and process parameter selection, data collected during this project will be used to train ML algorithms to predict combinations that produce high-quality AM structures.

Interest in AM with cement-based materials is quite high, and collaborations are being developed to ensure that solutions will be applicable to the construction field. NIST will participate in the *First International Conference on 3D Printing and Transportation*, sponsored by the Transportation Research Board of the National Academy of Sciences, Engineering and Medicine, in November 2019.[8] NIST will also lead a task group in the American Concrete Institute that will coalesce industrial standards needs in cement-based AM. Finally, NIST is

[8] http://www.trb.org/Calendar/Blurbs/177388.aspx

establishing a consortium of industry and academia partners to identify measurement science needs to advance adoption of cement-based AM technology.[9]

Advanced Composites in Infrastructure

The American Society of Civil Engineers 2017 Infrastructure Report Card delivered a D+ grade to U.S. infrastructure, stating that $2 trillion in funds would be needed to bring our critical infrastructure up to grade and calling for "new approaches, materials, and technologies to ensure our infrastructure is more resilient." Knowing that NIST frequently provides a neutral forum where industry members can speak candidly about challenges, the American Composites Manufacturers Association (ACMA) asked us to help convene the composites community to identify barriers for new materials in infrastructure. Advanced composites may in certain applications be stronger, lighter, and longer lasting than traditional building materials, thereby offering many cost savings. For example, it may take less fuel to transport lighter components, the equipment required to assemble advanced composite components into bridges or other structures may be lighter, and advanced composites may better resist corrosion from weather and exposure to chemicals. Longer lifespans for infrastructure components would mean fewer service days lost to maintenance of the bridges, roads, dams, levees, highways, railroads, utility poles, and other elements that support movement of the goods and services that underpin our economy.

Disaster and Failure Studies

Buildings, bridges, and other man-made structures fail due to a variety of reasons, including high winds, fires, earthquakes, errors in design and construction, flaws in materials, and even terrorist attacks. The NIST Disaster and Failure Studies Program establishes teams to assess building and infrastructure performance in the wake of disaster and failure events that have resulted in substantial loss of life or posed significant potential for substantial loss of life.

The objectives of NIST's disaster and failure studies may include (1) establishing the likely technical factor or factors responsible for the damage, failure, and/or successful performance of buildings and/or infrastructure in the aftermath of a disaster or failure event; (2) evaluating the technical aspects of evacuation and emergency response procedures that contributed to the extent of injuries and fatalities sustained during the event; (3) determining the procedures and practices that were used in the design, construction, operation, and maintenance of the buildings and/or infrastructure; and (4) recommending, as necessary, specific improvements to standards, codes, and practices as well as any research and other appropriate actions based on study findings.

NIST studies are documented in technical reports containing data, findings, and recommendations for consideration by: private sector bodies responsible for developing national model codes, standards, and/or practices; federal, state and local officials for adoption and enforcement of national model codes and standards; and research-performing organizations such as universities, national laboratories, and private sector entities. By identifying the technical

[9] More information on the MACE Consortium can be found at https://www.federalregister.gov/documents/2018/05/22/2018-10913/nist-consortium-for-metrology-of-additive-construction-by-extrusion-mace

causes leading to building or infrastructure failures, making that information public, and then promoting and tracking adoption of recommendations, NIST engineers and scientists seek to prevent similar failures in the future. Studies previously conducted by NIST have led to significant changes in practices, standards, and codes to enhance the health and safety of the American public.[10]

NIST Hurricane Maria Program

NIST is currently investigating the effects of Hurricane Maria in Puerto Rico.[11] On September 20, 2017, Hurricane Maria made landfall in Puerto Rico, damaging infrastructure that its communities relied on for medical care, safety, mobility, communications, and more. To better understand how the buildings and infrastructure failed, and how we can prevent such failures in the future, NIST began to study how critical buildings and infrastructure systems performed during the storm.

In Puerto Rico, NIST will seek to understand Hurricane Maria's wind environment and the conditions that led to injuries and deaths; how critical buildings and designated safe areas within them performed—including their dependence on electricity, water, transportation, and other infrastructure; how emergency communications systems performed and the public's response to such communications; and the impacts to, and recovery of, selected businesses, hospitals and schools, as well as the critical social functions they provide.

National Windstorm Impact Reduction Program

The purpose of the National Windstorm Impact Reduction Program (NWIRP) is "to achieve major measurable reductions in the losses of life and property from windstorms through a coordinated Federal effort, in cooperation with other levels of government, academia, and the private sector, aimed at improving the understanding of windstorms and their impacts and developing and encouraging the implementation of cost-effective mitigation measures to reduce those impacts."[12] In addition to NIST, which is designated as the lead agency, other NWIRP agencies include FEMA, the National Oceanic and Atmospheric Administration (NOAA), and the National Science Foundation (NSF). The Federal Highway Administration (FHWA) has also participated in NWIRP from its inception.

Lead agency responsibilities at NIST include ensuring that the Program includes the necessary components to promote the implementation of windstorm risk reduction measures; supporting the development of performance-based engineering tools, and working with appropriate groups to promote the commercial application of such tools; coordinating all Federal post-windstorm

[10] For more information on some of the impacts that NIST Disaster and Failure Studies have had on building codes, standards, and practices, see https://www.nist.gov/topics/disaster-failure-studies/impacts-and-recommendations.
[11] A public announcement of the Hurricane Maria study can be found at: https://www.nist.gov/news-events/news/2018/05/nist-launches-study-hurricane-marias-impact-puerto-rico
[12] National Windstorm Impact Reduction Act Reauthorization of 2015, Public Law 114-52, codified at 42 U.S.C. 15701 *et seq.*, can be found at https://www.congress.gov/114/plaws/publ52/PLAW-114publ52.pdf.

investigations to the extent practicable; and when warranted by research or investigative findings, issuing recommendations to assist in informing the development of model codes. In addition to lead agency responsibilities, NIST conducts research and development to reduce windstorm losses by transferring science and engineering knowledge to committees and organizations responsible for model building codes, voluntary standards, and best practices for the design, construction, and retrofit of buildings, structures, and lifelines, including transportation infrastructure.

As required under the 2015 reauthorization, windstorm loss reduction strategies, including research needs, are assessed in the *Strategic Plan for the National Windstorm Impact Reduction Program.*[13] Specific to transportation infrastructure, Objective 5 of that strategic plan identifies the need to advance understanding of windstorm effects on the built environment, including an improvement in the understanding of civil infrastructure vulnerabilities in extreme windstorm events and refinement of computational tools to predict performance of civil infrastructure, including transportation systems. Objective 8 identifies the emerging need to understand how windstorms impact communities as a whole – for example, data collection on characteristics of the emergency response and also recovery times for return to functionality for critical facilities and key infrastructure, such as hospitals, power, and transportation networks.

Conclusion

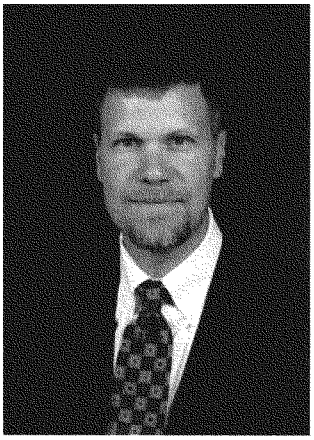
NIST has a long history of addressing the Nation's needs through measurement science. Resilient infrastructure, particularly transportation, is the backbone of U.S. economic competitiveness and NIST is proud to collaborate with industry, academia, and government agencies to meet critical national needs.

We greatly appreciate the efforts of the members of these committees and other members of Congress to support resilience programs that keep the Nation globally competitive and secure, and that contribute to our quality of life.

I will be pleased to answer any questions you may have.

[13] The 2018 NWIRP Strategic Plan can be found at https://www.nist.gov/sites/default/files/documents/2018/09/24/nwirp_strategic_plan.pdf.

Jason D. Averill



Jason D. Averill is Chief of the Materials and Structural Systems Division (MSSD) of the Engineering Laboratory (EL) at the National Institute of Standards and Technology (NIST).

Since joining the Engineering Laboratory in 1997, Mr. Averill has focused his research on making communities safer and more resilient to hazards.

Mr. Averill is a member of the American Society of Civil Engineers, has served on the International Code Council's Means of Egress Committee, the NFPA Life Safety Code Committee (Means of Egress), and was a member of the ASME A17 Task Group developing guidelines for Occupant and Firefighter Use of Elevators During Fire Emergencies.

In 2005, Mr. Averill received the U.S. Department of Commerce Gold Medal Award for Distinguished Achievement in the Federal Service for his work on the Federal Investigation of the Collapse of the World Trade Center Buildings. In 2011, Mr. Averill received the U.S. Department of Commerce Silver Medal for characterizing the deployment of firefighting resources and in 2004 received the U.S. Department of Commerce Bronze Medal Award for Superior Federal Service for research into the characterization of the performance of home smoke alarms

The Materials and Structural Systems Division serves as the world-class resource for developing and promoting the use of science-based tools – measurements, data, models, protocols, and reference standards – to enhance both the global competitiveness of U.S. industry through innovations in building materials and construction technology; and the safety, security, and resilience of the nation's buildings and physical infrastructure. In addition to NIST measurement science research, the Division is also responsible for managing three statutory programs, including the National Earthquake Hazard Reduction Program (for which NIST is the lead agency), the National Windstorm Impact Reduction Program (for which NIST is the lead agency), and the National Construction Safety Team Program.

Education

M.S. in Fire Protection Engineering from Worcester Polytechnic Institute

B.S. in Civil Engineering from Worcester Polytechnic Institute

Chairwoman SHERRILL. Well, thank you so much.
Mr. Reeve?

TESTIMONY OF SCOTT REEVE,
PRESIDENT, COMPOSITE ADVANTAGE, LLC

Mr. REEVE. Chairwoman Sherrill, Ranking Member Norman, and Members of the Subcommittee, on behalf of my company Composite Advantage and my fellow members in the composite—American Composite Manufacturers Association I appreciate the opportunity to testify today.

This hearing comes at a critical time. For many years we have heard that our crumbling infrastructure was in desperate need of attention. That need has only intensified in the wake of increased episodes of severe weather and other environmental challenges. Confronting these challenges requires a new way of thinking about how we build and what are the best materials to use to enhance resiliency for preventive measures and not just reactive.

Composite Advantage is one of over 3,000 manufacturers of fiber-reinforced polymer composites across the United States, including each of the districts represented on this Subcommittee. Composites—combinations of polymer resins and fiber reinforcements like glass and carbon—are used in a wide range of sectors. They were first widely used in boats and aircraft, but now companies like mine are using the materials to build high-performance and infrastructure components like bridge decks, rail platforms, and waterfront protection systems. Composites are stronger and more durable than traditional alternatives and have lower environmental impact. Many applications can be prefabricated to reduce installation times and can be fully sourced from American-made materials.

When Superstorm Sandy devastated the Northeast, the Canarsie Tunnel between Brooklyn and Manhattan was flooded with 7 million gallons of saltwater. This tunnel is used by a quarter million train passengers per day. The walls have corroded and need to be replaced. Traditional reconstruction would require a 15-month shutdown, but our company is manufacturing shells to line the tunnel walls and prevent the crumbling concrete from falling on the tracks. The shells can be installed without a full rebuild meaning 99 percent less demolition work and no shutdown. Even if the tunnel is flooded again, the composite shells will still do their job.

Composites are being used in increasing quantities on America's waterways since the materials are forever resistant to water corrosion. Composites were used to rehabilitate the dock of the Statue of Liberty and repair and protect the Long Beach New York boardwalk after Superstorm Sandy. But composites can do even more. Using prefabricated bridge structures will minimize traffic disruption. And thanks to the elimination of rust and degradation, composites improve longevity and performance of these structures. Wraps can be externally bonded to decaying or damaged structures, restoring the strength of the bridge to its original level, again, with minimal traffic disruption. Composite rebar is making concrete bridges and tunnels resistant to corrosion that occurs with steel.

In the Virgin Islands Hurricane Maria destroyed every utility pole that was wasn't a composite. Only the composite poles were left standing. Because of this real-life performance test, the Virgin

Islands decided to rebuild their electric grid with composite structures to prevent future problems and avert the future costs.

The strides made by our industry in a short period have been significant but more needs to be done. We need continued research such as that underway at institutions like Turner-Fairbank and others on the next generation of composite solutions appropriate for much larger-scale applications. Most of all, we need to broaden awareness of composites and increase their deployment in infrastructure projects by helping engineers and asset owners to be more comfortable using these new materials.

NIST, working with industry, has developed a roadmap of activities to achieve this goal, first by aggregating and validating existing standards and design data and then working to develop better models of durability. Coupled with a robust education plan, NIST's work will help provide assurance to engineers on how these new materials will perform under specific conditions.

Legislation has been introduced by Congressman McNerney and Congressman Webster authorizing these activities by NIST in H.R. 2393. I encourage Members of both parties to support it.

Finally, Congress should support innovative grant programs that foster new technologies and demonstrate how these technologies can make our transportation infrastructure more resilient.

Bipartisan Members of the House and Senate have introduced legislation called the *Innovative Materials for America's Growth and Infrastructure Newly Expanded (IMAGINE) Act*, H.R. 1159. This legislation would create new bridge and water infrastructure innovation grant programs, as well as direct needed research on innovative materials to facilitate broader use. I hope all Members will consider supporting this important measure.

Opportunities abound to build a more resilient tomorrow and should not be wasted. The composites industry stands ready to work with Congress to further study, develop, and deploy real solutions to these real challenges.

Thank you for your time.

[The prepared statement of Mr. Reeve follows:]

Statement of Scott Reeve
President of Composite Advantage
(on behalf of the American Composites Manufacturers Association)
Before the Subcommittee on Oversight and Investigations
"The Need for Resilience: Preparing America's Transportation Infrastructure for Climate Change"
May 21, 2019
Washington, DC

Chairwoman Sherrill, Ranking Member Norman and members of the Subcommittee on Oversight and Investigations, my name is Scott Reeve and I am the President of Composite Advantage in Dayton, Ohio. On behalf of our company and my fellow members of the American Composites Manufacturers Association (ACMA), I appreciate the opportunity to testify before you today.

This hearing on building a more resilient infrastructure network comes at a critical time, as increasing stresses are being put on our built environment. In this testimony, I will provide examples of technologies from the composites industry that can be used to mitigate against those stresses, as well as recommendations Congress should consider as you work with the Administration and the states to rebuild and restore America for the 21st Century.

Composite Advantage is one of over 3000 manufacturers of fiber reinforced polymer (FRP) composites industry in the United States. This includes manufacturers in every district represented in this Committee. ACMA would be pleased to meet with each office to provide information on these manufacturers and further elaborate on the benefits composites bring to infrastructure and other markets.

Composites, combinations of polymer resins and fiber reinforcements like glass, carbon or basalt, are used in a wide range of sectors. Their performance characteristics, which I will elaborate on, allow for delivery of greatly improved performance relative to other material options while reducing long term costs and extending service life.

The domestic composites industry contributes more than $50 billion to the US economy and is growing at more than twice the national Gross Domestic Product. Composite materials were first developed for the US military during World War II and the United States continues to be the world's largest producer.

Fiberglass recreational boats are a well-known and instructive example of composites. Saltwater destroys traditional metal and wood hulls for boats, but fiberglass remains unscathed after decades of high salinity contact and has come to dominate that sector due to its superb performance. Over 50 years of demonstrated superiority provides a parallel to what can be accomplished in infrastructure through increased application of composite materials.

I have been in the composites industry for the bulk of my career. I founded Composite Advantage fifteen years ago after experience in aerospace composites, recognizing the capability of these materials to improve our infrastructure network. We design and manufacture a range of large infrastructure products including vehicle bridge decks, rail platforms, waterway protection systems, and mooring systems for the US Navy's submarines and aircraft carriers. All made of composite materials.

Key Characteristics of Composite Materials

There are many attributes of composite materials that make them uniquely capable of addressing American infrastructure challenges, including those caused by climate and environmental factors.

Durability
Because they are corrosion-proof, the service life of composite structures typically last at least twice as long as steel and wood equivalents and require little maintenance.
Strength
Per pound, composites are stronger than other materials such as steel, aluminum, concrete and wood. The two primary components of composites – fibers and resins – contribute to their strength. Fibers carry the load, while resins protect the product from the environment and distribute the stresses and loads throughout the composite part as required.
Weight
Composites are light in weight compared to most woods and metals. Lighter leads to lower transportation and construction costs and fewer installation delays. Lighter components also require less additional supporting materials, further reducing costs.
Resiliency
Composites resist damage from weather and harsh chemicals that can eat away at other materials. They will never rust or rot, making them a good choice for applications that face constant exposure to saltwater, deicing salts, toxic chemicals, temperature fluctuations and other severe conditions.
Design Flexibility
A wide range of material combinations can be used in composites, which allows for design flexibility that tailors performance exactly to the unique specifications of each application. Composites can also be easily molded into complicated shapes.
Positive Environmental Impact
Composite structures require significantly lower amounts of energy to be produced than traditional construction materials such as steel, aluminum and concrete. In addition, the resulting structure is chemically inert and will not degrade or leach harmful substances into the environment.

Prefabrication
Large composite structures like bridge decks can be fabricated offsite in a factory, minimizing service disruption to only a brief installation period. Where traditional construction methods could cause traffic disruptions for several weeks as a structure is built from the ground up, prefabricated composites structures with superior performance can be installed in less than one day.

American Made
While our industry has a global footprint, most products available in the market are produced in the United States from raw materials (reinforcements, resins, and other chemicals) produced in the United States.

Climate Resiliency Further Explored

There are greater environmental and weather-related stresses placed on infrastructure than ever before. Severe winter storms necessitate more road salt and other treatments that can accelerate degradation of traditional construction materials. Hurricanes and other related weather events also cause increased exposure to moisture and similarly expose constructed assets to high wind

and other factors that can damage infrastructure assets. Rising sea levels put increased strain on coastal maritime infrastructure.

Greater use of composites will allow infrastructure to be more resilient in the face of these challenges. Composite structures in place prior to the severe events will regularly withstand the impact of storms and remain fully operable.

In addition to mitigating against the environmental impact of a changing climate, the materials themselves have environmental benefits worth noting. Composites have lower embodied energy, meaning they require less energy to produce. Because they are longer lasting than alternative options, they need to be replaced less and therefore manufactured and constructed less often. They relatedly consume less materials for repair purposes. These factors lessen the overall consumption of resources needed for the service period of an asset relative to alternatives. Because composites are lighter, they also require less fuel consumption per unit for transportation and installation.

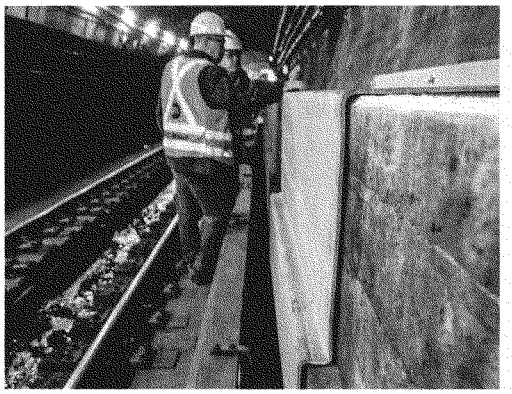
Examples of Resiliency Based Installations

For all the reasons previously described, composites make enormous sense for broader deployment in infrastructure of all types, and, relevant to this hearing, transportation infrastructure in particular. The following examples from Composite Advantage and fellow ACMA member companies may be instructive to Congress as you consider ways to rebuild and restore American infrastructure to withstand 21st Century challenges.

Tunnel

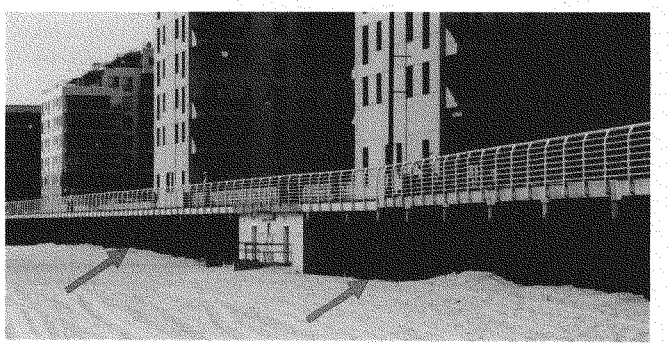
Superstorm Sandy in October 2012 has become the example of disruption and danger that can occur. A costly and disruptive result of Sandy is currently being avoided by using fiber composites.

The storm surge from Sandy flooded the Canarsie Subway Tunnel in New York City, used by 225,000 train passengers per day between Brooklyn and Manhattan. The 7 million gallons of saltwater in the tunnel started corrosion of the sides of the concrete tunnel. These bench walls carry utility cables and provide emergency egress. The crumbling walls threatened the safety and function of the rail line. The traditional repair plan would mean 15 months of shutdown that was unacceptable to the commuting public and city and state government. Once FRP composites were added to the options, the new repair plan means 99% less demolition work and no tunnel shutdown. The lightweight, prefabricated shells can be carried into the tunnel every night after a busy train schedule and repaired. Composite Advantage is starting production of these shells so the first tunnel can be repaired by end of summer. This effort will make the tunnel more resilient in future storms, by reinforcing it against potential damage and minimizing service disruptions.



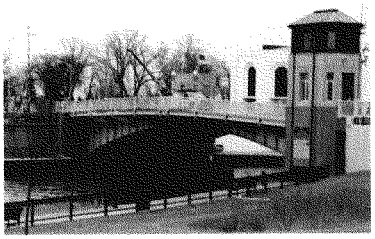
Coastal Seawall

The Long Beach Boardwalk was severely damaged during Hurricane Sandy. After the boardwalk was replaced, a retaining wall of composite sheet pile was constructed to protect the board walk and flooding of the residential neighborhood from future devastating storms.



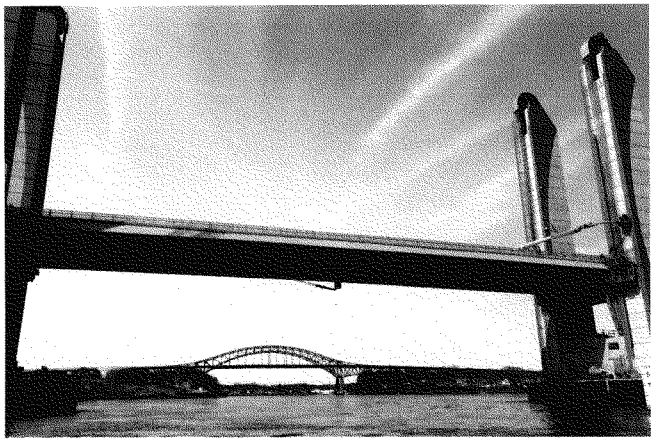
Bridge Decks

There are various components to bridges, including entire bridge systems, that can be fabricated with composites. Our company provided components to the Franklin Street Bridge in Michigan City, IN. During the very cold spell last February, concrete and steel decking on the draw bridge buckled from extreme cold. The bridge was unusable by vehicles. Being in the down position, the bridge blocked boats from getting to Lake Michigan. The City selected composite bridge decking for the emergency repair since the composite panels could be prefabricated for fast installation. The bridge was repaired in just over one month. The corrosion resistant deck will not deteriorate from water and chemicals so it will not be susceptible to this weather-related failure in the future.



After seeing the many benefits of composites after damage, engineers are now designing with the material to make new structures more resilient. Higher loads are being specified to counteract extreme weather.

Sarah Mildred Long Bridge is a vital link carrying US Route 1 between Portsmouth, New Hampshire and Kittery, Maine. Carrying both vehicle and rail traffic, this lift bridge moves vertically to allow larger ships to pass underneath. The bridge is the first of its kind in the U.S. with four 200 ft. tall towers that support a 300 ft. long lift span. The area is prone to high winds which destabilize traditional constructions. To stabilize the bridge during severe weather and deflect high winds, engineers needed a strong, yet lightweight wind fairing. FRP composites were molded in an angle shape to help the bridge withstand the 100 mph winds that could occur.



Concrete Reinforcement

Composite rebar is another revolutionary application being produced by many companies. These rebars are a quarter of the weight and twice as strong of traditional steel, last more than twice as long and will never rust and degrade. Degradation of the internal reinforcement is the primary cause of degradation of the superstructure of concrete bridges. Concrete is porous by its nature, with moisture and deicing salt causing the rusting of the steel. Rusted steel expands and weakens, causing spalling of the concrete and reductions in strength.

Corroding steel rebar was the start of the problem for the Canarsie Tunnel. Composite rebar has been used and in service for concrete bridge decks for over 20 years and is starting to be used to reinforce concrete structures in tunnels, piers and structures in harsh marine environments. When the storm surges hit those structures, the rust-proof, composite reinforcements will prevent the start of a corrosive chain reaction. Many states with either high salinity atmospheres, like coastal Southern states, or that use significant amounts of road salt, like many states in the Northeast and Midwest, have begun using composite rebar more.

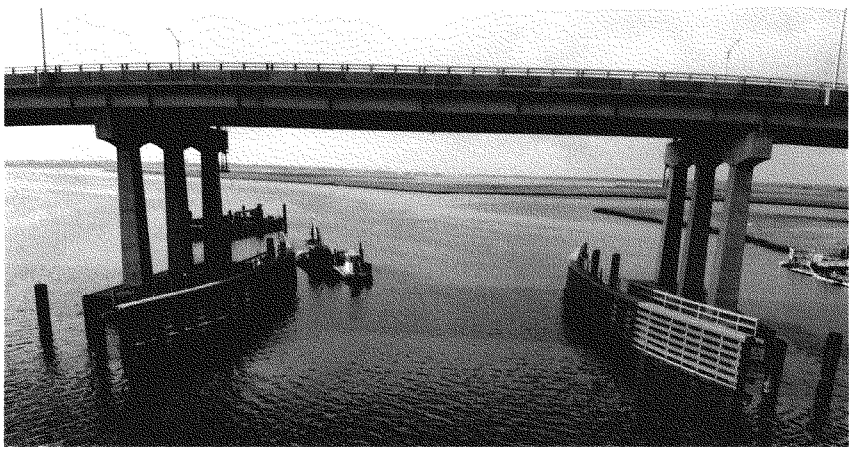
Rail Transit Platforms

Since composites are unaffected by the deicing chemicals, more rail platforms are being constructed using composite materials. Besides the corrosion resistance, the lightweight, prefabricated platform panels allow for fast installation around train schedule. We are also seeing constantly increasing design requirements including higher snow loads.

Waterways

Waterways are a critical part of the transportation infrastructure; it is just not as noticeable to the general public. There are 12,000 navigable waterways in the US and the economic impact is huge. One barge is equivalent to 58 semi-trailers. Composites are being used in increasing quantities on the waterways since the materials are forever resistant to water corrosion. There is no leaching of chemicals into the water as happens with treated wood.

Composites are a key part of the protection systems built around critical infrastructure like bridge piers and to make waterways more resilient. The FRP piles offer the strength of steel, but a much lower bending stiffness which allows for far greater energy absorption than traditional materials. Unlike rigid concrete and steel fender systems, the FRP fender pile system is designed to deflect and then recover, without damaging either the vessel or the fender.
There are increasing requirements from larger vessels navigating in higher winds and faster currents; and composites are designed to handle these impacts.



Advanced ultraviolet additives protect coastal reinforcements from sunlight and heat degradation and are coupled with composites' proven ability to withstand corrosion and structural degradation in fresh and saltwater environments. These properties allow for extended service life along with reduced maintenance costs. This type of system was used to rehabilitate the service dock at the Statue of Liberty in the wake of Superstorm Sandy

External Repair

In addition to new construction, composites have the ability to repair aging concrete structures and restore nearly all of their functional strength. Composite wraps can be affixed to deteriorating structures, extending service life for several more decades. External strengthening systems also allow structures to better withstand the impact of destructive seismic forces in earthquakes. This can be done without taking the bridge, tunnel, or dam out of service thus minimizing disruption. The cost is much lower than new construction.

Considerations to Accelerate Deployment

Given the relatively short period of time that composites have existed in the infrastructure market by comparison to traditional materials, the strides made on product development and performance improvement have been significant. There are still barriers to broader deployment that need to be addressed to further accelerate the use of resilient composite infrastructure.

Composite solutions can contribute longer service life and making a bigger impact with its inherent design flexibility. As federal research institutions like Turner Fairbank Highway Research Center and others continue to explore the next generation of building materials for transportation structures, it is worth exploring ways to build and validate larger assets with

innovative materials like composites than are currently being deployed, like long span bridge decks for example. This would allow composites to be used to in larger scale applications, which are increasingly needed as the impact of extreme weather becomes more pervasive.

Another barrier the industry is working aggressively to overcome is recyclability. The reason composites perform so well in construction applications is because of the extreme strength of thermoset polymers. By design, these materials do not breakdown. They are chemically inert so they will cause no pollution in a landfill, but nevertheless it would be ideal if materials taken out of service could have a second functional life. Our industry, aided by the Department of Energy backed Institute for Advanced Composites Manufacturing Innovation, is developing several promising recycling technologies that will make our products even more sustainable.

Perhaps the biggest barrier for broader use of composites can be boiled down to is the awareness of this material. Most civil engineers active today probably received little academic training on composites, particularly as a material for infrastructure. Because these materials are newer and less understood, there is a natural reluctance to take a perceived risk and use them. The way to overcome this is through development of more design standards, which provide assurance to engineers on how materials will perform under specific conditions, and ongoing stakeholder education.

What Congress Can Do

That National Institute of Standards and Technology developed a roadmap[1] for activities that can overcome these barriers, including specific activities the agency can take toward this end. These include aggregation and validation of existing data in a publicly available clearinghouse, development of durability testing protocols that will facilitate development of more standards, and development of a stakeholder outreach program to diffuse information about composite materials to the academic and engineering communities. Having NIST as the central clearinghouse for the composite technology data and information would greatly aid the use of composite materials. If owners and designers could find the necessary information, then they can apply it to solve their issues and have more confidence in a successful application.

Legislation authorizing a NIST composites program as described has been introduced by Congressman Webster (R-FL-11) with bipartisan cosponsors. The bill is HR 2393, known as the NIST Creation of Composite Standards Act, and has been referred to the Science, Space and Technology Committee. I strongly urge Members to consider supporting this important legislation.

As Congress works with the Administration to develop infrastructure policies for the future, consideration should be given to innovation grant programs. A recent Transportation Research Board[2] report explored the effectiveness of a previous Federal Highway Administration program

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[1] Sheridan, Richard J. et al. *Road Mapping Workshop Report on Overcoming Barriers to Adoption of Composites in Sustainable Infrastructure.* December 2017. https://www.nist.gov/publications/road-mapping-workshop-report-overcoming-barriers-adoption-composites-sustainable

[2] TRB Special Report 330: *Performance of Bridges That Received Funding Under the Innovative Bridge Research and Construction Program.* January 2019. http://www.trb.org/Main/Blurbs/178664.aspx

called the Innovative Bridge Research and Construction program, which existed in the late 1990s and early 2000s and funded the construction of more than 300 bridges with varying newer technologies and techniques, including widespread use of composites. The TRB panel determined that these innovative materials have great promise for building a stronger, more resilient, and longer lasting infrastructure. Likewise, the panel found that innovation grant programs have great success in highlighting new technologies and seeding wider implementation.

Recognizing the success of previous programs and the value newer materials can have, bipartisan members of the House and Senate have introduced legislation called the IMAGINE Act in both chambers, HR 1159 in the House. The legislation would create new bridge and water infrastructure innovation grant programs, as well as direct needed research on innovative materials to facilitate broader adoption. I also encourage members of this panel to support that legislation as a stand-alone bill and to encourage its inclusion in any broader infrastructure packages.

As the Committee on Science, Space and Technology considers needed components of the federal research portfolio, infrastructure should not be taken lightly. Additional attention should be paid to applications like breakwater structures and movable walls that can be deployed prior to storm surges in coastal areas and reused.

Additionally, while allocating federal funds for infrastructure projects of all modes, special consideration needs to be given to critical at-risk infrastructure. In many instances, it would make sense to spend a small percentage to make infrastructure stronger that connects people to key services like schools, hospitals and government buildings, or in remote areas that may only have one thoroughfare connecting a community to the broader region.

State and Regional Activities

Many states have begun considering and adopting policies to mitigate infrastructure against climate and weather impacts, such as Maryland's CoastSmart Communities Program that assists coastal communities address short- and long-term hazards, or New York State requiring construction permit applications to demonstrate consideration of sea level rise. These activities should be encouraged.

Many state and regional authorities have begun to deploy preventative structures to protect the most at-risk infrastructure. Composite sea walls will not corrode so they will be in place to protect vulnerable coastal roads from wash-outs whether the storm occurs next year or in 100 years. Breakwater structures and movable walls can be deployed prior to the incoming storm to protect roads, bridges and ports. Being corrosion resistant and light weight makes composites the perfect material for protection from storm surges on the coast.

One of the difficulties in making longer term decisions is having the data on the economic impact. This is especially true for understanding the economic cost of extreme weather events. Storms that damage transportation infrastructure have a cost for loss of use and a cost for replacement. Spending a fraction of that later cost to make the structure resilient to weather now

can save a lot more when a storm arrives. At the upfront point, better materials and preventive structures can be employed so the damage never occurs.

Procurement of infrastructure is primarily based on initial acquisition cost; with little consideration for long term maintenance and replacement costs. Owners who want to account for long term costs must do extra work justifying the choice and obtaining funding. Long term costs should be considered in procurement decisions. The Federal government could do a great service to state and local asset owners by helping them better understand the full economic impact of extreme weather and the implication that has on maintenance costs of various material options. This could help facilitate greater consideration of total lifecycle costs to assure the most effective use of taxpayer dollars. Infrastructure planning and design needs to consider the magnitude of the increased weather events.

While not transportation infrastructure specifically, another key element of our built environment that is largely impacted by extreme weather is the electric grid. Composite utility structures outperform traditional wood polls and cross-arms because of the performance benefits described previously. Hurricane Maria in 2017 wiped out every utility pole in the US Virgin Islands, except for the eight composite poles that had been previously installed. Upon testing, those poles showed a negligible impact on performance. As part of their rebuilding, the Virgin Islands Water and Power Authority has widely deployed composite poles to mitigate against future storms. This is an example of effectively rebuilding for mitigation that should be considered by other jurisdictions across various modes of infrastructure.

Conclusion

It is encouraging that Congress is grappling with ways to strengthen our national infrastructure in the face of increasing extreme weather events and environmental changes. The demands placed on America's infrastructure today have never been greater. To build an infrastructure network that can support the realities of a 21st Century population, economy, and environment, it is more important than ever to take advantage of 21st Century technologies. Composite infrastructure products are one such technology.

Infrastructure applications are unique because the parameters around it are unique and changing. Like any material, composites are not a one-size fits all solution; they are highly engineered to guarantee the level of performance that is needed will be maintained forever. As advanced as composites are today, there is still so much farther we can go. Material advancements can allow for imbedded sensors with instantaneous monitoring of performance, ensuring that any needed upgrades can happen long before an asset is at risk. Materials are becoming stronger, meaning less will be needed per unit lowering the economic and environmental footprint of production. Importantly, newer materials can work well in combination with traditional materials, so that we can harness the best qualities of all to build structures that can last centuries rather than years.

Opportunities abound to build a more resilient tomorrow and should not be wasted. It is important that Congress work with federal and state agencies to further study, develop and deploy solutions that can make transportation more reliable for all Americans. There are immediate actions like the NIST Composite Standards Act and the IMAGINE act that will

strengthen our infrastructure in the long term. The composites industry stands ready to work with Congress on this mission, to rebuild America to be a country ready to face tomorrow's challenges.

SCOTT REEVE
PRESIDENT
COMPOSITE ADVANTAGE

Scott Reeve is founder and President of Composite Advantage. With more than 35 years of experience in the composites industry, Scott provides composite FRP solutions to new markets. His company builds large structural parts for the infrastructure market including bridges, rail platforms, waterfront protection systems and mooring structures for the US Navy. Prior to starting Composite Advantage in 2005, Scott successfully managed technical projects for Lockheed Martin and as the Vice-President for the National Composite Center. He is very active in the composite industry trade association and community development organizations. He received a Master's Degree in Engineering Management from Washington University and Master and Bachelor of Science degrees in Aeronautical Engineering from Purdue University.

Chairwoman SHERRILL. Thank you. Before we proceed, I would like to bring the Subcommittee's attention to two statements I received in preparation for our hearing. The first is written testimony from the Union of Concerned Scientists highlighting the need for climate resilience across all modes of transportation. The second is a letter from the Region Plan Association, RPA, describing the vulnerability of the Northeast Corridor and the importance of the Gateway project for the region's transportation network.

Without objection, I am placing these documents in the record.

At this point, we will begin our first round of questions, and I'll recognize myself for 5 minutes.

Mr. Winfree and Ms. DesRoches, I want to start by talking about strategic planning. How can DOT elevate climate resilience as a strategic research priority?

Ms. DESROCHES. Thank you. So DOT and in particular FHWA (Federal Highway Administration) has been working on a climate adaptation program for a number of years. I think that the—all of DOT could elevate it as a strategic priority for the agency, and therefore, it would lend itself to the evaluation of Federal dollars, right? So if a project is getting federally funded, DOT could make the determination as to how resilient that project is and tie that to the Federal funds.

Mr. WINFREE. I certainly concur with my colleague, and I would only offer and add that DOT will do as Congress directs, so requiring DOT to have that as a strategic objective I believe would get the ball rolling certainly, but more importantly, it would help it become universally applicable across the Department. As Ms. DesRoches stated, Federal Highways is out on front on those issues right now, but in order for it to become a departmental objective, it needs to be placed on their to-do list in order to get that done.

Chairwoman SHERRILL. Thank you. And then, Mr. Winfree, you talked a bit about all the data out there and the collection being done. Do you have a sense—I think you spoke a bit about how there needs to be a better software for that and then better able to collate that data in one place for user ease. Can you talk a bit about how that would look and what, you know, options there are for that?

Mr. WINFREE. The talk around transportation now as we look at it more from the mobility standpoint is that it is the safe and efficient movement of people, data, and goods. So it's the data part that's lagging behind the movement of people and goods. So what we are championing and what you're hearing across the industry is a focus toward moving all of these disparate data sets into a clearinghouse so it's a two-part analysis. One, you have to know what data is out there and what data is usable, and that data has to be cleansed. And then once it's in a form and fashion that it can be used by the research community, that's when you start to see useful information coming out of those disparate data sets.

So it's a bit amorphous right now. There's a lot of data out there. There are a lot of data streams. Vehicles are producing more data as they become more and more computerized, systems writ large, traffic operations systems, so there's a lot that's out there but starting to put a research focus and brilliant minds on it to start to

amass what's out there and start to determine how it can be used most effectively is the initial step.

But what we foresee is a data clearinghouse where traffic operators, traffic managers, asset managers, and researchers would be able to tap into and utilize that information.

Chairwoman SHERRILL. Thank you. And then, Mr. Reeve, Picatinny Arsenal in my district is really at the forefront of a lot of the military research and development, and I've seen them doing some amazing work with composite materials. I guess what I'm questioning is, how do we ensure that we are doing as much as we can to rebuild our infrastructure with the most resilient materials? What's being done? What more needs to be done?

Mr. REEVE. And the first thing in terms of what needs to be done is—again, is part of what we do is just education awareness so that the people who, when they're making the decisions of what materials they can use, they have that information because a lot of times they're sitting there with, OK, they've listened to one place or another place, but where can they get all of that in one—at one location? So that's part of what I—we mentioned on the NIST side, to have that clearinghouse, that—sort of that impartial location in which the asset owners can get that information. There's a good bit out there of information but it's all in disparate places.

Chairwoman SHERRILL. Thank you. And I'm afraid I'm running out of time, but briefly, Mr. Averill, can you talk a bit about how NIST has provided that clearinghouse?

Mr. AVERILL. So NIST has a long history of doing scientific work and taking the results of that, making it publicly available to both end-users, as well as people like the building codes and standards community to ensure that there's a strong scientific basis for any decisionmaking being done at the local level or any policy that's developed in, for example, building codes and standards.

Chairwoman SHERRILL. Well, thank you all so much.

I now recognize Mr. Norman for 5 minutes.

Mr. NORMAN. Thank you, Chairwoman Sherrill.

Mr. Reeve, in your written statement you described some of the characteristics in composite materials and provide examples of resilience-based composite installations that have been used and are currently being deployed. Could you elaborate on what specific properties make composite materials a viable option for incorporating these into our infrastructure?

Mr. REEVE. The—there's a number of applications and uses depending on what is the need. The first thing with the composite materials is the corrosion resistance, you know, saltwater, chemicals, de-icing compounds, even most acids do not affect the materials. So—and no matter what happens in that environment, that material is going to maintain its high strength.

The other thing is there's a lot we can do in terms of design flexibility and lighter weight. So where the light weight comes into play is, again, in the installation side, minimizing the traffic—the disruption on traffic and the current infrastructure when they are having to do replacements or upgrades of the materials.

And then the other thing is from an environmental point of view, the material's inert, so there's no chemicals that leach out of it, so there's not like with the treated wood or other things where people

have to make use of it. So those are the big things, again, the materials will be there for 75 to 100 years and maintain their strengths.

Mr. NORMAN. You and I were talking earlier, you know, there's more needs than there is money to go around when you talk about this, so in your opinion what are the major barriers to actually getting the adoption and deployment of composite solutions particularly as it relates to incorporating them into the transportation infrastructure?

Mr. REEVE. Again, in tying a little bit to that awareness and education side, one of the things that's worked in the past and we see as a big help in the future would be some demonstration projects with innovative materials, composite materials and other new materials that are out there because a lot of times when the engineers are having to make a decision and they're—of what materials they use and they have public safety in mind, they rely on what's been done previously. And so when there's the case studies out there of using a new material on this type of bridge or this type of sea wall, then they can look at that and say, OK, that works, I'm confident, I'm much more comfortable using that and deploying it because, again, they only have so much time and resources for making those decisions. So having those cases out there from some of those innovative projects for demonstration and view will help the most.

Mr. NORMAN. Thank you. Mr. Averill, can you elaborate on the work at NIST and what it's doing to facilitate and accelerate the deployment of composite materials? As an example, how has NIST and the composite industry collaborated in the past, and has this collaboration been fruitful? And have you got plans to put this to work in the future?

Mr. AVERILL. Sure. The most recent and specific example is where we partnered with the ACMA to do a roadmap that looked forward to what are the issues and barriers that might be present for use of composite materials, particularly for infrastructure applications. I came up with three main areas. One was looking at doing durability assessment and test data. The second was making that data available to researchers and to end-users, and the third was a piece on education and training. That roadmap is published and available on the NIST website so that the community can use that moving forward.

We at NIST are looking at the various performance characteristics of lots of different materials. Most materials have various strengths and weaknesses. We want to ensure that we are able to characterize the performance of various materials so that we can make an informed science-based decision at the end-user level.

Mr. NORMAN. Well, and I just urge you, what we hear at the local and State level are a lot of the decisions are made at the local level, and they're set in their ways with using a particular type of product that they've used just because they used it for years and the salesmen are good salesmen. So I would ask you to stay involved on a local level and ask questions like what tests do you need that I can do to help you make a decision.

Thank you so much.

Chairwoman SHERRILL. Thank you. And now the Chair recognizes Congresswoman Bonamici for 5 minutes.

Ms. BONAMICI. Thank you, Chair Sherrill and Ranking Member Norman, and to all of our witnesses today.

According to the Fourth National Climate Assessment, if we don't address our aging and deteriorating infrastructure by 2025, we're talking about $3.9 trillion. We already have more than 60,000 miles of U.S. roads and bridges that are experiencing problems from extreme storms and hurricanes. And I was thinking about this hearing today as I was watching the national weather news.

Most of today's infrastructure and building standards don't take into account future climate trends. Current levels of infrastructure investment are not enough to cover even the needed repairs and replacement now, so clearly, we have more work to do in our communities to prepare for and respond to the effects of the climate crisis.

And I do want to note that the Department of Transportation was one of the 13 Federal agencies that contributed to the National Climate Assessment, so I'm disappointed that they were, according to what I understand from the Committee, not willing to cooperate today with this hearing. This Committee does have jurisdiction over the Federal research enterprise, so it's concerning that the Department of Transportation is not represented for this discussion today.

Ms. DesRoches, I'm concerned about a lack of coordination among Federal agencies and the exclusion of localities in deciding where to direct future scientific research efforts on the effects of climate change on infrastructure, and I'm working on a bill to help provide States and local governments with science and best practices to prepare for and respond to the climate crisis. And so I want to ask you, if a city wants to access Federal climate data to help support their transportation resilience planning but like New York, they don't have an independent panel on climate change, is it obvious where to look, and how can Congress help make sure that this research is accessible and formatted in a way that cities and States can actually use it effectively?

Ms. DESROCHES. You know, I think that NOAA (National Oceanic and Atmospheric Administration) does an excellent job of providing climate data. I would say that your point is well-taken. Localities need to be using forward-looking climate data if we're going to address the issues that you raised. So the most important thing is that the data is readily accessible and it's at least a regional level. Even our local data in New York City is good for about 100 miles around New York City, so it can be down-sampled to a regional level. And then that information does need to be made more accessible at the local level so that all of the things that we're talking about today where, you know, engineers are doing the—you know, what they've known at the local level for so long can be utilizing forward-looking climate data, which will in fact change the design strategies that we're implementing.

Ms. BONAMICI. Any suggestions on how we can best do that?

Ms. DESROCHES. So in New York City we've published climate resiliency design guidelines that lay out a step-by-step process for the design and engineering industry in order to take that climate data and apply it to the built environment. This is a really important tool. I think we could use that tool at a Federal level so that

codes and standards actually get up to speed in terms of what we're looking forward to, not what we are seeing from behind.

Ms. BONAMICI. Thank you. Mr. Winfree, in my home State of Oregon the Transportation Research and Education Center, TREC, is leading research on the integration of transportation and land-use electric vehicles, resiliency of engineered structures, and transit service. It's a collaboration—the University Transportation Center—a collaboration of several regional schools, including Portland State University, the University of Oregon, and the Oregon Institute of Technology. So are these types of UTCs equipped to address the multidisciplinary research recommendations you outlined in your testimony? And how can the regional model of UTCs help define climate resilience for transportation systems across the country?

Mr. WINFREE. I think it's important to keep in mind how the competitions since the *Moving Ahead for Progress in the 21st Century (MAP-21) Act* have required the UTCs to be formulated so they're under a consortia model. So I think that's really at the root of what we're talking about. The region—region 10 I believe it is—is a consortia of those universities that you've identified, so it's not specifically for the region. I believe all of the 35 granted centers utilize the consortia model. So I am a huge fan and proponent for that. That was a change we made when I was Assistant Secretary, and I believe it's a change that you will hear is universally well-regarded in the research community.

So I would say step one is, as reauthorization is under consideration, when you're looking at potentially refunding and hopefully funding at even greater levels the UTC program, that the consortia model remain a factor in that, as well as to keep the—to keep it a competitive process as well.

Earlier, the UTCs were more legislative, you know, earmarks to use a pejorative term——

Ms. BONAMICI. Right.

Mr. WINFREE [continuing]. But what that had done in those instances were those centers were more aligned with the legislative priorities than U.S. DOT. So ensuring that DOT gets what it needs from the research community works best when it's a competitive model where the U.S. DOT is able to set forth what they're looking for from the research outcomes. And all of the centers work——

Chairwoman SHERRILL. OK. I think we're going to have to——

Ms. BONAMICI. That's——

Chairwoman SHERRILL [continuing]. Leave it at that. We're over time——

Mr. WINFREE. Yes, that's——

Ms. BONAMICI. Over time, but that's very helpful. I yield back.

Chairwoman SHERRILL. Thank you.

Ms. BONAMICI. Thank you, Madam Chair.

Chairwoman SHERRILL. And next, the Chair recognizes Mr. Waltz for 5 minutes.

Mr. WALTZ. Thank you, Madam Chairwoman.

So hurricane season is on us. I represent the 6th District of Florida. It's on us again starting June 1, and we already have a subtropical storm Andrea out in the Atlantic, so here we go again.

You know, in my area representing Daytona Beach, sea levels are expected to rise by 5 inches just in the next 15 years. I have nearly 70 miles between Volusia, Flagler, and St. Johns counties that are at risk and continue to be at risk by a series of storms. So, number one, I want to commend Governor DeSantis, my predecessor in this seat, for making the environment and resiliency a priority in his new administration. He has recently named a Chief Science Officer and plans to name a Chief Resiliency Officer for the State of Florida, and I want to give him due credit for that. I myself have joined the National Flood Coalition. So I think we are changing the nature of actually what we're doing on this side of the aisle to get things done.

But, you know, in my State and certainly in my area, you know, this flooding issue isn't just homes. It's roads, it's evacuation routes. It's a military issue according to recently released DOD (Department of Defense) reports. So we truly need to take this on and get serious about it. And I'm certainly serious about it, and I know the Governor is serious about it.

So the first question for you, Mr. Averill, given your research and based on your knowledge at NIST of the available technology to map flooding and sea-level rise and the materials available to build transportation infrastructure, specifically what types of technologies should we be using?

And I understand, Mr. Reeve, your point that you made repeatedly, that this is really an education process. I'd be interested in your thoughts as well as specifics of what this Committee can do, what we can do from a Federal standpoint or encouraging our State colleagues to get that word out to our various builders and folks setting the codes at a local level.

But what types of technology and materials should these vulnerable areas be using? And really, I think the white elephant in the room is planning going forward, should we be putting infrastructure in these flood-prone areas? But presuming that we continue to, give me some specifics on what we should use.

Mr. AVERILL. Thank you. So at NIST we've worked a lot with communities because we recognize that at the end of the day decisionmaking for our built environment occurs at the local level. And so at NIST we've done a number of activities to support that decisionmaking, principally, our Community Resilience Planning Guide provides a structure for resilience planning and ensuring that it's got stakeholder input and that it's incorporating some of the other plans that communities do.

We also do a lot of research, as I mentioned previously and discussed in my testimony——

Mr. WALTZ. Just not to interrupt you, do you find that that guide is actively being used? Is there a high level of awareness at the local level?

Mr. AVERILL. We certainly are publishing it as broadly as we can. We are presenting it at conferences where people we think need to hear that, and we have a specific stakeholder outreach strategy to try to get that as broadly taken up as possible. We're also coordinating with other Federal agencies, for example, coordinating with RRAP (Regional Resiliency Assessment Program) to try to——

Mr. WALTZ. Just in the interest of time, do you have any metrics on it actually being used rather, I understand you're pushing it out, right, but do you have any metrics on local communities actually adopting what you're recommending?

Mr. AVERILL. We have four or five communities that we're currently actively working with in partnership, and then we hear from——

Mr. WALTZ. Was that four to five?

Mr. AVERILL. Yes, four to five that we're doing specific projects——

Mr. WALTZ. OK.

Mr. AVERILL [continuing]. Side-by-side with, and then we periodically——

Mr. WALTZ. How do we broaden that? How do we make that more than four to five?

Mr. AVERILL. Well, I think we need to continue to make the information available, and we're ready to work as opportunities arise.

Mr. WALTZ. Mr. Reeve, I think I'm out of time, but, Mr. Reeve, any comment from the private sector?

Mr. REEVE. One comment on that where you tied on making some of that happen is the fact that when there is Federal funding that is part of the local project administrations, the LPA programs and other ones that are there is that you push down and say one of the requirements is that they reference and they take a look at the documents that are out there.

Mr. WALTZ. You're saying that's currently in place or needs to be in place?

Mr. REEVE. That's—it needs to be in place. You know, there are certain things that get pushed down when Federal funding is involved, but if there are other ones in there, like I said, if you're looking at it from a point of view, looking at the resiliency side, then those are some of the ones, if it's not getting out there, that's at least a way in which you can——

Mr. WALTZ. Thank you.

Mr. REEVE [continuing]. You could push it on them.

Mr. WALTZ. Thank you, Madam Chairwoman.

Chairwoman SHERRILL. Thank you. Hopefully, we can get back to some of these lines of questioning, but I do want to get everyone in with questions, so now the Chair recognizes Ms. Wexton for 5 minutes.

Ms. WEXTON. Thank you very much, and thank you to the witnesses for being here today. And I'm glad that Madam Chair mentioned continuity of questions because the gentlelady from Oregon brought up the UTC in her State, and my home State of Virginia, George Mason University, which is in Fairfax, is part of an excellent UTC, the Center for Integrated Asset Management for Multimodal Transportation Infrastructure Systems, which is a mouthful.

And how various transportation assets integrate with one another as a part of the whole national network is really at the heart of the matter, I think, when we talk about climate resilience because we can't ensure that a community will tolerate climate impacts well if we address the roads but not the subway or other transit assets.

And so, Mr. Winfree, given your experience at the Federal level and with the Transportation Institute, do you think that the various modes are coordinated well enough within DOT when it comes to the issue of climate resilience?

Mr. WINFREE. Certainly in my experience when I was there, the focus was on state of good repair, roads and bridges and crumbling infrastructure. Climate change, extreme weather was discussed, but the leadership was through Department of Energy and EPA. I can't exactly describe what the thinking is at DOT as we sit here today, but I would certainly—I think it's fair to say that there could be better coordination led by the Secretary's office to make it more of a universal issue for the Department.

Ms. WEXTON. So would you say that, historically, it's been more of a damage control looking back and just fixing the damage that's already been done rather than prospectively trying to make sure that our assets are safe for the future?

Mr. WINFREE. Absolutely. And I think that's still the case from the approach other than New York City and other municipalities, from the Federal level a lot of the focus is on recovery, disaster recovery, getting systems back up as quickly as possible and not enough research into how do you harden assets, how do you prepare for the inclement weather events that we know are coming. That's still lagging.

Ms. WEXTON. And related to that, also in my State of Virginia we're seeing more flooding, recurrent flooding—increased, frequent high precipitation in a short amount of time. And I know we're not alone in this. And we are also at risk for sea-level rise and really vulnerable in that regard. But we're seeing it across the Commonwealth, and I would imagine other folks are as well.

Ms. DesRoches, how might insufficient stormwater management systems accentuate the risk to road systems and other transportation assets in cases of increased precipitation and sea-level rise? How do those infrastructure commitments integrate with one another?

Ms. DESROCHES. So it's a complex system in that both of those tend to be, at least on East Coast, historical systems where they're legacy systems. They were designed, you know, for what we saw in the past. And yes, when we have more increased precipitation with sea-level rise that the coastal areas are being inundated by both types of risks. I think that integrated planning between stormwater and roadways and our transportation infrastructure could be stronger and needs to be stronger. We're working hard on that in New York City and are always happy to share best practices.

But first, we need to understand better how those systems are affecting each other, and those studies need to be done first in order to figure out how the drainage system and the roadway network can actually increase resiliency. Can we make upland areas more absorbent to try to hold back some of that precipitation through green infrastructure and other measures? How do we think about not just the roadway but the land use around the roadways and our transportation network in order to be able to withstand more of those increased precipitation and the sea-level that you talked about.

Ms. WEXTON. Thank you very much. Do any of the other witnesses have any thoughts on that issue?

Mr. REEVE. My only other comment would be somebody had mentioned on the economic side, I think that's important in the decisionmaking as you look at what's the economic impact on this part of the infrastructure versus another one when making those decisions. So, you know, again, and limited resources put that preventive measures on the ones that are, again, the most critical.

Ms. WEXTON. Thank you very much. And I see my time is up, so I yield back.

Chairwoman SHERRILL. Thank you. And the Chair recognizes Mr. Casten for 5 minutes.

Mr. CASTEN. Thank you, Chair and Ranking Member Norman, for giving me the opportunity to waive onto this Subcommittee today. This is critically important stuff, and I know I always tell people that the problem with our little tiny human brains is that we really have a hard time with nonlinear trends and, you know, the climate is not only changing but the rate of change is accelerating. We know this intuitively because these 1,500-year floods seem to happen every year now, especially in coastal areas, and yet we still have zoning rules based on those historic pieces of data where we celebrate, you know, people who project linear trends when in fact everything is accelerating. To me, that strikes me as a problem because we build our infrastructure on the assumption that history is a predictor of the future, and in fact it's not.

And the private sector has in many cases started to figure that out, and in 2017 Argonne National Labs that's located just south of my district in Illinois partnered with AT&T to produce a "Road to Climate Resiliency" white paper that detailed the results of a project that they did that used three climate models, 30 years of history, and months of time on Argonne supercomputers layered over where AT&T's physical assets were to figure out a long-term climate resiliency map.

Madam Chair, I'd like to ask unanimous consent to enter into the record the white paper entitled, "The Road to Climate Resiliency" on the joint study conducted by Argonne and AT&T.

Chairwoman SHERRILL. Without objection.

Mr. CASTEN. Mr. Winfree, given what the private sector is already doing, do you agree that the Department of Transportation should make an effort to incorporate similar Federal climate models into their planning and prioritization activities as much as possible?

Mr. WINFREE. I don't think there's—you can't—you won't solve the issue by not looking at every available resource, and I believe every scientific study, every peer-reviewed work that is done in this space should be on the table. We know from a resource perspective that DOT, the Federal Government writ large can't answer every question in every instance, so the more information on the table, the better I think is the proper approach, particularly, as you pointed out, since these issues are not linear. We need to look at them from every angle and try and come to some common approaches and some common understanding as to how best to address it.

Mr. CASTEN. Are you aware that DOT is doing anything like what Argonne and AT&T have done of this level of model analysis as they think about where they're going to build and how they're going to build?

Mr. WINFREE. That is not an area of research that I'm familiar with. Like I said a bit earlier, my understanding was EPA, Energy, and other departments and agencies were out in front and that DOT was going to be capitalizing upon the results of that research.

Mr. CASTEN. Mr. Averill, what can NIST do to start to incorporate this modeling into their resilience work in a more complete way? Are you guys partnering with the national labs? Can you work some of this into your standards that you're using for building codes?

Mr. AVERILL. Well, at NIST we are a nonregulatory agency, so what we do vis-a-vis standards and building codes in particular is we take the results of our research and we participate in those consensus processes, but those are run through, for example, the International Code Council or various standards, organizations as separate nongovernmental entities. So we are certainly interested in making sure that our research is answering the questions that we know that the end-users have and that would be most useful for addressing the issues you raised.

Mr. CASTEN. So a question then for all of you or all of you or any of you, how do you define success in resiliency? I mean, I get that these are consensus processes, but if we're going to sit there and say a community is going to be resilient or a standard is going to be designed for resilience, what's the metric you design for?

Ms. DESROCHES. OK. I'll take that. So in New York City the way that we are looking to the built environment is to say this is how long the useful life of that asset will be, and when we design and engineer that asset, we use climate change data in order to build that asset to last the whole length of its useful life. So we're utilizing the existing climate models and basically saying, OK, at 2050 sea-level rise will be roughly here. We will build that asset to that height.

So while, you know, we—you can't totally predict, there is uncertainty in those climate projections. We can't totally predict exactly to the inch how high sea-level rise will be in 2050. We have a good range, and we understand where that trajectory is going, and we feel strongly that we need to be incorporating that data today in order to ensure that asset lasts as long as it can.

Mr. CASTEN. I think I'm of time, so I will yield back. Thank you.

Chairwoman SHERRILL. Thank you. The Chair now yields to Mr. McAdams for 5 minutes.

Mr. MCADAMS. Thank you, Chair Sherrill and Ranking Member Norman. We thank you for holding this very important hearing and helping us to talk about some of the impacts of climate change and climate resiliency.

And I represent Utah, and so in the Salt Lake and Utah valleys we're feeling the effects of climate change in several different ways. Most obvious is the pollution that hangs over the valley floor, especially in the winter, causing a litany of health impacts. Utah is one of the fastest-growing States in the country right now, and in par-

ticular the Wasatch Front that I represent is experiencing the bulk of that growth.

With more people comes more cars on the road, more passengers in our trains, and more flights coming in and out of our Salt Lake International Airport. It also means more pollution and wear and tear on our infrastructure. So while the Utah Department of Transportation and other organizations like the Utah Transit Authority, our MPO (Metropolitan Planning Organization), and Wasatch Front Regional Council and Mountainland MPO, I think they're rising to the challenge of addressing this growth. The problem becomes significantly harder when we also factor in climate change, intense fluctuations in heat, more intense weather patterns, et cetera. Given the elevation of my district, I don't think the sea-level rise is going to be an impact to our transportation infrastructure per se.

But, you know, one of the things that Utah has done really well, we were one of the first areas in the country to adopt what we call the Wasatch Choice for 2050, a unified transportation plan that incorporates our transit authority, our local government, State government, our DOT in a unified transportation plan. And it looks at our growth projections through the year 2050 and what infrastructure investments we're going to need to accommodate that growth, both maintenance and then new capacity on our roads.

I guess my first question for the panel is, with extreme weather—and I'm thinking in particular in a cold area that I represent, the freeze-thaw cycles, and we look at the impact and the life of an asset. And, you know, I think when we looked at this we have a number of what we need for transportation infrastructure investment, and clearly there's not enough funding. We're funding what we can, but we don't have enough to fund that infrastructure that we need, and so you know, we need the transportation funding at the Federal level. But I'm wondering if we also need to evaluate the life of our assets with climate change and if the life of our assets may not be as long as projected with the increased freeze-thaw cycles. And can you help me to quantify that impact?

Mr. WINFREE. Well, certainly at TTI, you know, we're one of the lead institutes that look at pavement materials whether they're cementitious, whether they're asphalt, so there's no substitute for testing and analysis at the front end in all weather and climate conditions.

Now, I know Carlos Braceras, your Executive Director, he's keenly aware of that and is a partner with AASHTO (American Association of State Highway and Transportation Officials) and with NCHRP (National Cooperative Highway Research Program) in that regard, but the testing and analysis in all climate conditions, there's just no replacement for that. And there are several UTCs that focus on cold-weather climate impacts for, again, asset, you know, installation, as well as asset performance. So writ large, performance measures are needed across the board.

Mr. MCADAMS. What can we do at the Federal level specifically with the Department of Transportation to support our State agencies in developing climate-resilient infrastructure plans, recognizing that they will differ from region to region then?

Mr. WINFREE. There are a lot of resources that are out there now. Better publication and coalescing them into a form and fashion that can be used by the practitioner has always been the challenge. I'm aware of the Volpe National Transportation Systems Center having amassed resources, but I don't know about the publication of that end report. So again, the work is out there, the research is out there, but getting it in the form and fashion that's easy and accessible for the practitioner is the challenge.

Mr. MCADAMS. You know, I think as we are looking at investing in maintaining our transportation infrastructure and how expensive that is and knowing that every tax dollar is precious and important and competing with other priorities, for me, the importance of planning ahead, understanding the impacts of climate change, and then investing in climate resilience will make sure that we use those tax dollars efficiently and as effectively as possible, and then also to improve and maintain the quality of life whether it's reducing the wear-and-tear on the road or the capacity of our transportation systems to handle the growing population that we serve effectively.

So thank you, and I yield back.

Chairwoman SHERRILL. Thank you. And now the Chair will recognize myself for another round of questions for 5 minutes.

Just to kind of give an overview of what I'm hearing, we have a lot of programs going on. We have the programs going on in the New York City area, what I like to call the suburbs of north Jersey. We have the work going on at many of our university transportation centers like at Texas A&M, and I know we have it at Rutgers. We've heard from different Members today about those centers. We have NIST doing research into composite materials. What we don't seem to have is a real understanding of how, if you are a small to medium-sized city or municipality and want to go do some infrastructure work, how you would engage with all this research or all of these new composite materials? And it makes sense what Mr. Norman is saying that generally what you probably do is just use the same contractor you've always used with the same materials that you've always used and probably getting the same results that you've always gotten.

So I think I would—you know, to the extent that we have you here today, Ms. DesRoches, when you're looking at planning throughout the greater metropolitan area, what engagement did you have with NIST, what engagement did you have looking at cost—or does the region have looking at new composite materials or is it just a factor that the city is large enough to really conduct its own research and develop its own tools for use? Or do you interact with these university research centers or NIST or any of our private people who are working in this area?

Ms. DESROCHES. Sure. Well, certainly, we do interact with a number of Federal agencies. You know, I would say I was a partner on the community resiliency planning guide when it rolled out to different sectors when we were working on guidance for transportation specifically. TRB, Transportation Research Board, is another place that has been doing some great research. They set up a resiliency section, which is the first new section they've set up in I think over 10 years. And that's really the—and I'm on that section.

That's really meant to organize all that research that TRB does across many different committees with a resiliency lens.

So, you know, I think that no locality can do this on their own. We do need the research from the institutions that we've been discussing today. I do think, however, that some of the standards-setting industry groups that's a consensus process is not moving fast enough in order to incorporate this future-looking climate data. I think that it takes a long time for those standards boards to set new standards, to modify standards, and all of these standards still use historical weather data. And I think until we change that, the localities will not have enough resources to be able to change how they design, but if the standard changes and the standard says you need to be designing for extreme heat, then that will change the design outcome.

So I think that we both need these resources that we've been talking about in the research, but we also need that research to be plugged into the standard sooner and that there's a level of urgency there that needs to be sped up.

Chairwoman SHERRILL. And I sit on the Armed Services and come from somewhat of a DOD background, and in that department there's always a lead agency, whether it's the Navy or the Army or the CIA or Homeland Security. In this space, in this resiliency space we've heard that the EPA had a hand in it, we've heard of DOT, but when we're talking infrastructure resiliency, who are we looking to to be the lead agency in this space? And that question is for all of you.

Mr. WINFREE. Well, I think that raises challenges. The term infrastructure is extraordinarily broad. If you're talking transportation, then certainly I think DOT should be at the lead, but one of the things I was considering on the way here are the interdependencies between really asset owners, right? So particularly in New York, New Jersey, whenever there's a watermain break, it impacts the road network. Well, the water company or the water transmission folks don't necessarily work hand-in-glove with streets and maintenance or with the highway department. So getting across those—really lack of communication from agency to agency, from department to department is hugely important to make sure everybody's at the table. So, you know, again, infrastructure is a broad term. We need some discipline as to what falls in those categories so that we can prioritize.

Chairwoman SHERRILL. Thank you. I think what we're struggling with a bit here is many of us have worked on infrastructure projects—I'm sure Mr. Norman has in all your development—in our home districts, and we've seen how, you know, I think we're a little concerned about more regulation because we've seen how some outdated or poorly functioning regulation is really harming. So to the extent we could have—I think what I'm looking for is a group to take the lead and then start to really dig down into how we can streamline the regulations but then make sure we have the regulations that are forward-looking, that are looking into climate change. I do worry about just adding layers of standards and regulations over poorly functioning ones because then we seem to kind of butt heads with what we're trying to accomplish in our districts.

So it sounds like the place to start is with the DOT, who is unfortunately not in attendance today. But thank you.

Mr. Norman, would you have further comments?

Mr. NORMAN. Yes, just one question for each of you. You know, when we have an issue with what we're building, and I go to the ones that are actually doing the work, the contractors, the individual people doing the layers. From where you sit, and it's pretty much back on what Mikie was talking about. From where you sit, what should we be doing in our roles? If you were sitting in Congress now, knowing what you know in your different departments, what should we be doing?

Mr. REEVE. From my side, you know, what we see right now is, most of the infrastructure is just acquisition cost-based, OK? What's—it's low bidder, OK? So a contractor is going to bid—to win the job, he's going to bid with some of the lower-cost materials, which, again, in a lot of cases is the same thing that they've done in the past. And often, you know, if you're looking for, you know, on the procurement side to say you need to consider the resiliency and the lifecycle costs, the longer-term maintenance costs in making that decision, so you pick something that even though it may cost, you know, a premium, 10, 15 percent now, it's saving you in 30 years from doing it over again. And so that's a change somewhat in—just in the procurement practices.

Mr. NORMAN. So you would recommend I do what?

Mr. REEVE. Recommend that in those cases—in the infrastructure side say that you need to consider, OK, a life-timeframe of 30 years, 50 years, 75 years when you're making the choices of what is the lowest—you know, lowest-cost solution and that it's not just today's cost, it's what's this going to cost you in the future. And part of that future cost is making sure you account for what's going to be those future weather events.

Mr. NORMAN. So advocacy, is that right? OK. Mr. Averill or Mr. Winfree?

Mr. AVERILL. I agree with my colleague here. The Economic Decision Guide is a formal framework for accounting for economically decisions that might include lifecycle analysis. We've been discussing with communities this notion of a resilience dividend, so it's the idea that you might be designing for a particular event in mind over a long time horizon, but in doing so, you actually get a day-to-day benefit that's guaranteed that you don't have to condition on the probability of the event that might be, for example, less maintenance or better resistance to the frequent sort of annual events that you're going to see. So using a more formal and lifecycle-type cost analysis would be helpful.

Mr. WINFREE. And I would certainly follow on Mr. Reeve's point. I think the flip side of what he was talking about is lessening the fear of taking risks. Contractors by definition take the conservative view because they don't want to get sued, they don't want to have a bad outcome, they don't want to get blamed for something going wrong that could have been innovative. So it prevents a closer nexus between the research community and the contract community that does the work because they are risk-averse. So if there is any kind of measure that provides guarantees on the backend or lessens the risk for the contractor community I think is a benefit.

Ms. DESROCHES. And I'll just add briefly that, you know, as I was talking about in my testimony, if we ask questions about resiliency as they relate to funding, you will get more creative answers, and that's another way to raise everyone's awareness. So if I'm asking for this amount of Federal funding for a bridge, if the question comes back how is that bridge resilient to extreme rain events that we expect in that area, you will get a different answer than what the standard built practice is today.

Mr. NORMAN. Thank you so much. You all have and very informative, and I have no further questions.

Chairwoman SHERRILL. Thank you, Mr. Norman.

I'm about to go to my colleague Mr. Beyer, but I do have one quick question for all of you since you're sitting here that occurred to me. To your knowledge, has there been any work done when looking at the plans for the Gateway tunnel project on new, more resilient materials, composite materials?

Ms. DESROCHES. I'm not aware. I don't have that information with me, and so it's outside of my area of expertise, the specific tunnel design.

Mr. REEVE. You know, I personally don't know, but I will—you know, through the association, will see if any of the other, you know, suppliers out there have been approached.

Chairwoman SHERRILL. Thank you. Did you have something, Mr. Winfree?

Mr. WINFREE. Yes, I was just going to say that I do know that lessons learned from the tunnel failure are being utilized in the forward planning, right, so some of the things that were discovered were the solid-state machinery down there failed where some of the 100-year-old tube equipment survived the water, right? So there are lessons learned that are being thought-forward about how to install the Gateway operation.

Chairwoman SHERRILL. Thank you very much.

I now recognize Mr. Beyer for 5 minutes.

Mr. BEYER. Madam Chair, thank you very much. And I'm sorry I missed most of the hearing. We were struggling with trade policy in Ways and Means, something unimportant compared to this, but thank you for being here.

And I think this is such an incredibly important hearing. Thank you for doing this.

I represent Virginia, northern Virginia, but we have Norfolk, Portsmouth, and Virginia Beach, which is not only sinking slowly but the water's rising most rapidly there I guess than anywhere along the East Coast. It seems like 14 inches in the last 20 years. And I think Northrop Grumman that did the charts suggested that Norfolk and Portsmouth will be underwater something like 60 percent of the year, their downtowns by 2040.

And then we have a little Sears home in Oxford, Maryland, and it's always encouraging to look at the LIDAR numbers and see if sea-level rise is just 1 foot in the Chesapeake Bay, how much of the village is underwater and how do you get there for the places that aren't?

Ms. DesRoches, this may be best for you coming from New York City, which is—I mean, I'm sure you've seen the pictures of what's going to happen to Manhattan. I live in Alexandria across the river

just south of the airport, and the last big storm we had, the storm surge came and flooded scores and scores of homes, and so one of the lingering infrastructure resilience problems is, do we build a wall around the neighborhood or do we build a berm in the middle of the G.W. Parkway or do we continue to expand the wetlands to provide resilience, or the most popular idea is, do we build a submersible surge wall in the Potomac River downstream about 5 miles, and when the surge comes, the wall comes up and holds the surge back. This is the $5 billion option.

Where is your engineering New York City background taking you on trying to protect all these low-lying cities?

Ms. DESROCHES. So great question, very complicated. So we are looking at all options. We are looking at new planning tools first and foremost. FEMA—we are collaborating with FEMA on a forward-looking flood map, which will incorporate climate change data, which will help inform residents, businesses, and the city as to what the future floodplain looks like. We are building coastal protection in some of our neighborhoods. We are cooperating with the Corps on a storm surge barrier study. We're supporting that study.

So my main answer is there isn't one silver bullet. We have to look at this across all of the tools we have, also including building codes, which we've talked some about today. How can we enhance that so that we are looking systematically about protection but also how do we enhance the resiliency of the assets that we have today?

Mr. BEYER. Great. Thank you very much. I know it's incredibly complicated, sort of living it with the constituents every day.

Mr. Reeve, you talked about the ability of composite materials to withstand saltwater. Is there a different scientific or engineering approach depending on the salinity of the water?

Mr. REEVE. No, it—the materials that we use in there, you know, work with any of the different types of salinities, again, even up to the acidic side so whether it's brackish or anything. You know, those materials will do fine.

I will say we supply a Navy berthing—we supply berthing structures for the Navy submarines and the aircraft carriers and do that at—for a lot of bases across the United States. I will say the ones—the equipment in Norfolk station gets beat up the most.

Mr. BEYER. Yes.

Mr. REEVE. It has the roughest time with where you're located so——

Mr. BEYER. Yes. Thank you very much. Mr. Averill. On the materials requirements for resilient roads, bridges, transportation assets, are they different in coastal communities versus inland communities or are the materials requirements basically the same?

Mr. AVERILL. Certainly to the extent that we would see saltwater exposure, that would increase the chlorides, if you're in a northern climate, for example, and you look at the de-icing compounds that would be used up there versus maybe a more southern climate where we don't need to treat for that. So our research tries to work with the standards community to come up with performance requirements for materials for a variety of different hazards that might represent what materials across the United States would be exposed to.

Mr. BEYER. All right. Great. Thank you all very much.

Madam Chair, I yield back.

Chairwoman SHERRILL. Thank you. Mr. Norman, do you have anything further?

Mr. NORMAN. No.

Chairwoman SHERRILL. Before we bring the hearing to a close, I want to thank our witnesses for testifying before the Committee today. The record will remain open for 2 weeks for additional statements from the Members and for any additional questions the Committee may ask of the witnesses.

The witnesses are excused, and the hearing is now adjourned. Thank you.

[Whereupon, at 11:28 a.m., the Subcommittee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Jason Averill

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY SUBCOMMITTEE ON INVESTIGATIONS & OVERSIGHT

"The Need for Resilience: Preparing America's Transportation Infrastructure for Climate Change"

Questions for the Record to:
Mr. Jason D. Averill
Chief of the Materials and Structural Systems Division Engineering Laboratory
National Institute of Standards and Technology

Congressman Michael Waltz (R-FL)

1. **Mr. Averill-** During our exchange, you mentioned that NIST is working with 4 or 5 communities on utilization of the Community Resilience Planning Guide for Buildings and Infrastructure Systems (Guide). Can you please provide a list of these communities to the Committee?

NIST Response:

NIST has worked diligently with communities to utilize the Community Resilience Planning Guide for Buildings and Infrastructure Systems (Guide). Exemplary "Success Stories" can be viewed on the NIST website:

- Fort Collins, CO. More information can be found at https://www.nist.gov/sites/default/files/documents/2019/03/08/fort_collins_021319.pdf.
- Nashua, NH. More information can be found at https://www.nist.gov/sites/default/files/documents/2019/03/08/nashua_02132019.pdf.
- The Boulder County Collaborative (Colorado). More information can be found at https://www.nist.gov/sites/default/files/documents/2019/03/08/boulder_county_collaborative_co_020419.pdf.

NIST also has worked closely with Bozeman, MT, as the city sought to "establish local resilience initiatives to prepare for the effects of climate change and other hazards."[1] The contributions of NIST staff members Dr. Therese McAllister and Mr. Stephen Cauffman were acknowledged in the resultant resilience plan.

NIST also is working with the state of New York, in partnership with the Department of Homeland Security's Federal Emergency Management Agency and Coastal Resilience Center of Excellence, to standardize resilience planning at the county level. The NIST Guide is expected to be a part of the resultant process.

Finally, NIST also has consulted less formally with several communities and organizations (California Office of Emergency Management, for example) who have downloaded the Guide from the NIST website and subsequently had questions about local implementation.

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[1] Climate Vulnerability Assessment & Resilience Strategy, April 2019
https://www.bozeman.net/home/showdocument?id=8958

2. **Mr. Averill-** How can NIST better notify coastal communities that the Guide is available and inform all communities about the advantages of its recommendations?

NIST Response:
NIST has worked diligently since the 2015 release of the Community Resilience Planning Guide for Buildings and Infrastructure Systems (Guide) to create broad awareness amongst U.S. communities, including coastal communities.

First and foremost, the guide is available for download free of charge from the NIST website (https://www.nist.gov/topics/community-resilience/planning-guide). The online presence is supplemented by several additional publications intended to aid Guide usage:

- A four-page brochure to make the scope and purpose of the Guide clear to (potential) stakeholders. For more information, please see https://www.nist.gov/sites/default/files/documents/2016/09/07/brochure_final_print_rightside_up.pdf.
- A more detailed 12-page pamphlet that provides an overview of the Guide process. For more information, see https://www.nist.gov/sites/default/files/documents/2019/04/03/nist_community_resilience_12_page_brochure.pdf
- Spanish language versions of the Guide (both volume 1 and volume 2) to assist disaster recovery planning in coastal communities.
    - Volume 1: https://www.nist.gov/sites/default/files/documents/2019/03/22/nist_crpg_volume_1_spanish.pdf
    - Volume 2: https://www.nist.gov/sites/default/files/documents/2019/03/22/nist_crpg_volume_2_spanish.pdf
- A *Frequently Asked Questions* site to address common questions NIST has received (https://www.nist.gov/sites/default/files/documents/2017/03/28/faqs-for-the-nist-cr-planning-guide-draft-10-27-15-final-for-posting.pdf).

In addition, NIST has met with national stakeholder groups whose members commonly participate in resilience planning activities to communicate the existence and benefits of the Guide, including, but not limited to:

- American Planning Association
- International City/County Management Association
- National Association of Counties
- National Association of Development Organizations
- National League of Cities
- National Association of Regional Councils

Appendix II

Additional Material for the Record

STATEMENTS SUBMITTED BY REPRESENTATIVE MIKIE SHERRILL

Testimony of Dr. Kristina Dahl, Senior Climate Scientist

Union of Concerned Scientists

"The Need for Resilience: Preparing American's Transportation Infrastructure for Climate Change"

House Science, Space and Technology Committee

Subcommittee on Investigations and Oversight

May 21, 2019

Introduction

I am a senior climate scientist at the Union of Concerned Scientists. I appreciate the opportunity to provide testimony as you examine the intersection of climate change and transportation infrastructure, as my research has shown that road and rail systems along our coasts are at risk of chronic high tide flooding in the coming decades as sea level rises.

Climate Impacts on Infrastructure

Our nation's infrastructure is already in a precarious state, consistently earning a near-failing grade of D-plus from the American Society of Civil Engineers (ASCE)[1]. Much of our infrastructure was built assuming past climate and usage patterns, with some margin of safety, which has led the ASCE to estimate that there is $1.2 trillion gap between our current transportation infrastructure and our actual needs[2].

Now climate change is adding an extra layer of risk.

The impacts of climate change are already upon us—in the form of longer wildfire seasons, stronger storms, worsening droughts, and flooding exacerbated by rising seas and heavy precipitation.

Climate-related extreme events are already exposing vulnerabilities in our infrastructure, and growing development in high-risk areas increases the potential damage. The number of billion-dollar weather and climate-related disasters is on the rise: compared to the long-term average, each of the past three years has produced more than twice the number of billion-dollar disasters in the US[3].

[1] https://www.infrastructurereportcard.org/

[2] American Society of Civil Engineers (ASCE). 2017. 2017 Infrastructure Report Card: A Comprehensive Assessment of America's Infrastructure. American Society of Civil Engineers, Washington, DC, 110 pp

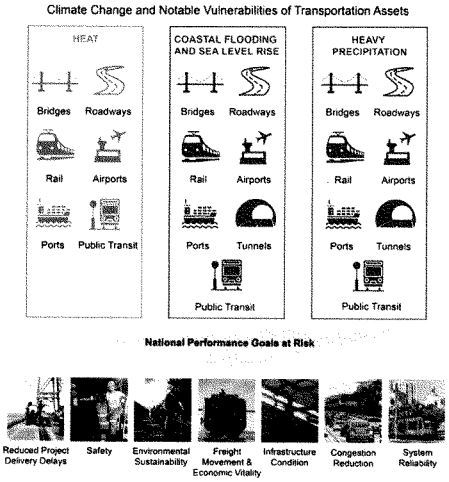
[3] https://www.climate.gov/news-features/blogs/beyond-data/2018s-billion-dollar-disasters-context

As the most recent National Climate Assessment report shows, without strong action to decrease our global warming emissions and adapt to unavoidable impacts, climate change could cost some U.S. economic sectors more than $100 billion annually by late century, surpassing the gross domestic product of many U.S. states[4].

We rely on our roads, rails, and airplanes for safe, reliable transportation, and they serve as a backbone for our country's economy. As our population grows in the coming decades, we will be relying even more heavily on our transportation infrastructure[5]. Infrastructure is typically designed to last 50 to 100 years. New infrastructure projects or improvements must therefore account for future usage increases as well as changes in the environment that could affect reliability or capacity[6].

Climate change is making extreme weather events more frequent and more severe, which amplifies the economic damage we're forced to absorb and imposes a steep toll on people's lives. Future climate change will amplify the risks our vulnerable transportation systems already face[7]. The most recent National Climate Assessment highlighted the many ways in which climate change could impact our transportation assets. In this testimony, I will focus on a few of these impacts.

The transportation sector is also the leading contributor to US heat-trapping emissions, and there are many opportunities to transition to a low-carbon transportation infrastructure while making it more resilient.



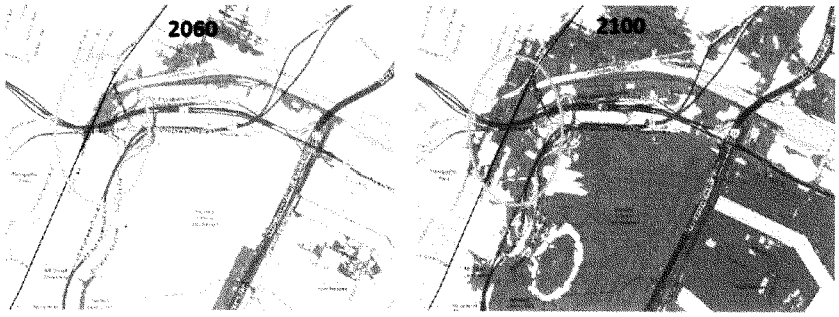
Source: Fourth National Climate Assessment. https://nca2018.globalchange.gov/chapter/12/

[4] https://nca2018.globalchange.gov/
[5] https://nca2018.globalchange.gov/chapter/12/
[6] https://transportation.house.gov/imo/media/doc/Majority%20SSM%20Climate%20Change.pdf
[7] USGCRP 2018

Sea Level Rise and Coastal Transportation Infrastructure

Union of Concerned Scientists (UCS) research shows that by the end of the century, 2.5 million US coastal homes and commercial properties currently worth more than $1 trillion today could be at risk from chronic flooding worsened by sea level rise. UCS developed an interactive map tool that lets you explore the risk sea level rise poses to homes in your congressional district and provides district-specific fact sheets about those risks[8]. No matter where you live along the coast, chances are that rising seas will begin to reshape your community to one degree or another in the coming decades. Communities wanting to be prepared for the changes to come will need representatives in Congress who will advocate for the research, funding, and policies we need to address sea level rise and coastal flooding head-on.

We also used our chronic flooding data to assess the risks of chronic flooding to Amtrak's Northeast corridor route between Boston and Washington, one of the most heavily travelled rail routes in our nation. Our maps were used in a Bloomberg story on this subject, *Rising Waters Are Drowning Amtrak's Northeast Corridor*[9].



Chronic flooding in the vicinity of Newark Liberty Airport in Newark, NJ, in 2060 (left) and 2100 (right). Chronically flooded areas are defined as flooding 26 times per year or more and are shown in orange. The Amtrak rail line, shown in black, cuts through the area exposed to chronic inundation highlighted by the green oval.

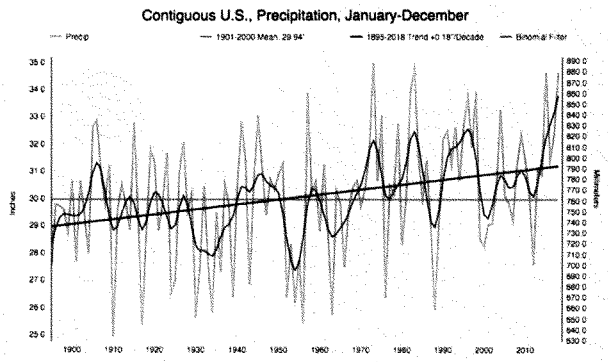
Many parts of the Northeast Corridor rail route are at risk of chronic flooding starting by 2060, including sections near Wilmington, Delaware, and throughout Connecticut, New Jersey, and New York. Current preparation efforts fall far short of these realities.

Impacts of inland flooding on transportation infrastructure

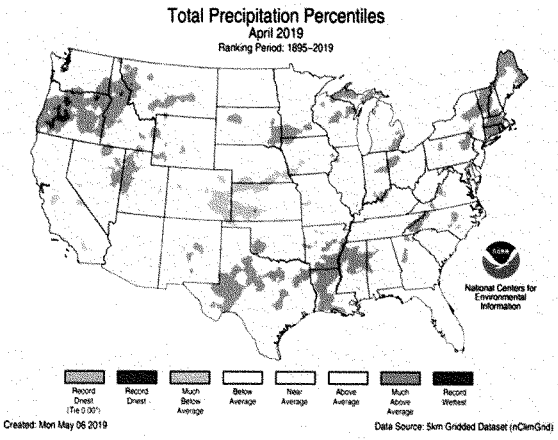
Climate change is changing rainfall patterns, making heavy rain more frequent in many parts of the country[10]. With human alteration of the land—like the engineering of rivers, the destruction of natural

[8] https://arcg.is/1TXHXj
[9] https://www.bloomberg.com/graphics/2018-amtrak-sea-level/
[10] https://www.ucsusa.org/sites/default/files/attach/2018/07/gw-fact-sheet-epif.pdf

protective systems, and increased construction on floodplains—many parts of the United States are at greater risk of experiencing destructive and costly floods[11].



While there is considerable variability from year to year and from decade to decade, total annual precipitation for the contiguous US as a whole has increased since 1900. Source: NOAA[12]



April 2019 capped the wettest 12-months on record for the contiguous US. Above normal precipitation and the subsequent flooding across the central US lead to widespread disruption of transportation by road and rail. Source: NOAA[13]

[11] https://www.doi.org/10.1038/nature26145; https://www.propublica.org/article/boomtown-flood-town-text
[12] https://www.wunderground.com/cat6/Wettest-12-Months-US-History?cm_ven=cat6-widget
[13] https://www.ncdc.noaa.gov/temp-and-precip/us-maps/1/201904#us-maps-select

This spring alone has brought extended flooding to many parts of the country, including Louisiana, Texas, the Midwest, and along the Mississippi and Missouri rivers. NOAA data confirm that (at the end of April 2019) the US has just experienced the wettest 12 months on record.

This record-breaking flooding has washed out roads and bridges in many places, sometimes for days on end, making it difficult for people to travel safely to work and school[14]. In Nebraska alone, the flooding caused an estimated $100 million in damage to the state's highway system[15]. Rail lines in Nebraska and Missouri were shut down for weeks[16]. Businesses that rely on safe and reliable transportation have also been affected[17].

A growing body of evidence has linked specific extreme rainfall events to human-caused climate change. The record-breaking rainfall during Hurricane Harvey, for example, was made about three times more likely because of human-caused climate change[18]. Projections of future climate suggest that the frequency and intensity of extreme precipitation events will continue to increase across much of the United States in the coming decades[19]. Models of our transportation infrastructure suggest that as our climate changes, even small increases in the amount of rain falling during a downpour could cause a "systematic malfunction" of our road network[20].

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[14] https://www.washingtonpost.com/nation/2019/05/10/really-genuinely-scary-torrential-rain-houston-strands-cars-leaves-thousands-without-power/?utm_term=.9612e14621c9
https://kfor.com/2019/05/08/odot-several-highways-closed-due-to-flooding-across-the-state/

https://www.wxyz.com/getting-around-metro-detroit/flooding-across-metro-detroit-closes-several-roads-highways

[15] https://dot.nebraska.gov/news-media/nebraska-flood-2019/
[16] https://www.grainnet.com/article/166508/transportation-impacts-of-midwest-flooding
https://www.freightwaves.com/news/railroad/rail-volumes-drop-for-march-30
[17] https://www.mprnews.org/story/2019/04/21/flooding-roundup-communities-weary

[18] van Oldenborgh, G.J., K. van der Wiel, A. Sebastian, R. Singh, J. Arrighi, F. Otto, K. Haustein, S. Li, G. Vecchi, and H. Cullen. 2017a. Attribution of extreme rainfall from Hurricane Harvey, August 2017. Environmental Research Letters 12(12):1–11. doi:10.1088/1748-9326/aa9ef2.
[19] Easterling, D.R., K.E. Kunkel, J.R. Arnold, T. Knutson, A.N. LeGrande, L.R. Leung, R.S. Vose, D.E. Waliser, and M.F. Wehner. 2017. Precipitation change in the United States. In Climate science special report: Fourth national climate assessment, volume 1, fourth edition, edited by D.J. Wuebbles, D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock. Washington, DC: US Global Change Research Program, 207–230. doi:10.7930/J0H993CC.
Intergovernmental Panel on Climate Change (IPCC). 2012. Summary for policymakers. In Managing the risks of extreme events and disasters to advance climate change adaptation: Summary for policymakers, edited by C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley. Cambridge, UK, 1–19. Online at http://www.ipcc.ch/pdf/special-reports/srex/SREX_FD_SPM_final.pdf
[20] Wang, W., S. Yang, H.E. Stanley, and J. Gao. 2019. Local floods induce large-scale abrupt failures of road networks. *Nature Communications* 10:2114. https://www.nature.com/articles/s41467-019-10063-w

The effects of heat on transportation infrastructure

For much of the contiguous United States, the frequency of extreme heat events has been increasing since the mid-1960s and the number of high temperature records has outpaced the number of low temperature records, particularly since the mid-1980s[21]. Cities throughout the country have experienced not only more frequent extreme heat over the last 60 years, but also more intense and longer-lasting heat waves[22]. As heat-trapping emissions accumulate in the atmosphere, the frequency and intensity of extreme heat events is projected to rise[23].

Extreme heat can affect many types of transportation infrastructure[24]:

- Air travel. High temperatures constrain the allowable weight of aircrafts during takeoff, as we saw when temperatures at the Phoenix airport rose to 119 °F during a 2017 heat wave, prompting the cancellation of 50 flights because the aircraft were above the operable weight limit in such heat (Wang 2017). The cancellation of flights due to heat creates costs for the airline industry and its customers and disrupts both passenger travel and air shipments[25].
- Roads. Depending on the paving materials and the traffic load of a given road, pavement can deteriorate as temperatures rise[26]. The paving material used for a given road is usually based on historical climate conditions, so the occurrence of extreme heat (or precipitation) outside of historical norms can cause pavement to buckle or deform, as occurred in Sacramento, California, during a June 2017 heat wave[27].
- Rail systems. Trains may need to reduce speeds to prevent accidents when the temperature reaches 90 °F[28]. At 110 °F, rails are at increased risk of buckling, which can create dangerous conditions that are costly to repair. While the redundancy in road networks can compensate for the closure of any one road, the same cannot be said for rail networks.

As extreme heat events become more frequent and more severe in response to rising atmospheric concentrations of heat-trapping gases, so too will disruptions to our transportation systems.

Solutions

Climate change and its consequences are already upon us. Given our past carbon emissions, we are committed to a certain amount of sea level rise and future warming. Ignoring the issue will not make it

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[21] Vose R, Easterling D R, Kunkel K and Wehner M 2017 Temperature changes in the United States 36

Abatzoglou J T and Barbero R 2014 Observed and projected changes in absolute temperature records across the contiguous United States - Abatzoglou - 2014 - Geophysical Research Letters - Wiley Online Library Online: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014GL061441

[22] Habeeb D, Vargo J and Stone B 2015 Rising heat wave trends in large US cities *Nat. Hazards* **76** 1651–65

[23] Projection data can be explored using the US Climate Resilience Toolkit at https://crt-climate-explorer.nemac.org/.

[24] For more information see https://www.ucsusa.org/sites/default/files/attach/2018/08/extreme-heat-impacts-fact-sheet.pdf

[25] Coffel, Horton, and de Sherbinin 2017

[26] Daniel et al. 2014; Rowan et al. 2013

[27] Holsinger 2017; NBC 2017

[28] Rowan et al. 2013

go away or lessen its impacts. Solutions to the issue of climate change must focus on both adaptation to cope with the changes that lie ahead and mitigation to reduce future carbon emissions, which will limit the magnitude of future warming. Adaptation can have limits—for example port facilities need to remain on the water to serve their function and is not feasible or advisable to protect every mile of shoreline with a seawall. Because many of the adaptation-oriented solutions will require years of planning and an even longer implementation period, it is imperative that we begin planning now.

Adaptation

Policymakers must ensure that federal investments in the transportation sector strengthen the resilience of transit systems to climate change impacts while also ensuring an acceleration towards low-carbon transit systems. These efforts must also address long-standing inequities that have left many communities disproportionately exposed to climate risks.

New long-lived transportation infrastructure must be designed to withstand the future impacts of climate change. For example, to account for rising sea levels and intensifying rainstorms, infrastructure should be built at least two feet above the 100-year flood level (three feet for critical infrastructure)—a design standard that would have a high return on investment[29] and would serve as a benchmark for other public and private investments. Similar protective standards should be implemented nationwide to safeguard federally funded transportation projects from other climate impacts such as wildfires and extreme heat. The Federal Highway Administration has developed a vulnerability assessment framework that can be used to help agencies integrate climate adaptation measures into their transportation planning decisions[30].

Congress should set up a diverse and inclusive expert advisory body to provide guidance on transportation systems that not only accounts for climate change but historic injustices as well, by targeting investments in underserved and marginalized communities[31].

Congress also must invest in data and tools that can help address climate risks to the transportation sector. This means ensuring that states develop risk-based management plans and provide alternatives for transit infrastructure that is chronically in need of repairs.

Mitigation

The US transportation sector, which includes cars, trucks, planes, trains, ships, and freight, produces nearly thirty percent of all US global warming emissions[32]. This is more than any other sector. Over 90 percent of the fuel used for transportation is petroleum-based, with gasoline and diesel being the primary fuels. Given its contributions to global warming emissions, the transportation sector is in the position of being both a major contributor to global warming and highly vulnerable because of that warming. Because of this, the transportation sector would benefit greatly from global emissions

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[29] See NIBS 2018. The return on investment is as much as 11:1 for roads and railroads. https://cdn.ymaws.com/www.nibs.org/resource/resmgr/docs/NHMS-UtilitiesFactSheet.pdf

[30] https://www.fhwa.dot.gov/environment/sustainability/resilience/adaptation_framework/climate_adaptation.pdf

[31] https://www.ucsusa.org/sites/default/files/attach/2017/11/gw-whitepaper-smart-infrastructure.pdf

[32] https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

reductions; and the world would benefit greatly from emissions reductions from the transportation sector. There are many policies that could result in transportation emissions reductions while also reducing human exposure to harmful pollution, the burden of which falls disproportionately on traditionally underserved communities[33]. Such policies include, but are not limited to[34]:

- Increasing fuel economy and greenhouse gas emissions standards for vehicles[35]
- Increased investment in low-carbon public transportation systems, such as rail systems
- Replacing gas-powered public bus fleets with electric bus fleets[36]
- Incentivizing deployment of more electric vehicles, including through investment in charging infrastructure
- Research on highly efficient conventional vehicle technologies, batteries for electric vehicles, cleaner fuels, and emerging new technologies
- Implementing a market-based cap and invest program for the transportation sector, such as the proposed Transportation and Climate Initiative[37].

Action is needed

Long-term underinvestment in our nation's transportation infrastructure has resulted in a system that is already strained today. Recent climate events have exposed just how vulnerable our transportation networks are to climate-related events; future population growth and increasingly frequent extreme climate events will exacerbate the transportation sector's existing challenges.

Our transportation infrastructure needs to be built to last so that it is safe and reliable in the face of a changing climate. As we look to the future, we can make our transportation systems more resilient and adaptable by incorporating climate-safe design standards into the planning process. At the same time, rapidly transitioning to low-carbon transportation systems could significantly reduce emissions from the transportation sector and thus help to limit the scale of future warming and its impacts.

[33] Reichmuth, D. 2019. Inequitable exposure to air pollution from vehicles in California. Union of Concerned Scientists, Oakland, CA. https://www.ucsusa.org/sites/default/files/attach/2019/02/cv-air-pollution-CA-web.pdf
[34] For more information see https://www.ucsusa.org/clean-vehicles/fuel-efficiency/clean-car-standards.html
[35] https://www.ucsusa.org/clean-vehicles/fuel-efficiency/clean-car-standards.html
[36] https://ww2.arb.ca.gov/news/california-transitioning-all-electric-public-bus-fleet-2040
[37] https://www.transportationandclimate.org/content/about-us
https://www.ucsusa.org/sites/default/files/attach/vehicles-ne-transportation-factsheet.pdf

Regional Plan Association

May 20, 2019

Committee on Science, Space, and Technology
U.S. House of Representatives
2321 Rayburn HOB
Washington, D.C. 20515

The Honorable Mikie Sherrill
Chairwoman
Subcommittee on Investigations and Oversight
1208 Longworth HOB
Washington, DC 20515

The Honorable Ralph Norman
Ranking Member
Subcommittee on Investigations and Oversight
319 Cannon HOB
Washington, DC 20515

The Honorable Mikie Sherrill and The Honorable Ralph Norman,

I am writing to express how critical Amtrak's Gateway project is to the nation, and particularly to our efforts to make our infrastructure more resilient to destructive storms and heatwaves that are increasing in frequency and intensity.

Each day hundreds of thousands of Amtrak and NJ Transit passengers travel across a century-old, federally owned rail bridge and through a 108-year-old, one-track-in, one-track-out tunnel beneath the Hudson River. The bridge and the tunnels are in big trouble. In addition to its age, the tunnel was flooded during Superstorm Sandy, causing long-term damage.

Without the second tunnel that the Gateway project would provide, the Northeast remains vulnerable to future storms and other disruptions that could shut down the entire Northeast corridor. A recent Regional Plan Association report entitled *A Preventable Crisis* showed how a partial shutdown of the tunnel for necessary repairs would mean dramatically expanded commute and travel times. It would also lead to increased congestion on public transportation and already stressed roadways and airports, and increased business and consumer costs, job loss, home devaluation, and health risks Effects of a four year shutdown would cost the national economy $16 billion, $1.5 billion in federal tax revenue, and $1 billion in state tax revenue outside of New York and Jersey.

The Northeast's other critical infrastructure, already struggling with the effects of age and underinvestment, is also facing additional threats from climate change. Superstorm Sandy demonstrated how flooding from storms can wreak havoc on the power, transportation, wastewater, telecommunications, and social-service systems, but the gradual rise of sea levels also threatens to inundate dozens of critical facilities in the coming decades.

Higher temperatures and more-intense precipitation can also exacerbate existing weaknesses in our infrastructure. The region must not only upgrade and repair assets like power plants and wastewater treatment facilities to withstand the threats of climate change, but also redesign critical systems like energy and telecommunications so that disruptions are as limited as possible, and do not lead to cascading failures across multiple systems.

New York
One Whitehall St, 16th Floor
New York, NY 10004
212 253 2727

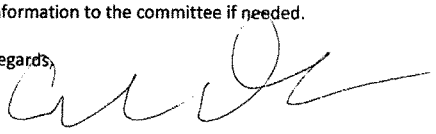
New Jersey
179 Nassau St, 3rd floor
Princeton, NJ 08542
609.228.7080

Connecticut
Two Landmark Sq, Suite 108
Stamford, CT 06901
203 356 0390

Of particular concern are the threats to the region's rail infrastructure, including the Northeast Corridor and particular stretches of New Jersey Transit, PATH and Metro North rail lines and maintenance, power and storage facilities. Without action, these lines will become increasingly at risk from sunny day flooding and eventually permanent flooding from rising seas. Each agency responsible should include capital funding to study the threat of sea level rise flooding on their facilities.

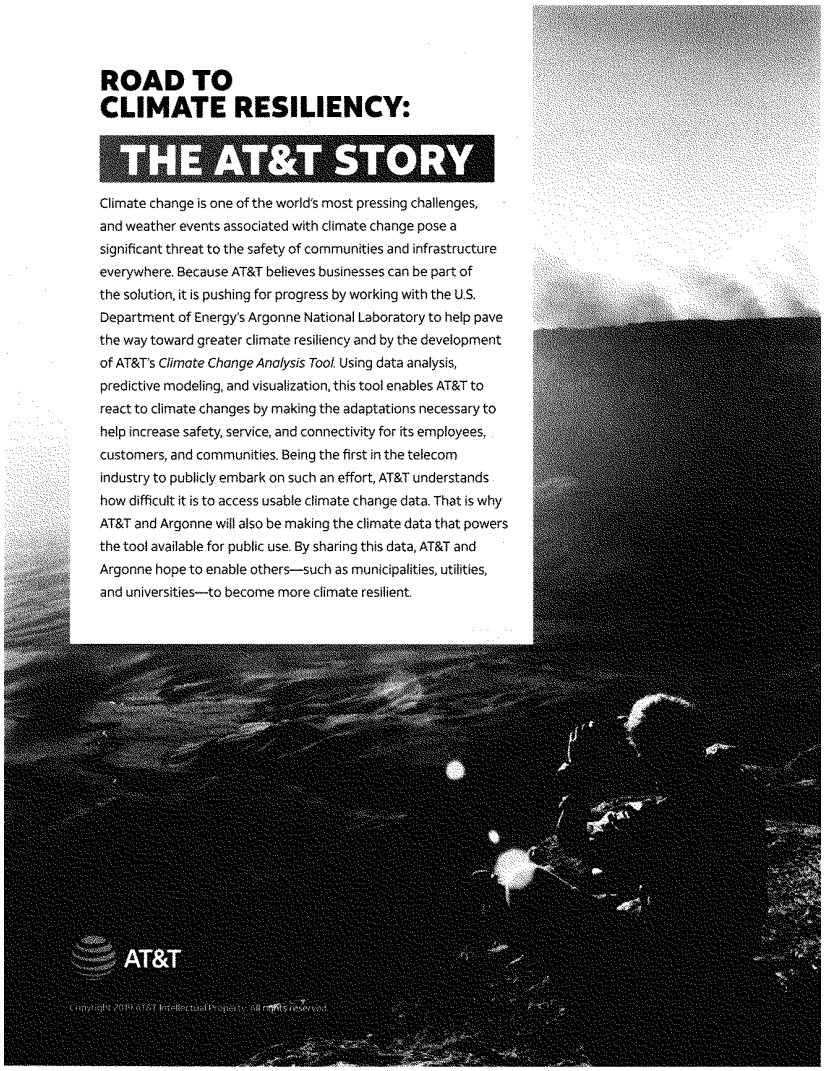
Thank you for this opportunity to highlight this critical need. We would be happy to provide additional information to the committee if needed.

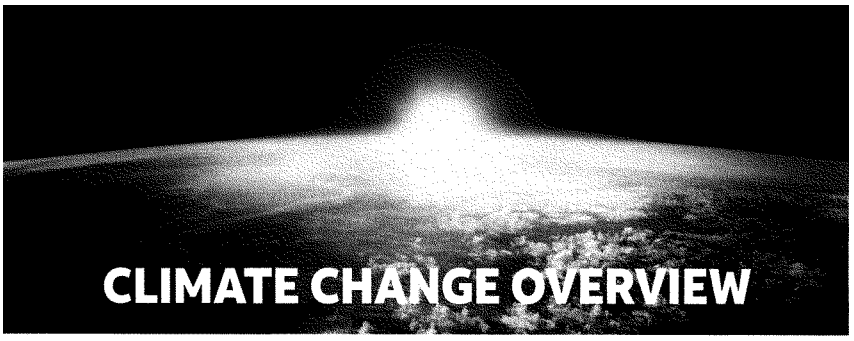
Regards,



Christopher Jones
Senior Vice President & Chief Planner

WHITE PAPER SUBMITTED BY REPRESENTATIVE SEAN CASTEN





CLIMATE CHANGE OVERVIEW

Climate change affects peoples' daily lives in many ways. For example, people may notice unseasonably warm or unpredictable weather, or pay higher food prices at their grocery stores. The Universal Ecological Fund (FEU-US) released a report linking food availability and price increases to severe climate-related events such as more frequent and intense droughts and flooding.[i] People may also hear climate change discussed around the globe, and scientific research such as the 2018 Intergovernmental Panel on Climate Change (IPCC) report warns that the world must cut carbon emissions 45% below 2010 levels by 2030 or risk irreversible effects to the environment.[ii] Throughout the world, people are experiencing the effects of climate change in their own backyard with the destruction of homes, businesses, and cities in the wake of climate-related weather and natural disasters. This will continue as the future impacts of climate change will include a rise in temperatures and sea levels, changes in precipitation patterns, more droughts and heat waves, more intense hurricanes, and continued artic ice melt.[iii]

Notably, the way recent natural disasters have impacted infrastructure and human life has been unprecedented. From 2016–2018, the southeastern region of the U.S. endured catastrophic hurricanes including Matthew, Irma, Maria, and Michael.

- **The 2,975 deaths that occurred in Puerto Rico because of Hurricane Maria place Maria among the top-five deadliest disasters in U.S. history.**[iv]
- **Hurricane Irma is the strongest hurricane on record globally, with sustained winds of 185 mph for more than 36 hours.**[v]
- **2017 was the costliest year ever as damage to U.S. infrastructure resulting from natural disasters totaled $306.2 billion in cumulative damages.**[vi]
- **The number of extreme weather events causing at least $1 billion in economic losses has increased from 21 in the 1980s and 38 in the 1990s, to 92 from 2007 to 2016.**[vii]
- **The southeastern U.S. faces a trend of increasing precipitation—already experiencing a 27% change in precipitation levels from 1958 to 2016.**[viii]

As these numbers compound upon each other, factoring climate resiliency into current and future infrastructure projects becomes increasingly critical for communities, and companies like AT&T. Vulnerable regions such as the southeastern U.S. face a persistent need for proactive resilience planning. Anticipating, adapting to, and recovering from the impacts of climate change will only become more difficult and costlier in the future if left unchecked. That is why responsible companies, communities, and institutions are analyzing risks to protect their employees, assets, and customer experiences in the face of climate change.

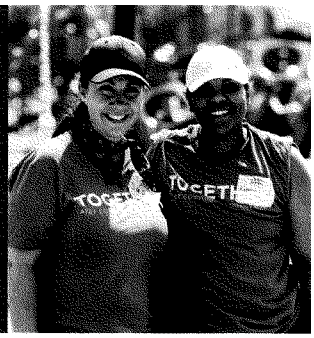
AT&T HUMANITARIAN SUPPORT FOR RECENT CLIMATE-RELATED EVENTS

AT&T has donated over $5.2 M in humanitarian aid to support communities impacted by natural disasters in the U.S. from 2014–2018.

- Nearly one-third ($1.6 M) of AT&T's humanitarian aid was directed to southeastern states impacted by natural disasters.
- More than half ($3.7 M) was in response to climate-related events, such as floods and hurricanes.

AT&T and its employees have provided an additional $5.4 M in aid to more than 5,700 U.S.-based employees impacted by weather-related events through employee relief funds since 2011.*

*Employee relief funds refer to programs paid by the AT&T Foundation Employee Disaster Relief Fund and the AT&T Employee Relief Fund. Visit https://employeereliefatt.com for more information.



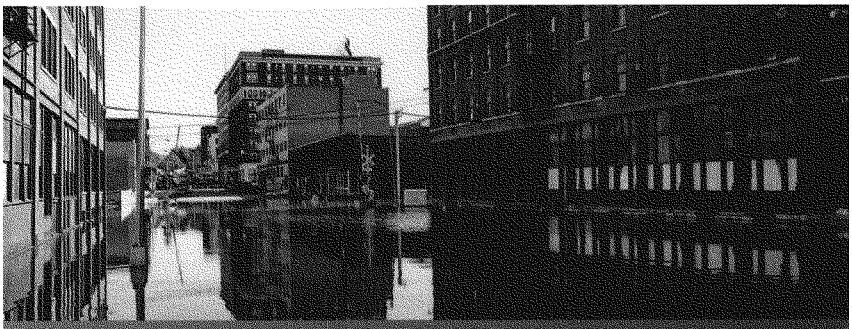
THE ROAD TO CLIMATE RESILIENCY

AT&T knows businesses can play a role in the global collaborative effort to address climate-related change. It is committed to helping care for the planet and is working to help mitigate climate impacts. For example:

- In 2015, AT&T set a **10x carbon reduction** goal to enable carbon savings 10 times the footprint of its operations by 2025.[ix]
- Since 2010, AT&T has implemented more than 83,000 energy efficiency projects, resulting in annualized savings of $575 million for the company.[x]
- By the end of 2017, AT&T reduced fleet emissions by 174,403 metric tons of CO_2, reduced the size of its domestic fleet by 1,100 vehicles, and has committed to reduce its fleet emissions 30% by 2020.[xi]
- AT&T is also one of the largest corporate purchasers of renewable energy in the country as demonstrated by its investments to help deliver up to 820 megawatts (MW) of wind energy per year. If AT&T is successful, the clean energy produced will enable a reduction in greenhouse gas emissions equivalent to taking more than 530,000 cars off the road a year. [xii]

More information on AT&T's climate mitigation efforts can be found in **AT&T's annual sustainability reporting**.

However, in today's changing environment, AT&T recognizes it must take steps now to help ensure the resiliency of its business, its customers, and its communities. From adapting how the company chooses where to place new infrastructure such as fiber and cell sites, to enhancing current network redundancy in disaster-prone areas, the climate planning and adaptations AT&T undertakes today will help boost its climate resiliency for years to come—and help the company deliver on its commitment to safety, service, and connectivity. But how are the most needed adaptations determined? This is the story of how AT&T worked with Argonne National Laboratory to derive cutting-edge forecast data and developed its *Climate Change Analysis Tool* to map those climate forecasts onto AT&T facilities and infrastructure to help AT&T make smarter, climate-informed decisions and better serve its customers and communities.



"WITHOUT ADAPTATION, CLIMATE CHANGE WILL CONTINUE TO DEGRADE INFRASTRUCTURE PERFORMANCE OVER THE REST OF THE CENTURY, WITH THE POTENTIAL FOR CASCADING IMPACTS THAT THREATEN OUR ECONOMY, NATIONAL SECURITY, ESSENTIAL SERVICES, AND HEALTH AND WELL-BEING." [xiii]

The Fourth National Climate Assessment, *the U.S. Global Change Research Program's mandated report to United States Congress and President*

AT&T'S CLIMATE CHANGE ANALYSIS TOOL

I. RESILIENCY ASSESSMENT

The idea: create a tool that can visually layer AT&T's physical asset data upon future climate impact data to help AT&T ensure safety, service, and connectivity in current and future build plans. The pursuit of this tool was spearheaded by Shannon T. Carroll, Director of Environmental Sustainability at AT&T. In his role with the company's Corporate Social Responsibility (CSR) team, Carroll works across the business to strengthen its environmental business practices. "We knew it was time for AT&T to take a deep dive into what we were doing as a company to plan for the long-term impacts of climate change," says Carroll on taking the first step of conducting an assessment of AT&T's climate resiliency practices. "We received an independent, unbiased, and credible point of view. It provided validation of some thoughts and challenged others, which is a good thing."

KEY FINDINGS OF RESILIENCY ASSESSMENT:

AREA OF FOCUS	STRENGTH	RECOMMENDATION
Expand long-term planning to include and account for climate change	AT&T's data, analytic, and technological resources	Leverage capabilities to develop a climate risk tool to enable long-term climate resiliency

II. KEY PLAYERS (AT&T & Argonne National Laboratory)

As the opportunity to improve resiliency became clear from the assessment, Carroll:

1. **Formed a climate resiliency project team** spanning across AT&T, including:

Shannon T. Carroll	Director of Environmental Sustainability, Corporate Social Responsibility
Antoine Diffloth	Director of Data Insights, Chief Data Office
Michelle McHugh	Lead Project Manager, Chief Data Office
Edmond Abrahamian, PhD	Principal Data Scientist, Chief Data Office
John Boyd	Geographic Information System (GIS) Lead, Strategic Planning
Joshua Dalton	Geographic Information System (GIS) Engineer, Technology Development
Colin Profitt	Senior Network Planning Engineer, Infrastructure Optimization and Implementation
Chris Maltese	Senior Business Manager, Technology Operations
Steve Poupos	Director of Advanced Technology Support, Technology Operations
Victor Devito	Area Manager Regulatory Relations, Strategic Planning
Jessica Pham	Project Manager/Communications Manager, Chief Data Office

2. **Engaged external third party climate experts** from Argonne National Laboratory (Argonne) to supply AT&T with the climate data needed for the project, including:

Rao Kotamarthi, PhD	Chief Scientist and Department Head, Atmospheric Science and Climate Research
Jiali Wang, PhD	Atmospheric and Earth Scientist, Atmospheric Science and Climate Research
Eugene Yan, PhD	Principal Scientist in Earth Science, Applied Geosciences and Environmental Management
Julie Bessac, PhD	Assistant Computational Statistician, Mathematics and Computer Science
Keith Roberts	Research Associate, Atmospheric Science and Climate Research
Alissa Jared	Research Associate, Applied Geosciences and Environmental Management
Mark Picel	Research Associate, Atmospheric Science and Climate Research
Thomas Wall, PhD	Senior Infrastructure & Preparedness Analyst, Decision and Infrastructure Sciences

Argonne NATIONAL LABORATORY

WHY ARGONNE?

After internal and external research and assessments, AT&T chose to partner with Argonne because of their expertise and access to:

- **climate models that are high-res, are physics-based, and project locally and regionally relevant climate impacts**
- **extensively evaluated datasets on topography, land cover, and surface water**
- **supercomputing resources that reduce processing times and provide crucial climate simulations**
- **a multidisciplinary team of scientists and engineers in climate science, environmental science, radar data analysis, inland and coastal hydrology, advanced statistics, infrastructure modeling and engineering, and decision science**

III. SCOPE

A project scope was solidified to begin developing a tool that would help AT&T analyze and visualize future climate change impacts in regions within the U.S. Due to this region's susceptibility to Atlantic hurricanes, AT&T narrowed the scope to four priority states within the southeastern U.S., and Argonne delivered forecast data that predicted the likelihood and level of severity for four priority climate impacts.[xiv]

SCOPE

Understand the impact of climate change on AT&T's products and services and create a tool to visualize climate change impacts on AT&T assets by:

1. Better understanding the climate risk and resiliency challenges of a company with significant infrastructure investment
2. Creating climate datasets to address the risk profiles relevant to AT&T's business
3. Developing actionable high spatial resolution climate data products for use in AT&T's *Climate Change Analysis Tool*
4. Identifying research and data gaps for continued development of climate data and science products to address identified risks and resiliency challenges

PRIORITY STATES

PRIORITY CLIMATE IMPACTS

- Inland Flooding Caused by Increased Precipitation
- Additional Coastal Flooding Caused by Sea Level Rise and Hurricane Surge
- High-Intensity Winds (Non-Hurricane)
- High Intensity Winds (Hurricane)

IV. SCIENTIFIC APPROACHES

1. Tools

Argonne used three major regional-scale climate environment models to deliver on the project scope:

a. *The Weather Research and Forecasting Model (WRF)* was developed by the National Center for Atmospheric Research (NCAR) and was used to create the foundational dataset of dynamically downscaled historic and future climate information over North America.

b. *The WRF-Hydro® (Version 5) Model* was run at a spatial resolution of 200 meters using the output generated from the WRF downscaled climate output to simulate historic and future inland hydrology and flooding. "The 200m spatial resolution of the WRF- Hydro® simulations was informed and enabled by a number of factors, including the types of flood risks of greatest concern to AT&T, the availability of baseline input data for the hydrological simulations, and the availability of advanced computational resources. The 200m spatial resolution generates sufficiently detailed outcomes to inform local decisions, while maintaining statistically robust outcomes needed for extreme value analysis," said Rao Koramarthi, Chief Scientist and Department head at Argonne.

c. *The ADvanced Hydrodynamical CIRCulation Model (ADCIRC)* was used to perform coastal flooding simulations, with input from the WRF downscaled climate projections and historical data for the recent major hurricane events to drive those simulations. ADCIRC uses unstructured gridding and extremely high resolution (approximately 50 meters).

To develop its high-resolution, regional climate model projections for North America (WRF Model), Argonne dynamically downscaled existing global climate model simulations that were developed for the United Nations Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). This global climate dataset is known as the CMIP5 repository.

The CMIP5 global climate data was regionally downscaled for a business-as-usual carbon emission scenario, known as RCP 8.5, and a second case, known as RCP 4.5, that is closer to the Paris Agreement (2015). Under RCP 8.5, it is expected that the total atmospheric concentration of CO_2 will be more than double current concentrations by 2100.

2. Computational Power

Argonne is home to world-class high-performance computing systems, which allow Argonne climate scientists to run large-scale climate simulations in an exceptionally short amount of time. Computations for the project were performed on leadership computing facilities operated by the U.S. Department of Energy at Argonne and at the National Energy Research Scientific Computing Center.

These simulations project future climate on an hourly basis, decades into the future. For example, simulating one year of future climate in the four priority states would require more than 4,000 hours of computation time on a standard computer. On the AT&T project, Argonne made use of more than 30 years of data for future climate in the four priority states. While the total computing time was in excess of 50 million core hours, when run on Argonne's supercomputers, it was completed in a matter of months.

The hydrological simulations for inland flooding were performed using a version of the WRF-Hydro® model, using Argonne supercomputing resources.

3. Priority Climate Impacts

a. Coastal flooding

Argonne conducted climate environmental modeling to explore future impacts of warm-season tropical cyclones on coastal flooding. The primary goal of this work was to develop a modeling system that was capable of accurately simulating flooding along the coastline of the four priority states. This modeling system was then used to explore how coastal flooding may change given a projected warming global climate.

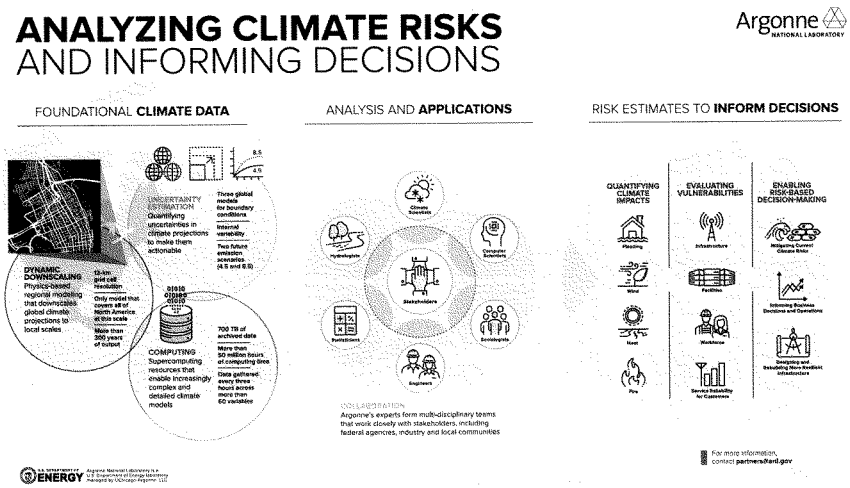
Two tools were used as a coupled model to simulate the coastal environment (i.e. storm surge and wave action) with an unstructured mesh and up to 50-meter resolution:

i. ADCIRC was used to solve the non-linear, barotropic shallow water equations, which represent tidal process and storm surges. ADCIRC uses an unstructured mesh that allows variable model resolution ranging from 50 meters along the shore to 10 kilometers in the open sea. This unstructured mesh enhances the resolution of coastal flooding effects near the shore and reduces the computation time for the area away from the shore.

ii. The Simulating WAves Nearshore (SWAN) Model was coupled with the ADCRIC model to solve phase-averaged wave processes that occurred during tropical storm events.

Five land-falling hurricanes [Hugo (1989), Charley (2004), Irene (2011), Sandy (2012), Matthew (2016)] were simulated to identify relationships between historic climate and hurricane-related coastal flooding.

To explore how coastal flooding may change in the future, meteorological fields (sea-level pressure and near-surface wind) from Argonne's WRF climate model dataset were used as inputs for the hydrodynamical models to project hurricane-related flooding at mid-century in the four priority states.



b. Inland flooding

In addition to coastal flooding, inland flooding resulting from heavy rainfall is a major concern to AT&T. The WRF-Hydro® (Version 5) was employed to simulate the entire hydrological cycle in watersheds across a region. The model used a range of inputs—from future climate variables (precipitation, temperature, humidity, wind, solar radiation) to topography and vegetation—to inform a physics-based model.

With projected precipitation and other climate parameters as input across the region, WRF-Hydro® computes the extent of inland flooding that can be expected, as well as other characteristics such as depth of surface water accumulation, stream flow and flood duration.

c. Wind speeds

Argonne conducted a statistical analysis on wind speed conditions under historic climate conditions and under future conditions, including the scenarios mentioned earlier (RCP 4.5 and RCP 8.5). Climate change will affect wind conditions in terms of intensity, frequency, and the duration of intense events.

To quantify these changes, wind speed distributions and some commonly used statistics (mean, variance, quantiles) for historic conditions were compared with the same statistics for future conditions. In addition, statistical analysis methods specific to extreme events were used to assess potential extreme future wind conditions. The study is based on the multiple regional climate model datasets generated by Argonne, previously discussed. Results of the study indicate that changes in wind conditions occur according to seasons and geographical areas.

V. CHALLENGES

TOOL INVESTIGATION: To deliver maximum benefit from this project, a data visualization tool that was able to integrate AT&T's asset data with Argonne's climate data was needed. "The tool needed to have layering capabilities and support for topological and geolocational features, at a minimum. If this tool were not already available in-house, we would have had to either build it from scratch or license it from a third party," said Edmond Abrahamian, Principal Data Scientist at AT&T. Fortunately, AT&T discovered a viable internal tool compatible with Argonne's platform.

IDENTIFYING BUSINESS-RELEVANT CLIMATE VARIABLES: Argonne recognized the need to identify and develop climate decision products that would be most useful to AT&T's climate resilience initiatives. Discussions between AT&T and Argonne early in the project led to a series of additional focused simulations, data processing, and novel statistical analyses to identify climate extremes and define modeling uncertainty—better aligning to AT&T's needs.

PROJECTING CLIMATE EXTREMES: Probabilities of climate extremes are projected using advanced statistical analysis of the output of the physical climate models. Generally speaking, the statistical confidence in future projections decreases farther into the future. For example, there is greater confidence in predicting the 10-year or 25-year extreme event than in predicting the 50-year or 100-year extreme event. This study explored multiple methods to increase the confidence of the prediction, and a relatively robust approach was applied. However, as this is an active area of ongoing research, newer and better approaches continue to be developed.

MODELING UNCERTAINTY: Argonne's North American regional climate model (i.e. WRF) uses the input of three different global climate models to project future climate. Each of these three global climate models predict slightly different variations in climate, but are in general agreement with respect to the types and direction of changes that are expected to occur. However, the amplitude of those changes differs across the models.

VI. OUTPUTS/RESULTS

Argonne's modeling produced results for four priority climate impacts that were of greatest concern to AT&T for the resilience of its systems. These results of the four impacts include:

INLAND FLOODING: WRF-Hydro® (Version 5) simulated the water cycle to project the depth and extent of inland flooding for historical and mid-21st century timeframes. These mid-century results project increased surface water accumulations over 5% in inland and coastal regions in the southeastern U.S. under a business-as-usual emission scenario during warmer seasons (spring, summer, and fall). Extreme flood events are also projected to increase across the four priority states. For example, by mid-century, a 50-year flood event will produce flood waters up to 10 feet deep across inland and coastal areas of southeastern Georgia.

COASTAL FLOODING: Two decades of water level simulations were conducted for a historical (1995-2004) and mid-century time period (2045-2054). Overall, the results are in agreement with other studies: severe hurricanes in climate models tend to be under-predicted and occur less frequently as compared to observations. This is reflected in our model validation statistics. Additionally, the sea level rise signal associated with warming projections consistent with the RCP8.5 scenario appear to be the largest driver of future warm-season flooding and increases nuisance-level flooding events and severe flooding along the four priority states.

HURRICANE AND NON-HURRICANE WINDS SPEEDS: The comparison of Argonne simulations of wind conditions between historical and mid-century time periods reveal various changes in statistics that vary across regions and seasons. For instance, southern Florida tends to show the greatest change in maximum sustained wind conditions between past and future in both basic statistics and extremes conditions. Fifty-year event wind speeds of 90 mph are possible for a large part of the southern Florida coastal region by mid-century.

Output Types

Argonne's climate models produced multi-dimensional data that can be easily mapped to show the impact of multiple climate variables across a region. The models directly output the data into Network Common Data Format (NetCDF) files, which allows easy storage and access to the data across a wide variety of software applications.

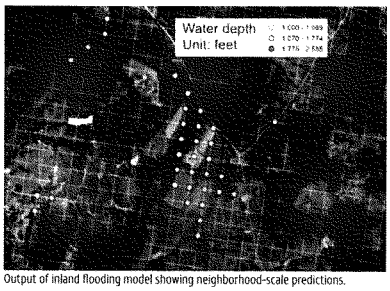
For climate resilience studies such as this one, NetCDF-based climate data is frequently imported into geospatial information systems (GIS) software to generate climate impact maps across regions of interest. The climate impact maps can be overlaid with infrastructure, agriculture or other mapping data to assess the climate impacts to regions and communities.

A subset of the climate model dataset developed for this project focused on projecting various climate extremes (e.g. hurricane wind speeds or extreme flood depth).

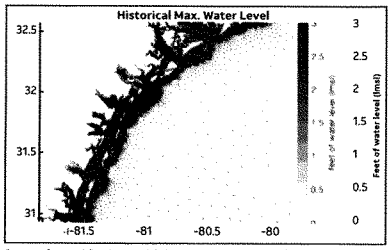
To do this, an extreme-value analysis was performed using statistical distributions to extrapolate the simulated intensity of extreme climate and hydrologic variables (e.g. hurricane winds and flood water depths). Parameters of these statistical analyses outcomes were identified and then saved for each grid cell in the four priority states.

Estimated parameters of these distributions in each grid cell were then used to calculate the extreme intensity of climate and hydrologic variables at any return period of interest (e.g. 50-year wind speeds and 25-year flood depths).

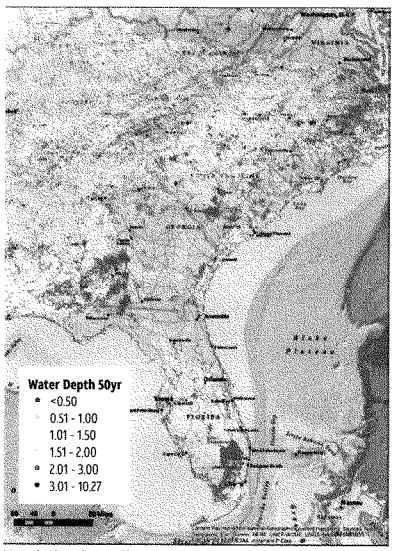
SAMPLE OUTPUTS



Output of inland flooding model showing neighborhood-scale predictions.



Output of coastal flooding model showing variable density of measurement points.



Water depth predictions, 50-year event.

VII. RELIABILITY OF RESULTS

Confidence Estimates:

Confidence estimates of the predicted change in various climate variables for future timeframes can be a useful statistic for assessing the reliability of climate model results. Confidence levels are estimated by assessing the outputs of multiple climate variables across different climate models. If projections calculated by several different models point to similar changes or agree on the types, direction, and magnitude of changes, there can be greater confidence in climate model outcomes. This study used outputs from three different models for each climate-change emission scenario to assess and develop robust statistics of confidence.

Estimating Extremes:

Estimating values can be challenging when assessing impacts for relatively short future time periods (e.g. a 10-year period in the future). To overcome this, Argonne scientists evaluated multiple statistical analysis methods to identify those that produced the most robust outcomes while minimizing uncertainty for the four priority states. These included:

1. **evaluating the performance of four different statistical distribution models for extreme values analysis**

2. **increasing the dataset size using p eak-over-threshold (POT) instead of annual maximum series (AMS)**

3. **increasing the size of the dataset by identifying regions with homogeneous grid points and aggregating them into a larger grouping of data points. The final approach was made based on performance of each approach.**

Another challenge is the parameters that define the statistical distributions used to calculate future climate extremes can carry some uncertainty that must be quantified. This uncertainty derives from the fact that the output of three different global climate models were used to drive the regional climate model (WRF) and hydrologic model (WRF-Hydro®). To quantify these parametric uncertainties, this study randomly sampled model outputs from the historical and mid-century datasets, and then derived a range of variation for each parameter. These ranges provide a basis for quantitatively estimating parameter uncertainty, and therefore can be used to estimate the uncertainty of extreme wind speed and flood depths.

Lastly, conventional extreme value analysis uses stationary statistical distributions, where the parameters that define them do not change over time. For climate change applications, the assumption of stationarity may underestimate the intensity of extremes events as climate continues to change over time. To account for these effects in this project, Argonne evaluated the statistical distributions with both stationary and non-stationary parameters using historical and future projections of extremes. If the non-stationary parameters at any grid improved the agreement between distribution predictions and the actual data, then the non-stationary distributions were applied. This approach provides more accurate projections of the future climate and hydrologic impacts.

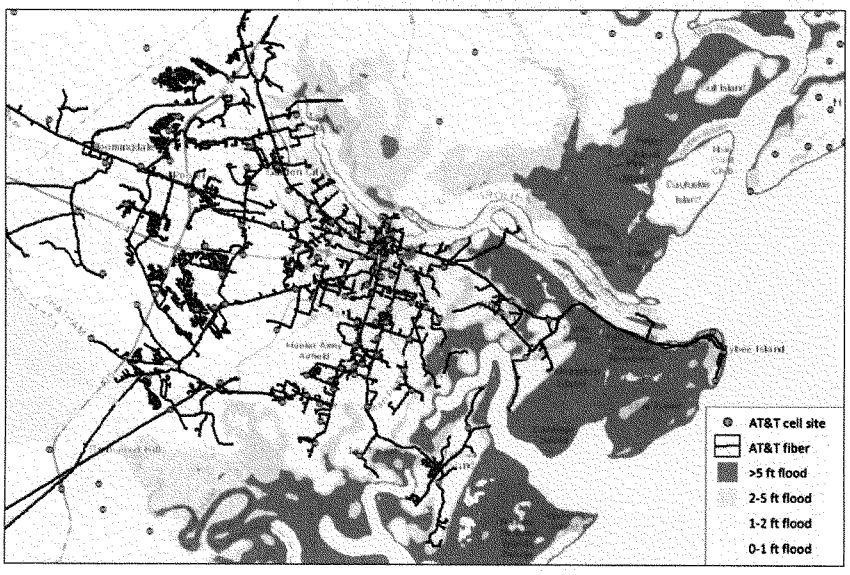
VIII. TOOL

AT&T has several GIS systems currently in service. These systems have hundreds of map layers for tracking assets including real estate locations, central offices, fiber and copper lines, cell sites, and even undersea fiber. The company's network planning and construction teams use this data to plan maintenance, disaster recovery, and future construction to best serve its customers.

While AT&T's GIS systems contain data on current weather and the company's planning teams consider the locations of historical flood plains, there is no data available on the accelerating changes brought on by climate change.

Incorporating Argonne's new climate data will add incalculable risk identification and mitigation value. For example, AT&T can now cross reference its fiber cable locations with projected sea level rise in the year 2060, making for smarter financial decision-making by mapping risky and conservative areas for new build plans. Offering anywhere from 10-year to 100-year return periods of climate change risk, AT&T's *Climate Change Analysis Tool* will allow network planners to understand the range of possible impacts to AT&T assets and align risk tolerance with the expected lifespan of those assets.

"Having climate data in numerical form is great for feeding into geospatial calculations and decision-making processes, but nothing compares to the visual impact of seeing climate change overlaid on our company's assets in an interactive map," said Antoine Diffloth, Director of Data Insights at AT&T.



Visualization of flooding data overlaid on AT&T fiber and cell sites.

NEXT STEPS

AT&T and Argonne are exploring the potential expansion of the existing tool. Geographically, the tool could expand to include the East Coast, Gulf Coast, and West Coast regions of the U.S. before completing the entire United States and Mexico.

Expansion of the tool could also include other climate change impacts such as wildfires and droughts. The largest and deadliest wildfires in California's history occurred just last year (2018).[xv] Though the Mendocino Complex and Camp wildfires were not directly caused by climate change, climate events such as exceedingly dry winds, drought, and vegetation die-off due to anomalous temperatures create conditions that exacerbate the damage caused by fires.[xvi] To have a more complete tool, other pressing climate change impacts such as increased temperatures and changing precipitation patterns will eventually be included.

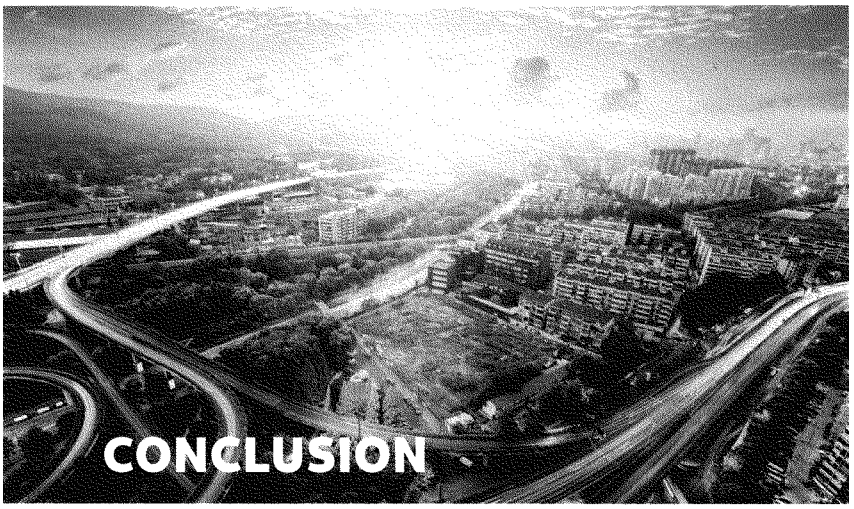
Developing climate projections for the southeastern U.S. has allowed Argonne climate scientists to apply new analytical techniques to project regional climate impacts of interest to telecommunications, infrastructure, and other related sectors. These techniques will be extended to generate similar climate data for the rest of the continental U.S.—enabling broader study of climate impacts across the country, and providing the opportunity for Argonne scientists to further hone their analyses.

One such planned enhancement will be to apply bias correction—a systematic correction to model outcomes where models have been found to consistently under- or over-predict certain results—to each of the precipitation projections from the WRF model that were used to inform WRF-Hydro® and predict inland flood effects. This will improve confidence levels estimates for inland flooding by sampling bias-corrected results from all three climate models.

BOOSTING COMMUNITY RESILIENCY

Climate change affects everyone. That is why AT&T and Argonne are committed to making the climate data used to develop AT&T's tool available to those who need it. Providing everyone—from municipalities to universities—with the opportunity to better understand the risks posed by climate change, will better equip communities to become more climate resilient.

Taken together, the high resolution, rigorous statistical analysis, and broad regional coverage enables this one-of-kind dataset to give users a powerful tool for analyzing projected flooding and wind extremes, and therefore to quickly develop first-look estimates of potential risks to infrastructure, operations, and services. More on the public release of this project's data will be shared in the future.



CONCLUSION

The effects of climate change have become increasingly critical for communities and companies like AT&T to address. Solutions that mitigate the impact of CO_2 emissions on our planet must also be paired with solutions that help people adapt to the inevitable climate events that will occur today and tomorrow. As a result of this project, AT&T has developed the *Climate Change Analysis Tool* to visualize the forecast data from Argonne National Laboratory so that it can begin making smarter, climate-informed decisions for its business, customers, and communities for years to come. In this white paper, AT&T shared its journey from asking questions and seeking help from experts, to building a tool that is now part of a broader solution to climate adaptation. And soon, AT&T and Argonne will be making this valuable data accessible to those who seek to build solutions too.

This is AT&T on the road to **RESILIENCY.**

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