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A Summary of Climate Change Impacts and Preparedness Opportunities for the Transportation Sector in New Jersey

This report is one of a series of working briefs prepared by the New Jersey Climate Adaptation Alliance to provide background information on projected climate impacts for six major sectors in New Jersey, including agriculture, built infrastructure (utilities and transportation), coastal communities, natural resources, public health, and water resources. These working briefs present information to be used throughout the Alliance's deliberations to develop recommendations for state and local public policy that will enhance climate change preparedness and resilience in New Jersey. These briefs are living documents that are periodically updated. This document updates a prior version from January 2013. For more information about the Alliance and its activities, visit http://njadapt.rutgers.edu.

This report provides an assessment of transportation-based infrastructure perspectives on the topic of adaptation planning for climate change in New Jersey including roads, bridges, rail, aviation, ports, and navigable waters. Current New Jersey efforts, as well as current and planned adaptation practices and strategies in other states, are presented as the basis for a series of recommendations to address additional needs as a starting point for discussion and prioritization of comprehensive adaptation planning for New Jersey.

Transportation Infrastructure in New Jersey

Transportation infrastructure in New Jersey consists of the roads, rails, waterways, and bridges and tunnels over which people and goods travel daily. For each type of infrastructure, there are different governance models and responsibilities, complicating the need to understand the appropriate party for responsibly managing these assets for adaptation to climate change.

Road

New Jersey contains 38,000 miles of roadway.[1] An average of 2.6 million vehicles of travel occurs in each lane-mile of roadway in New Jersey each year, compared to a national average of 1.5 million vehicles per lane mile.[2] The annual vehicle miles traveled (VMT) on the state's highway system are nearly 70 trillion. Trucks accounted for almost 10 percent of this travel, at 6.7 trillion vehicle miles. In addition to the New Jersey Department of Transportation, the NJ Turnpike Authority and Port Authority of New York and New Jersey also have oversight and maintenance responsibilities for roadways. Counties and municipalities are also responsible for the construction and maintenance of local roads. New Jersey Transit operates public transit bus services, along with private commuter bus lines offering services to New York City, Philadelphia, and Atlantic City. Trucks are the dominant mode of movement for the freight system, accounting for 75 percent of all goods moved by weight (tons).[3]

Rail

New Jersey's rail system provides critical capacity for the movement of both freight and passengers. New Jersey has four types of railroad infrastructure owners: large Class I freight railroads, smaller regional and short line freight railroads), NJ Transit, and Amtrak. These entities own and maintain the right of way and yards as well as dispatch or control trains. The operating railroad network within New Jersey is essentially divided into northern and southern parts of the state, connected only by the NJ TRANSIT River Line, which operates light rail passenger service during the day and freight shipments at night. The only link from the rail network in southern New Jersey to Class I railroads is across the Delaware River via the Delair Bridge at Philadelphia. This bridge is also connected to Amtrak's

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[1] NJDOT (2008)
[2] PBQD (2008)
[3] PBQD (2008)

Northeast Corridor passenger line, limiting its use for freight operating from the South Jersey port and points north due to its circuitousness, clearance and scheduling conflicts.[4]

Passenger services are operated by NJ Transit, the Port Authority of New York and New Jersey (PATH), and the Delaware River Port Authority (DRPA). Amtrak also operates interstate passenger rail service in New Jersey. NJ Transit owns approximately 982 route miles of rail right-of-way and Amtrak owns and operates the Northeast Corridor and controls 58 route miles in New Jersey. There is a significant amount of sharing of rail rights-of-way among the freight and passenger railroads in New Jersey, through the use of trackage rights agreements, which permit specific carriers to operate over rail lines owned by another company or public agency.[5] Two Class I freight railroads, Norfolk Southern and CSX, and short line railroads operate over the rail network in the State. Through traffic represents almost 19 percent of all rail freight movements in the State, while intrastate rail shipments account for less than one percent of all rail traffic, reflecting the predominant use of the railroads as a long-distance mode of freight transport.[6]

Airports

New Jersey's current airport system consists of 46 public use facilities, three of which (Newark Liberty International, Atlantic City International, and Trenton-Mercer) offer scheduled passenger airline service with the remaining airports serving general aviation. New Jersey's public use airports accommodate more than 2.5 million general aviation operations (landings and takeoffs) each year. Based on FAA data, over 4,400 general aviation aircraft are registered in New Jersey, and approximately 460,000 commercial airline operations take place at New Jersey's three commercial-service airports annually accounting for thirty-five million passengers.[7] The majority of air freight in New Jersey moves through Newark Liberty International Airport (EWR). Nearly 75 percent of the cargo had domestic origins, and most of this cargo was handled by the integrated carriers, with FedEx handling the most.[8] On-airport functions include the operations and development of EWR, which is primarily the responsibility of the Port Authority of New York and New Jersey (PANYNJ). Federal government responsibilities include the Federal Aviation Administration (FAA), which regulates and funds on-airport infrastructure and operations; the Department of Homeland Security/Transportation Security Administration, which manages security-related functions; and US Customs and Immigration, which handles international matters.[9]

Waterways

New Jersey has two major ports areas: A New Jersey/New York port region in the north and a New Jersey/Pennsylvania port region in the south. The Port of New York and New Jersey is a landlord port, which means that the PANYNJ is responsible for providing basic infrastructure (i.e. electricity, water, piers, etc.) to terminal operators, who lease space on the port facility. The Port of New York / New Jersey includes several privately operated container terminals that together rank third in the nation for container volume.[10] The port complex also contains several other types of privately owned terminals for shipping and receiving diverse products such as automobiles, orange juice, petroleum products, scrap metal, and other goods. The former Military Ocean Terminal at Bayonne has a long-term lease agreement with Royal Caribbean Cruise Lines. The South Jersey Port Corporation is an agency of the State of New Jersey that owns, operates and manages the Ports of Camden and Salem (accessed via the Delaware River), overseeing the import and export of international bulk, and container cargos annually into and through South Jersey.[11]

Waterways are maintained through a combination of public and private initiatives. Management of

4 PBQD (2008)
5 PBQD (2008)
6 PBQD (2008)
7 Wilbur Smith Associates (2006)
8 PBQD (2008)
9 PBQD (2008)
10 PANYNJ (2012)
11 PBQD (2008)

dredging activities in New Jersey is divided into three main geographic areas: New Jersey/New York Harbor, Delaware River/Delaware River Ports and State Navigation Channels. The New Jersey Department of Transportation's Office of Maritime Resources manages port related dredging with the United States Army Corps of Engineers and Port Authority of New York and New Jersey, and coordinates with the NJDEP for state navigation channel dredging. The channel depth requirements for these vessels have increased in recent years, with many ports moving to deepen their waterway access channels to 50 feet or greater and also driving an increase to the height of the Bayonne Bridge to provide clearance for larger ships. The Port Authority can invest in terminals, waterway deepening and maintenance dredging (in cooperation with the federal government), and access roads and rail lines.[12]

Bridges and Tunnels

Bridges and tunnels can be held under public or private ownership, depending on the system for which it operates. The New Jersey Department of Transportation, Amtrak, NJ Transit, PANYNJ, and others are all responsible for the maintenance of bridges and tunnels along their rights-of-way in the New Jersey transportation system. A significant number of bridges on the state system are considered deficient. As of 2007, the average bridge age was 49 years old, and 20% of all bridges were over 75 years old, the average design life expectancy of a new bridge. Eight major high cost bridges (defined as those requiring more than $50 million in construction costs) were waiting funding for rehabilitation or replacement.[13] The backlog of bridges for repair, rehabilitation or replacement on the state system was estimated to reach nearly $8 billion by the ASCE.[14]

The construction, repair and maintenance of the state transportation infrastructure is funded through a number of different mechanisms. Public sector funding mechanisms for transportation exist at the federal, state and local levels. The federal government provides funding, either in the form of matching funds or grants, through a variety of mechanisms, including: Map-21, Congestion Mitigation Air Quality (CMAQ) funds, the Transportation Infrastructure Finance and Innovation Act, the FAA Airport Improvement Program and others. The North Jersey Transportation Planning Authority, Delaware Valley Regional Planning Commission, and South Jersey Transportation Planning Organization comprise the three metropolitan planning organizations (MPOs) responsible for managing some of these funds. The Transportation Trust Fund is the major source of state administered funding. In addition, authorities with their own bonding capacity can undertake projects, such as The Port Authority of New York and New Jersey and the New Jersey Turnpike Authority. Some localities may also use their own funding mechanisms to advance transportation projects. Private funding is used more extensively in the freight transportation system than in the passenger transportation system. Freight railroads invest in and maintain their own rights-of-way, equipment and yards, while trucking, maritime, and air cargo firms supply their own equipment and yards, but do not have primary responsibilities for maintaining roads, waterways, and air traffic.

Potential Sector Impacts

Climate change may affect transportation through warming temperatures, temperature extremes, intense precipitation events, drought, and rising sea levels, coupled with storm surges and land subsidence. The impacts of these events will vary by mode of transportation and region of the country, but are estimated to be widespread and costly in both human and economic terms. Potentially, the greatest impact of climate change for North America's transportation systems will be flooding of coastal roads, railways, transit systems, and runways because of global rising sea levels, coupled with storm surges and exacerbated in some locations by land subsidence. Federal, state, and local governments, in collaboration with owners and operators of infrastructure, such as ports and airports, and private railroad and pipeline companies, must understand critical transportation infrastructure in light

[12] PBQD (2008)
[13] NJDOT (2008)
[14] ASCE (2007)

of climate change projections to determine whether, when, and where projected climate changes in their regions might be consequential. We have grouped the impacts into the following categories for discussion:

1. Sea Level Rise and Storm Surge
2. Temperature extremes
3. Extreme weather events

Sea Level Rise and Storm Surge

Sea-level rise and storm surge will increase the risk of major coastal impacts, including both temporary and permanent flooding of airports, roads, rail lines, and tunnels.[15] Sea level rise and storm surges will increase the risk of major coastal impacts on vulnerable energy and industrial infrastructure and transportation, including temporary or permanent flooding of airports, roads, rail lines, and tunnels.[16] More intense precipitation events would increase the risk of disruptions and delays in air, rail, and road transportation, as well as damage from mudslides in some areas. Increases in the intensity of strong hurricanes would lead to more evacuations, infrastructure damage and failure, and transportation interruptions.[17] Underground tunnels and other low-lying infrastructure will experience more frequent and severe flooding. Higher sea levels and storm surges will also erode road base and undermine bridge supports.[18]

Given the high population density near the coasts, the potential exposure of transportation infrastructure to flooding is immense. Population swells in these areas during the summer months because beaches are very important tourist destinations.[19] Six of the nation's top 10 U.S. freight gateways (by value of shipments) will be at risk from sea level rise.[20] These landside facilities will be particularly vulnerable to flooding from an increase in intense precipitation events and to the impacts of higher tides and storm surges from rising. At a minimum, they are likely to result in increased weather-related delays and periodic interruption of shipping services.[21] The navigability of shipping channels is also likely to change. Some channels may be more accessible to shipping farther inland because of sea level rise. The navigability of others, however, could be adversely affected by changes in sedimentation rates and the location of shoals.

An estimated 60,000 miles of coastal highways in the United States are already exposed to periodic coastal storm flooding and wave action.[22] Those highways that currently serve as evacuation routes during hurricanes and other coastal storms could be compromised in the future. Although coastal highway mileage is a small fraction of the nearly 4 million miles of public roads in the United States, the vulnerability of these highways is concentrated in a few states, and some of these routes also serve as barriers to sea intrusion and as evacuation routes.[23] Airport runways in coastal areas face inundation unless effective protective measures are taken. There is the potential for closure or restrictions for several of the nation's busiest airports that lie in coastal zones, affecting service to the highest density populations in the United States.[24] Many critical transportation infrastructure facilities lie at elevations between 2 and 6 m (6 to 20 ft) above sea level, making them vulnerable to current and projected storm surges from hurricanes or nor-easters. As an example, many of the rail and tunnel entrance points, and portions of major airports in the New York metropolitan area lie at vulnerable elevations.[25]

Temperature Extremes

The increase in extreme heat will limit some transportation operations and cause pavement and track damage. Decreased extreme cold will provide some

[15] USGCRP (2009)
[16] NRC (2008)
[17] NRC (2008)
[18] USGCRP (2009)
[19] NRC (2008)
[20] NRC (2008)
[21] NRC (2008)
[22] NRC (2008)
[23] NRC (2008)
[24] USGCRP (2009)
[25] Jacob et al (2007)

benefits such as reduced snow and ice removal costs.[26] Periods of excessive summer heat are likely to increase wildfires, threatening communities and infrastructure directly and bringing about road and rail closures in affected areas. Longer periods of extreme heat may compromise pavement integrity (e.g., softening asphalt and increasing rutting from traffic); cause deformation of rail lines and derailments or, at a minimum, speed restrictions;[27] and cause thermal expansion of bridge joints, adversely affecting bridge operation and increasing maintenance costs.[28]

Warming temperatures and possible increases in temperature extremes will affect airport ground facilities—runways in particular—in much the same way that they will affect roads. More heat extremes, however, are likely to be problematic. They could cause heat buckling of runways. Extreme heat can also affect aircraft lift; hotter air is less dense, reducing mass flowing over the wing to create lift. The problem is exacerbated at high-altitude airports. If runways are not sufficiently long for large aircraft to build up enough speed to generate lift, aircraft weight must be reduced or some flights canceled altogether. Thus, increases in extreme heat are likely to result in payload restrictions, flight cancellations, and service disruptions at affected airports, and could require some airports to extend runway lengths, if feasible.[29]

Extreme Weather Events

Flooding from increasingly intense downpours will increase the risk of disruptions and delays in air, rail, and road transportation, and damage from mudslides in some areas. The increase in heavy precipitation will cause increases in weather-related accidents, delays, and traffic disruptions in a network already challenged by increasing congestion.[30] There will be increased flooding of evacuation routes, and construction activities will be disrupted. Changes in rain, snowfall, and seasonal flooding will impact safety and maintenance operations on the nation's roads and railways. Increased flooding of roadways, rail lines, and underground tunnels is expected. Drainage systems will be overloaded more frequently and severely, causing backups and street flooding. Areas where flooding is already common will face more frequent and severe problems.[31] Increases in road washouts, damage to rail bed support structures, and landslides and mudslides that damage roads and other infrastructure are expected. If soil moisture levels become too high, the structural integrity of roads, bridges, and tunnels, which in some cases are already under age-related stress and in need of repair, could be compromised. Standing water will have adverse impacts on road base.[32]

Impacts from extreme weather events can also affect other infrastructure systems that transportation systems are dependent on. Transportation operations are highly dependent on fully functioning utility systems, which can also be negatively impacted during severe storm events. After Hurricane Katrina, restoration of transportation services depended heavily on the availability of electrical power in order to operate traffic lights, rail signal systems and crossing gates, cranes and pumps, air traffic control nighttime runway lights, and many other transportation functions.31 Similar interdependency issues were experienced following Hurricane Sandy. For example, lack of electrical power limited NJ Transit's ability to refuel its bus fleet, and backup generators were not sufficient to sustain normal operations at most NJT facilities.[33] Loss of power also created a number of issues for the Port of New York and New Jersey, including loss of communications, inability for terminals to handle product, and safety and security concerns resulting from a lack of lighting and security fences.[34] The interdependence of these systems should be closely examined when determining the vulnerability or resilience of the system or operation as a whole.

[26] USGCRP (2009)
[27] NRC (2008)
[28] NRC (2008)
[29] NRC (2008)
[30] Potter et al (2008)
[31] USGCRP (2009)
[32] USGCRP (2009)
[33] NJ Transit (2013)
[34] Smythe (2013)

Table 1 : New Jersey Impacts and Risk for Transportation Infrastructure as a result of climate change

Climate Impacts	New Jersey Risks
Sea Level Rise, Flooding, and Storm Surge	• Inundation of low-lying infrastructure, including substations, delivery lines, roads, bridges, tunnels, rail lines and terminals, land-side port facilities, ferry terminals, airports, and storage and maintenance facilities • Washout and overtopping of roads, bridges, and rail lines • Bridge abutment scours and undermining of road and rail beds • Infrastructure closures resulting in travel delays and disruptions • Sand deposition and sedimentation in navigable channels
Severe Wind and Wave Action from Storms	• Damage to bridge piers and abutments, overhead road signs, traffic signal infrastructure, and overhead wires (from falling tree limbs and downed trees) • Delays in service restoration from interdependent system restoration (e.g., electrical system) • Travel and speed restrictions on bridges
Temperature Extremes and High Heat Days	• Rail expansion and overhead wire sag resulting in operation restrictions and lost distribution efficiency • Pavement damage such as softening of asphalt and increased rutting • Heat buckling of runways and rails • Thermal expansion of pavement and bridge expansion joints • Greater demand for air conditioning on mass transit vehicles and at transit facilities • Unsuitable maintenance and capital planning programs

Particularly Vulnerable Groups

Given the potential effects of climate change on transportation, certain disadvantaged groups have been identified as at risk communities related to the availability of transportation.[35] These groups include:

- Lower income, elderly, or disabled persons with limited mobility that are dependent on public transit for transportation between home and work or social services
- Hourly employees dependent on transit and transportation systems who risk lost wages commensurate with hours of work lost due to inaccessibility

Limited job accessibility, regardless of social status, presents a significant risk to the population and the regional economy. According to the NJDOT (2008), approximately 1 in 10 workers use some form of public transit to get to work, which was twice the national average at that point in time. It was also estimated that more than half of NJ Transit rail customers cross into New York each year, with the primary purpose of commuting to work.[36] Disruptions to the transit system, given the populations reliance on its operation for commuting, are particularly important for the state to manage. Losses of wages were estimated to account for two-thirds of the total financial losses during the 2003 blackout, partially due to the inability to access employment.[37] Maintaining access to employment,

[35] NYSERDA ClimAID Team (2010)
[36] NJDOT (2008)
[37] NYSERDA ClimAID Team (2010)

emergency services, and social services for the general population, and especially those with limited mobility, is necessary in order to mitigate detrimental effects on the population.

New Jersey Specific Impacts

New Jersey's transportation infrastructure is especially vulnerable to climate change because of a densely populated coastline, the presence of critical trade nodes, the location of critical infrastructure in low lying areas, and a high dependence on public transit services when compared to the rest of the nation. In 2009, the North Jersey Transportation Planning Authority (NJTPA) undertook a vulnerability assessment for certain portions of the New Jersey transportation infrastructure, including the Northeast Corridor rail lines and the coastal zones using a grant from the Federal Highway Administration (FHWA). In addition, New Jersey Transit completed a study in 2012 assessing the resilience of NJ Transit assets to climate impacts.[38] Several vulnerabilities for New Jersey came out of these studies.

Sea Level Rise and Storm Surge

As an outcome of the FHWA study, the NJTPA determined that sea level rise poses significant issues for the transportation infrastructure of New Jersey. Evacuation routes are potentially vulnerable, along with almost 260 NJ Transit bus route miles - a potentially significant burden on public transit users.[39] The Garden State Parkway and its principal redundant route (9W) may be subject to inundation in a few key locations (particularly northeast of Atlantic City). Additional roadway infrastructure in less critical tiers could be vulnerable, especially key entry points to Atlantic City and the northern Jersey Shore.[40] The effects of sea level rise and storm surge can be seen by the effects of Hurricane Sandy. More than 300 pieces of rail equipment were damaged. The storm flooded rail stations and terminals, washed out tracks, damaged bridge girders, and miles of catenary wire were pulled down by fallen trees.[41] The impacts felt by New Jersey Transit were indicative of impacts felt throughout public and private transportation systems, with facilities, rights-of-way and equipment all affected by the storm.

Extreme Weather Events and Flooding

Extreme weather events such as hurricanes and other strong storms can have significant impacts from high winds and inland flooding. The NJTPA study predicted increasing vulnerabilities across rail and road networks as a result of such impacts.[42] Potential wet weather impacts to infrastructure are a function of local and/or regional hydrology (e.g., stream flows, drainage capacity, standing water, etc.) and the intensity of the rain or snow event. Intense rainfalls can lead to track and road flooding from adjacent rivers and streams, consistent with the inundation observed during Tropical Storm Irene. For example, a lane of I-287 in Morris County was washed out by the adjacent stream in the wake of Irene. Washouts and flooding have also had effects on rail infrastructure and port infrastructure.[43] Vulnerabilities were also cited for NJ Transit, Amtrak (coincident with NJ Transit's Northeast Corridor Line), and all classes of freight rail lines.[44] Several segments of the River Line (some of which may correspond to bridges) would be potentially vulnerable, along with significant portions of freight track.[45] During the PANYNJ climate change risk assessment, an analysis of interdependent systems concluded that one of the electrical substations was identified as infrastructure at risk. During the planned replacement, the design criteria for the elevation of the substation were changed to account for additional flooding and/or storm surge impacts.[46]

[38] First Environment (2012)
[39] NJTPA (2011)
[40] NJTPA (2011)
[41] NJ Transit (2014)
[42] NJTPA (2011)
[43] NJTPA (2011)
[44] NJTPA (2011)
[45] NJTPA (2011)
[46] PANYNJ (2012)

Temperature extremes

Extreme temperature effects were found to have a significant impact on the infrastructure of New Jersey. The 2012 New Jersey Transit climate vulnerability assessment concluded that days over 90 degrees are problematic for NJ Transit because they cause buckling of rails, sagging catenary lines, damage electrical equipment, and increase the potential for power outages.[47] Through a series of interviews, the NJTPA determined the following physical vulnerabilities to climate change:

- Rail: Heat and cold stresses can often kink or fracture rail track, requiring additional maintenance and presenting a safety hazard. In extreme heat, fixed tension catenary may experience sagging, and constant tension lines may experience failures.
- Bridge structures: Temperatures at both extremes (high and low) cause expansion and contraction of bridge structures. Bridges are designed with dynamic ranges of movement to compensate for temperature fluctuations. Moveable bridges (draw, lift, or swivel) become more susceptible to binding or locking in extreme heat, and interlocking track at rail bridges may fail to connect properly.
- Passenger equipment: In hotter weather, air conditioning needs increase in order to maintain passenger comfort, potentially leading to some auxiliary system failures. This is a particular problem at enclosed stations (such as New York Penn), where hot air exhaust is trapped, and further increasing air conditioning loads.
- Pavement: Extremely hot days may lead to pavement rutting over time, especially for routes with heavy truck traffic. Extremely cold days may cause fatigue cracking, which then increases asphalt's susceptibility to moisture infiltration, which could lead to heaving and deteriorating during freeze-thaw cycles.

These vulnerabilities are a small sample of the potential for failure of infrastructure in an environment with more frequent temperature extremes. Such risks do not only apply to the infrastructure itself, but also to the equipment that operates on it. Effective assessment of the capabilities of equipment, in addition to the infrastructure that it travels on, is essential for maintaining the operations of transportation infrastructure under a changing climate.

State Benchmarking

Several states in the Northeast have formalized processes that account for climate adaptation at the state agency level. Entities in New Jersey have undertaken some initiatives to understand and plan for the impacts of climate change and how they might adapt to such changes. The Port Authority of New York and New Jersey underwent an extensive review of their facilities in order to identify critical assets and determine how to prioritize investment.[48] New Jersey Transit completed a report in 2012 assessing the resilience of NJ Transit assets to climate change impacts.[49] The NJTPA conducted the aforementioned study of vulnerability and determined adaptation recommendations based on analyses of certain critical corridors along coastal and tidal waterways.[50] The NJDEP has also provided analyses and recommendations for climate change adaptation planning. Such recommendations show that New Jersey has to understand a public and private focus on vulnerability and resilience to climate change.[51] However, there are currently no formal and ongoing processes for addressing climate adaptation for transportation infrastructure at the state level, although recent weather events have provided an opportunity for climate adaptation discussions under the auspices of extreme weather preparedness and hazard mitigation. Other states have succeeded in formalizing these approaches and measuring resilience and adaptation actions. In New Jersey, at a meeting to discuss "Preparing NJ for Climate Change," there was consensus

[47] First Environment (2012)
[48] McLaughlin et al. (2011)
[49] First Environment (2012)
[50] NJTPA (2011)
[51] NJDEP (2009)

that although the public is historically reluctant to support long term strategic planning for infrastructure investments, ways to address these challenges include ensuring sound communication between infrastructure planners and scientists along with stakeholders, through development of a statewide plan complemented by specific strategy development for small projects.[52]

In Massachusetts in 2008, the Global Warming Solutions Act was signed into law. Section 9 of the Act required the Secretary of Energy and Environmental Affairs (EEA) to convene and chair an advisory committee to analyze strategies for adapting to the predicted impacts of climate change in the Commonwealth and develop a report of findings and recommendations for the legislature. The report was completed in 2011, and entailed several recommendations for the legislature regarding transportation, as mandated by the GWSA. Those recommendations included developing data collection and analysis resources to fill gaps, analyzing infrastructure to understand vulnerability in greater detail, and other recommendations.[53]

The Maryland Commission on Climate Change (MCCC) was established in 2007 by Executive Order and charged them with developing an action plan to address the causes of climate change and prepare for the likely impacts. The Adaptation and Response Working Group developed an adaptation report addressing the funding and revenue constraints and subsequently understanding how to better spend revenues by assessing the vulnerability of infrastructure systems.[54] Additionally, the adaptation committee suggested that the state also focus on enhancing the education and preparedness of those needing to respond to events caused by increasing numbers of weather hazards. Furthermore, Maryland sought to further institutionalize the considerations of adaptation into state climate change plans. Maryland require updates each year detailing each applicable agency's activities in addressing their respective comprehensive climate plans, including the adaptation component, and plans for the coming year.[55] Maryland Department of Transportation (MDOT) modal administrations, including those responsible for roads, transit, ports, aviation, and other transportation issues, have formally incorporated sea level rise and storm surge projections into planning frameworks for future vulnerability assessment. MDOT agencies have also largely completed vulnerability assessments of infrastructure to sea level rise, and will develop plans to address any critical system vulnerabilities.[56]

New York State's NYSERDA report cites a number of adaptation strategies to be pursued by the State.[57] In 2008, New York City launched the Climate Change Adaptation Task Force, which is composed of 40 public and private entities that operate or regulate critical infrastructure in the city. The Task Force identified more than 100 types of transportation, energy, water and sewer, solid waste, telecommunications, and natural infrastructure that climate change could impact and will use this initial assessment to develop coordinated strategies to increase the resilience of the region's infrastructure, including changes to standard capital and maintenance processes. As part of these initiatives, the Metropolitan Transit Authority (MTA) has undertaken a review of system wide storm vulnerabilities and response policies to support system resilience. The MTA subsequently provides regular updates on progress toward planning for climate adaptation, in addition to mitigation strategies.[58] New York City's recently released report "A Stronger, More Resilient New York", written to address the need for additional resiliency planning following Hurricane Sandy, includes localized climate change projections and a risk assessment of how these changes will impact the city's residents and infrastructure. The report identifies strategies to make the city's transportation system more resilient, including elevating traffic signals and providing backup electrical power, integrating climate-resilient stormwater management features into future capital projects, installing floodgates to protect tunnels from flooding,

52 Rutgers University (2011)
53 EEEA and the Adaptation Advisory Committee (2011)
54 ARWG (2011)
55 ARWG (2011)
56 Maryland Department of Planning (2011); ARWG (2011)
57 NYSERDA ClimAID Team (2010)
58 MTA (2012)

and adding capacity to pedestrian, bicycle, ferry, and bus networks and facilities.[59]

Northeastern states have taken several measures to formalize climate adaptation planning within their jurisdictions. Some have created legislative actions, where others have used comprehensive planning as a measure for measuring and working on adaptation strategies. Each has formalized a stakeholder group important for monitoring, and measuring the progress toward their adaptation goals. They have identified vulnerable areas and potential impacts to those areas, and created partnerships to work together to resolve resilience issues with transportation infrastructure or to improve environmental resilience and outcomes in the face of a changing climate. State transportation and environmental agencies have partnered with the private sector to assess and address climate adaptation strategies.

Discussion and Recommendations

Adaptation efforts in leading states currently focus on identifying vulnerabilities and determining how best to approach climate change in the future. Certain states and municipalities have been able to implement "no-regrets" actions, particularly in developing better data collection protocols and vulnerabilities.[60] Similar recommendations were made as part of the NJ Transit FHWA pilot project, in addition to furthering those actions to develop a statewide and/or regional transportation adaptation plan as the appropriate next step after the completion of vulnerability and risk assessment.[61] New Jersey should coordinate its approach to assessing the vulnerability of the transportation infrastructure of the state. Understanding the vulnerability of the infrastructure can also help to develop more targeted investments in infrastructure to create more resilient systems.

States are subsequently using this understanding to help prioritize and identify areas for infrastructure investment. In compiling the FHWA study, the NJTPA suggests that, "It is unrealistic to believe that New Jersey can provide enough new roadway capacity to match and mitigate the peak period demands, nor enough new capacity to even maintain the level of service experienced today as time moves forward."[62] Further limitations based on climate change will exacerbate these conditions. Redundancy and reliability options will have to be created through the effective use of existing facilities, and the deployment of new technologies and policies throughout the state. Where investments are made, or maintenance is required, adapting such processes to a changing climate should be considered.

Some states and regions have been successful at incorporating climate change into official planning processes, varying from comprehensive plans, to transportation planning exercises undertaken by MPOs and a host of other exercises undertaken by various stakeholders. State transportation agencies, such as Maryland's modal agencies, are seeking to develop capital planning and strategic planning strategies that will help to account for climate change under current planning processes and project prioritization. Moving forward, New Jersey can focus on formalizing and coordinating transportation planning processes and incorporating climate adaptation into planning, design, construction, operation and maintenance of transportation properties.

[59] PlaNYC (2013)
[60] ARWG (2011), EEEA and the Adaptation Advisory Committee (2011)
[61] NJTPA (2011)
[62] NJTPA (2011)

Table 2 : Specific areas for investigation based on leading practices

New Jersey Adaptation Need	*Potential Initiatives for Investigation and Projects*
Understand Transportation System Vulnerability and Resilience	• Develop a work plan with local and regional scientists to improve understanding of climate change and projections • Quantify the vulnerability of the system to potential climate impacts of demonstrated risks such as saltwater intrusion, storm surge and inland flooding • Understand and promote resilience of critical facilities through partnerships with businesses • Review current regulation with a focus on climate adaptation including: o Project permitting o Capital planning and land use regulation o Design and construction standards
Integrate Climate Adaptation with Planning and Regulation Processes	• Develop a stakeholder group to organize and coordinate state-level adaptation planning and implementation • Investigate methods to incorporate climate change into long-term capital improvement plans, facility designs, maintenance practices, operations, and emergency response plans • Research investment analysis methods and design approaches that account for uncertainty, and clearly communicate tradeoffs to decision makers for funding authorization • Develop a process for better communication among transportation professionals, climate scientists, and other relevant scientific disciplines • Encourage the development and implementation of monitoring technologies • Investigate methods to incorporate climate change into federal planning for the development of public-sector, long-range transportation plans and collaboration in plan development with agencies responsible for land use, environmental protection, and natural resource management
Prioritize and invest in infrastructure	• Study interdependencies between sectors to ensure that capital planning and asset management strategies are coordinated to support overall resilience • Investigate adjustments to design and construction standards in highly vulnerable locations • Review protocols for inspection and maintenance of existing systems to account for long term climate impacts • Investigate incentives and financing programs for infrastructure improvements and maintenance • Perform engineering-based risk assessments of assets and operations and complete adaptation plans based on these assessments, including financing. • Assess viability of appropriate transportation infrastructure protection in coastal areas such as levees, sea walls, and pumping facilities; elevate bridge landings, roads, railroads, airports, and collision fenders on bridge foundations; design innovative gates at subway, rail, and road tunnel entrances and ventilation openings • Relocate critical systems to higher ground out of future flood zones. • Lengthen airport runways and expansion joints on bridges; upgrade to energy-efficient air conditioning on trains, subways, and buses; use heat-resistant construction materials for pavements and rail tracks.

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