CHAPTER 5

Case Examples

This chapter documents five case examples related to the incorporation of resilience practices by state agencies. Survey respondents were asked if they would like to showcase their agency's resilience practices through the development of case examples. The case examples were developed by using information from the survey, as well as in-depth interviews with staff. The case examples include the following state agencies:

- ADOT,
- CDOT,
- DelDOT,
- PANYNJ, and
- GTC (MPO).

Arizona DOT Case Example

ADOT was chosen as one of the case examples for this report because of their incorporation of resilience practices at different agency levels, use of technology, and willingness to participate. Based on an interview with Steven Olmsted, Innovative Programs Manager, Infrastructure Development and Operations at ADOT, information regarding the agency's projects for resilience, extreme weather and climate adaptation, sustainable transportation, and ADOT/USGS partnerships was gathered and summarized. Mr. Olmsted is responsible for developing Infrastructure Health and Sustainability initiatives along with resilience and climate adaptation projects.

ADOT is a multimodal agency responsible for over 30,000 maintenance lane miles (of the 140,000 state maintenance miles); 4,700 bridges (of the 7,800 state bridges); seven districts; 1,500 facility buildings; the Grand Canyon Airport; and the Department of Motor Vehicles. The agency's mission is "to provide a safe, efficient, cost effective transportation system" (Arizona Department of Transportation, Online). The strategic focus areas of the agency are safety, workforce development, infrastructure health, innovation, and financial resources.

Since 1966 Arizona has had 195 declarations of emergencies and currently has five federal disasters remaining in the open status (Arizona Department of Emergency and Military Affairs, Online). The five open federal disasters resulted from a range of events, including winter storms and monsoon storms that caused flash flooding, damaging winds, and hail. The major threats that ADOT has to manage include the effect of heat extremes, dust storms, wildfires, flooding, landslides, rockfall, and slope failure (Arizona Department of Transportation, Online).

In 2013, ADOT published a report based on a Preliminary Study of Climate Adaptation for the Statewide Transportation System in Arizona. In 2015 this study was followed by the agency's managed transportation infrastructure and state-specific Extreme Weather Vulnerability

Assessment included in FHWA's Climate Change Resilience Pilot Program [Arizona Department of Transportation, 2013 and 2015; FHWA Online (a)]. The vulnerability assessment focused on the interstate corridor conformed by I-19, I-10, and I-17 and included climate-related threats such as extreme heat, freeze–thaw, extreme precipitation, and wildfire. The project resulted in a qualitative assessment of the interaction between extreme weather and climate change with various land use and transportation facility types.

Based on these previous efforts, ADOT established the Resilience Pilot Program as an outgrowth of their Sustainable Transportation Program and subsequently operationalized a full resilience program (RP) in October 2015. The primary mission of the RP was to strike a balance between predictable asset deterioration curves and erratic extreme weather events. To do this, the RP is focusing its efforts on the following:

- Centralizing efforts to address erratic extreme weather events and their effects on assets within this office;
- Introducing extreme weather adaptation to the agency and engineering design processes;
- Establishing an understanding of transportation asset sensitivity to extreme weather events;
- Downscaling climate data to the transportation asset level for analysis;
- Incorporating actions into the decision-making process, including planning, design, construction, maintenance, and operations; and
- Capitalizing on available partnerships, technologies, and tools (Olmsted et al., 2016).

Capitalizing on partnerships, ADOT has established a working relationship with USGS through 2020 that provides $1 million a year to adapt digital, numerical, and dimensional data suitable for ADOT consumption and use (Olmsted et al., 2017). As part of this partnership, ADOT/USGS developed projects in December 2015 to study Arizona's state route (SR) 93 roadway expansion and realignment and SR 160 Laguna Creek Bridge Scour.

ADOT has successfully worked with analysts from USGS to better understand the potential flow and path of extreme rain events and how those flows may affect ADOT assets. As was noted by Steven Olmsted of ADOT, often hydraulic analysis is limited to right-of-way boundaries, and USGS is able to model accumulation and flow of rainfall much further upstream of ADOT assets, allowing for a better understanding of the potential effect of storms. The RP has expanded this work and is now incorporating advanced technologies, including direct storm monitoring and data collection, post-storm indirect event monitoring and data collection, and next generation LiDAR and drone data collection capabilities to its modeling capabilities through its partnership with USGS. This approach is allowing ADOT to better plan for and respond to flooding, overtopping events, and extreme weather events. They are also working to incorporate this new information into stormwater management practices, scour modeling, drainage location, design, and construction. From a policy standpoint, ADOT believes that this effort better aligns the agency to respond to federal extreme weather regulatory activities and informs the National Environmental Policy Act process and wetlands delineation (Olmsted et al., 2017).

ADOT has begun to incorporate their efforts into specific project designs. In October 2015, ADOT pilot tested the Resilience Investment Economic Analysis on a pavement preservation project on SR 191 with an estimated preliminary budget of $5 million. Initially the project was not to address drainage, but engagement of the RP staff helped flush out the expected return on investment and increased facility resilience through the replacement of multiple drainage structures. Inspection revealed that 61 of the 86 corrugated metal pipe drainage structures had suffered 25–100% degradation due in part from erosion and slope instability. The RP staff worked with district staff to gather information regarding costs associated with replacement of 31 drainage structures to further extend the project life cycle, address regulatory considerations, and lower the probability of water undermining the embankment, pipe washout, overtopping of the road due to buried or lower capacity, and end-of-life drainage structure capabilities. In the end the investment was estimated to increase the project budget by $300,000 in order to meet the objectives set out by the RP staff.

In 2016, ADOT initiated another project referred to as the Laguna Creek project in which data from the USGS Arizona Water Science group provided ADOT with real-time storm monitoring and data collection; post-storm event monitoring and data collection; and next generation hardware/software and surface water flow data, including LiDAR, drone data, rapid deployment streamgage, non-contact velocity sensors, video camera and particle tracking data collection, and 3D land surface models. As a result of this analysis, several design recommendations were made, including installation of spur dikes along Laguna Creek Bridge, channel improvements to increase the hydraulic performance of a bridge in the project area, and riprap spur dikes to protect bridge abutments from 500-year events.

All of the past resilience projects helped to identify lessons learned and areas of improvement for incorporating resilience practices at the agency. Some of the key lessons learned include the following:

- Challenges for data acquisition (e.g., the need for high, special resolution of climate data and processing tools).
- An understanding of data uncertainty within climate projections and vulnerabilities.
- The need to balance resources with project scope.
- The need of internal and external stakeholder input when conducting assessments.

ADOT sees the efforts of the RP touching on funding and tool development, its 5-year construction program, emergency response, roadway/bridge/drainage decisions, geotech, and more. The commitment to the program has helped to establish a continuity of the program that will improve its chances of success and incorporates different agency areas such as planning, design, construction, operations and maintenance taking advantage of available technologies, tools, and partnerships.

Colorado DOT Case Example

CDOT was chosen as a case example because of the experience the agency has had with the incorporation of resilient practices into their designs during the 2013 flood recovery effort. In addition to the 2013 major flooding event that resulted in over $750 million in highway asset damage, Colorado has experienced 10 major disaster declarations in the past 20 years with most of the declarations being related to floods, mudslides, landslides, wildfires, and tornadoes (FEMA, Online).

Following the most recent floods and fires in the state, the governor formed the Colorado Recovery Office in 2013, later renamed the Colorado Resiliency and Recovery Office (CRRO), which seeks to improve resiliency planning, development, and implementation through collaboration, coordination, and outreach to local, state, federal, and private partners. With support from the CRRO, the Colorado Recovery and Resiliency Collaborative was formed with representatives from local, state, and federal agencies whose focus is on working to improve communications and coordination between organizations involved in Colorado's flood and fire recovery. The vision of this group is to "Create, improve and promote resilient communities through mentorship and guidance in recovery." In support of that vision, the CRRO has published reports, including *Putting Disaster Recovery Lessons Learned Into Action*, a report that includes all the lessons learned after the 2013 floods and fires in the state, and the *Local Government Guide to Recovery*, a planning tool to help agencies develop emergency management programs from pre-event planning to emergency recovery (Colorado Recovery and Resiliency Collaborative, 2015 and 2017).

Another important effort from the CRRO was the publication of the *Colorado Resilience Framework* in May 2015 as a long-term commitment to a more resilient state and statement of partnership among many sectors, including federal, state, and local agencies; non-profits; and business and community members (State of Colorado, Online, b). The resilience framework integrates six major sectors: economic, community, health and social, housing, watershed and natural resources, and infrastructure. One of the main strategies from the framework for the infrastructure sector is the assessment of infrastructure risk to determine a comprehensive approach to hazard mitigation, along with the development of policies to integrate resilience approaches at the design and construction levels.

In addition to the efforts underway through the CRRO, CDOT has been proactively seeking resilient solutions to damage incurred during the 2013 flood event. In response to the event, CDOT established a flood recovery office (FRO) to coordinate and oversee recovery and resilience efforts (CDOT, Online, a). As part of this effort, CDOT adopted a process for their flood ER program, based on risk assessment, to justify resilience and mitigation projects at locations that suffered severe damages from the 2013 floods. CDOT adopted the ASME Innovative Technology Institute's RAMCAP Plus framework to assess future risk with existing or resilient design alternatives. RAMCAP Plus was developed in response to the terrorist attacks of September 11, 2001. Initially focused on terrorist or directed threats, it has evolved to include all physical threats, including those related to natural threats such as weather-related hazards and seismologic events. Since 2002, many hundreds of nationally recognized experts; scientists; engineers; industry leaders; academics; and federal, state, and local government officials have been involved in continual development of the RAMCAP Plus risk and resilience framework (AWWA Staff, ASCE/AWWA Committee, 2009). RAMCAP Plus has the additional advantage of more than a decade's worth of application across diverse sectors of the U.S. economy, and it is also well known among federal agencies. As an example of applicability of this framework in another sector, AWWA developed a set of standards (J100-10) for all-hazards risk and resilience analysis and management based on this framework (AWWA Staff, ASCE/AWWA Committee, 2009).

Since 2013, CDOT has tailored the generalized RAMCAP Plus^{SM} methodology to a sector-specific analysis framework, referred to as risk and resilience for highways process. Applying this framework, the likelihood and intensity of each specific threat for each asset, the system, and related services is calculated using the following risk equation:

$$R = C \times V \times T$$

where R (risk) and C (consequence) are measured in dollars; V (vulnerability) and T (threat) are each expressed as probabilities.

The expected consequences from each threat depend on the particular asset and threat under analysis, and it is calculated as the worst reasonable case for the event. These consequences are determined based on historical data and agency experts input. Consequence can be categorized as asset replacement cost, user costs (i.e., wages and vehicle running costs), human fatalities, injuries, and environmental impacts. The vulnerabilities of the asset or system are calculated as the probability to experience the expected consequences, which are also derived from literature, historic and empirical data, and stakeholder input. In addition, threat is calculated as the probability of a particular event to occur, and it is derived from historic and empirical data. As a result of the product of these three factors, risk is calculated as the expected annual monetary losses from applicable threats.

This formula makes it possible to weigh alternatives for managing risk and improving resilience. Benefits of potential mitigation measures can be assessed in terms of risk avoidance or increased resilience. Risk, mitigation, and resilience can then be incorporated into the prioritized annual investment decisions, aligning the risk and resilience assessment outcomes with an agency's overall performance goals.

Figure 17 provides an overview of the risk and resilience for highways process adopted by CDOT from the RAMCAP Plus process.

From its inception, one objective of the FRO was to adapt the RAMCAP Plus methodology to build back better. The model was used to quantify expected losses, evaluate consequences, and develop mitigation alternatives related to the flood. This approach was informed by the 1976 Big Thompson River/Cache la Poudre River floods, previous severe flooding in the same area as the 2013 floods (Shroba et al., 1979). Recovery decisions were guided by the definition of risk adopted by CDOT: "Risk is the expected annualized monetary loss of an asset from any defined threat that reflects the likelihood of that threat as well as the vulnerability of that asset to that threat" (Flannery et al., 2014). This methodology linked risk and resilience to risk-based asset management, quantifying results in terms of expected annual monetary losses. Models used in CDOT's risk and resilience analysis reflect the following:

- A probabilistic threat analysis,
- The asset condition,
- The threat geographic location and context,
- The interdependency of nearby assets,
- Vulnerability, based on asset condition and mitigation strategies,
- Asset engineering design standards, and
- Post-event emergency repairs and permanent repairs.

Risk- and resilience-based asset management decisions were developed from empirical data derived from various national databases maintained by organizations such as the USGS, FEMA, and the U.S. Department of Agriculture, as well as by regional data generated in response to the Colorado floods (e.g., LiDAR). Flood recovery decisions took into consideration the design standard of the asset, the age of the asset, the location of the asset, and the interdependency of assets with the network. Decisions reflect the interdependency between pavement, roadway prism, channel and bridge design, and mitigation strategies. Benefit–cost metrics and the annual reduction in risk and annual resilience metric provided by each mitigation strategy were calculated.

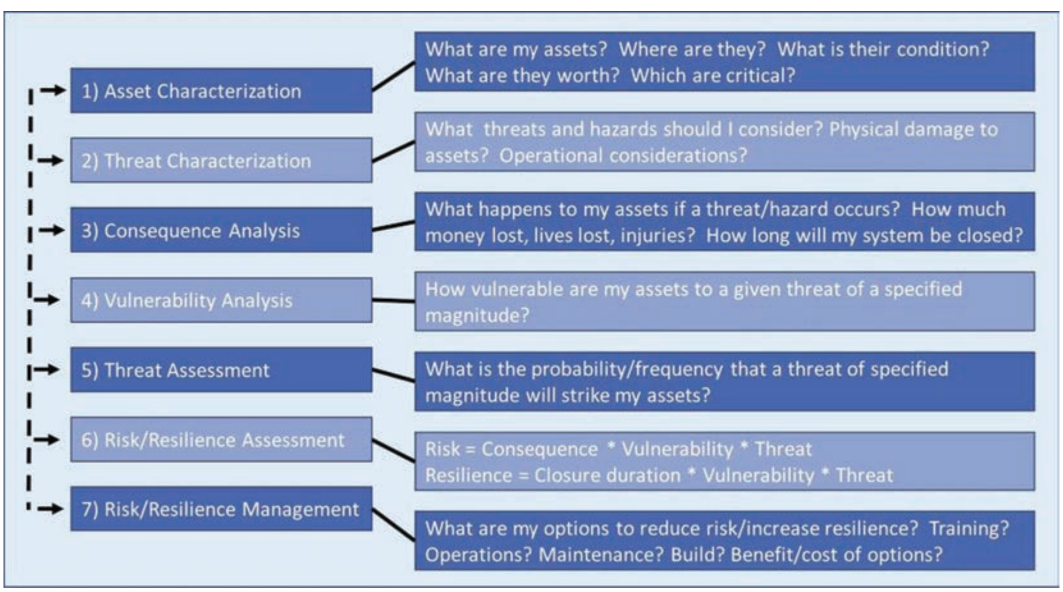

Figure 17. Risk and resilience for highways adapted from RAMCAP Plus.

Building on its experience with the risk and resilience for highways approach, CDOT initiated a pilot program in August 2016 for asset management for the I-70 corridor across the entire state (approximately 470 miles in length). The project addresses proactively the quantification of risk and resulting system resilience of relevant physical threats on the corridor. The project is conducting an all-hazards analysis for most assets in the corridor, including the following hazards: bridge strike, rockfall, flooding (including scour, overtopping, and debris flow), landslides, avalanches, wildfires, and direct threats (manmade). In addition, the assets analyzed included bridges, roadway prism, culverts, walls, tunnels, and ITS devices.

The project was completed in November 2017 and engaged staff from all five regions of CDOT through a working group comprised of 12 staff members with a range of expertise, including project engineers, operations engineers, transportation planners, asset managers, and maintenance supervisors. In addition, an executive oversight committee was engaged in the project to oversee the project findings and to help strategize as to the potential uses of the information being provided through the project.

Findings of the project included a criticality model developed with input from CDOT staff to help understand which assets along I-70 are most critical to corridor resilience and annual risk calculations that reflect owner and user costs (where user costs reflect the redundancy and additional travel time and distance for detours around closures). Risk calculations were developed at the individual asset level to reflect the vulnerability of each asset to each applicable threat in situ. Annual risk information can be provided at the individual asset level or asset class level or categorized by threat type.

CDOT has engaged their commission in the study and is currently considering next steps to expand the pilot study to additional corridors and a range of program areas, including planning, resilient design, risk-based asset management, maintenance, and operations.

Delaware DOT Case Example

DelDOT has been using resilience and sustainability practices in their agency for the past 10 years. These initiatives have been incorporated at different agency levels such as planning, engineering and design, operations, and policy. An interview with Dr. Silvana Croope (8 May 2017) from DelDOT offered an overview of this effort. Dr. Croope has an extensive knowledge on the development and implementation of resilience practices in the transportation sector, through the development of a decision support system to improve resilience of critical infrastructure.

DelDOT is a multimodal transportation agency that manages and provides users access to roads, rails, buses, airways, waterways, bike trails, and walking paths. The agency is responsible for 13,507 lane miles of highways, 1,520 bridges, 1 ferry, 56 toll lanes, over 8,000 miles of storm drains, 93 buildings, and many other assets (Delaware Department of Transportation, 2009). DelDOT offers a key connection to the Mid-Atlantic corridor, connecting dense populated areas of New York; New Jersey; Pennsylvania; Maryland; Washington, D.C.; and Virginia.

Delaware has been affected by natural hazards, including challenges associated with being a low-lying coastal state (the lowest average land elevation in the United States) with 381 miles of shoreline. The agency's most prevalent natural hazard is inland and coastal flooding along with the effects of high tides, winds, salt water intrusion, storm surges, and sea-level rise (Delaware Flood Avoidance Workgroup, 2016). Hurricanes and nor'easters can exasperate this hazard through strong winds, storm waves, and high tides that cause flooding and erosion to coastal areas. Earthquakes also affect the northern region of Delaware, which has been classified by FEMA to have a moderate seismic risk. Sinkholes are also being monitored by the Delaware Geological Survey and are considered a hazard in the state, especially in regions where the geomorphologic conditions are present (University of Delaware, n.d.). In addition, more than 17% (331 square miles) of the state's land area, including 6,000 road miles and over 18,000 structures, fall into FEMA's special flood hazard area [1% annual chance of flooding or 100-year flood insurance rate maps (FIRMS)] (Delaware Flood Avoidance Workgroup, 2016).

FEMA has recorded 16 major disaster declarations in Delaware since 1962, including the most recent winter storm and flooding in 2016 and Hurricanes Sandy and Irene in 2012 and 2011, resulting in five emergency declarations having been issued since 1993. Most of these major disasters and emergency declarations have been related to hurricanes, flooding, and major storms, with a few related to snowstorms, blizzards, and droughts (U.S. Department of Homeland Security, Online, b).

Due to the exposure of Delaware transportation assets and the effect of climate change, DelDOT has been studying and implementing many strategies to assess and reduce the vulnerability of state assets and increase the resilience of their systems and networks. Climate adaptation and resilience are terms widely used among Delaware state agencies in their efforts to avoid disruptions to their critical systems and networks. DelDOT defines resilience as "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events" (The National Academy of Sciences, 2012). Currently, DelDOT has not developed or adopted any formal resilience metrics.

To assess the resilience of DelDOT's systems and networks, DelDOT participated in one of the first vulnerability assessments for the State of Delaware for sea-level rise as a collaborative effort of multiple state agencies (Delaware Coastal Programs of the Department of Natural Resources and Environmental Control, 2012). Results of this assessment were released in July 2012, and a guide was published in 2013 with recommendations for state agencies, local governments, businesses, and individuals for building capacity for adapting to sea-level rise (Delaware Coastal Programs of the Department of Natural Resources and Environmental Control, 2012; Delaware Sea-Level Rise Advisory Committee, 2013).

As follow-up to this document, Delaware organized a workshop in March 2014 to bring together stakeholders from different areas to develop implementation actions for sea-level rise adaptation (Delaware Department of Natural Resources and Environmental Control, 2014). During the workshop, a Transportation and Infrastructure Workgroup was formed to focus on recommendations, particular to transportation assets, and the concern from transportation agencies regarding the management and maintenance of their infrastructure. DelDOT completed an analysis regarding legal issues of infrastructure disinvestments and completed a bridge rating based on sea-level rise. Some of the recommendations in this guide include improved coordination of permit decisions for adaptation projects among federal, state, and local officials and incorporation of sea-level rise into planning, policy, and budgeting levels.

At the policy level, Delaware has released multiple state policies to reinforce federal initiatives on the implementation of resilience practices. In 2011, a law (Senate Bill 64) addressing statewide flooding risk was signed by the governor to address Delaware's coastal and inland flooding vulnerability and to identify higher floodplain and drainage standards. Also, a sea-level rise adaptation policy was developed to serve as a pilot for future initiatives and statewide application. In 2013, the governor of Delaware created the Governor's Committee on Climate and Resilience and signed Executive Order 41 (EO 41): *Preparing Delaware for Emerging Climate Impacts and Seizing Economic Opportunities from Reducing Emissions* (State of Delaware, 2013). EO 41 builds on previous policies and requires state departments and agencies to incorporate measures and initiatives to prepare for emerging climate impacts and to incorporate sea-level rise scenarios and increased flood heights into construction projects and long-range planning. Three workgroups were created under the secretary's direction, and the work and collaboration of these workgroups was summarized on the Delaware climate framework approved by the governor in December 2014 (Cabinet Committee on Climate and Resilience, 2014). The climate framework proposed a series of 150 recommendations to state agencies related to regulations, policies, mitigations, and implementation plans to reduce state greenhouse gas emissions and to improve state preparedness and resilience to climate change.

In March 2016, a manual titled *Avoiding and Minimizing Risk of Flood Damage to State Assets: A Guide for Delaware State Agencies* was released to help state agencies in this process (Delaware Flood Avoidance Workgroup, 2016). In addition, 11 existing policies and programs were identified where flood risk reduction practices at the project planning, design, and funding programs levels, among others, should be incorporated (Delaware Flood Avoidance Workgroup, 2016). Along with this guide, many other projects have been developed to assess the vulnerability and resilience of Delaware to flooding and sea-level rise. A key component of asset vulnerability assessment is the development of the state climate change scenarios and projections. In 2014, a Climate Change Impact Assessment was developed for the State of Delaware releasing historic climate change trends and future climate change projections for temperature and precipitation (Delaware Department of Natural Resources and Environmental Control Division of Energy and Climate, 2014). In this assessment, there is a study of the effects of changes in precipitation, temperature, and sea-level rise in different sectors, including infrastructure.

In addition to the assessment of climate change scenarios and the resulting consequences on the resilience of the state transportation infrastructure, the development of mapping tools for flood risk identification has been an important factor in determining the vulnerability of transportation assets. With the collaboration of engineering consultants and state agencies, three types of maps were developed for Delaware that can be used for flood risk identification: the FIRM, normally used and developed by FEMA; the Sea-Level Rise Inundation Map, created by the Department of Natural Resources and Environmental Control Delaware Coastal Programs in 2009 to estimate potential inundation from sea-level rise; and the Flood Risk Adaptation Map, which is the only one of the three maps that combines the risk of sea-level rise and coastal storms. Only the FEMA maps are regulatory, but the three maps can be used as planning tools to identify areas of potential flood and inundation risks. All three maps have their limitations and uncertainties and are mainly used as screening tools to identify sites with potential vulnerability to flooding.

To support the use of these additional data sets and mapping, DelDOT has invested to improve their asset inventory, bridge design manual, data collection systems for roadway weather information, monitoring of traffic flow, and roadway conditions and traffic operations. Some of the initiatives include projects to develop an inventory of their roadways using LiDAR, the addition of sensors to measure water levels, speed and volumes to collect and analyze flood data and support climate analysis, improvement of their data analysis capabilities and GIS, use of risk assessment tools such as mapping tools and an improved data exchange to Hazus model (FEMA), and scenario-based debris estimates, among many other initiatives (Cabinet Committee on Climate and Resilience, 2014). To document the progress toward these recommendations along with challenges and identified required resources to achieve these goals, DelDOT is currently developing a Strategic Implementation Plan for Climate Change, Sustainability, and Resilience for Transportation.

Some of the challenges faced by DelDOT to achieve its resilience goals include funding, especially for projects not mandated by regulations; lack of training for climate change impacts and its effects on agency investments; lack of knowledge of available tools; lack of clear direction and training regarding climate change; and the need to coordinate across divisions, districts, other state agencies and establish a holistic regional and subregional coordination. Related to funding challenges DelDOT faces is the revision of the need, or not, for transportation catastrophe insurance in order to be able to fund mitigation alternatives to recover from catastrophic events (Croope, 2017).

Some of the next steps for DelDOT's work on resilience include the creation of an asset inventory that any other state agency can use and update, utilization of new 3D models and simulation, development of a statewide transportation risk map, and exploration of different funding opportunities to support resilience initiatives. These efforts will help policy makers, designers, planners, emergency response managers, and others to make better decisions when incorporating adaptation and resilience practices at different levels. To overcome some of these challenges, an ongoing effort is working with support from the National Institute of Standards and Technology to evolve transportation resilience in consideration to the community and adopt a programmatic and project level economic assessment (Croope, 2017).

Some of the challenges DelDOT faced during the implementation of their Hazus risk assessment and loss estimation tool on their projects include the ability to input local transportation data. As part of a collaboration with the Delaware Emergency Management Agency, DelDOT got into an agreement with the University of Delaware to build a user-friendly solution to enabling all Hazus users of the state to work with Hazus in a supported technical process and a user friendly GIS portal. This is up and running and has been given to FEMA's Mitigation Framework Leadership Group for considerations (Croope, 2017).

DelDOT has developed multiple projects and is collaborating with multiple state agencies. In addition, DelDOT has strong support from the state and upper-level leadership to the incorporation of resilience initiatives. However, DelDOT is facing many of the same challenges as other transportation agencies regarding guidance, standards, better policies, lack of sufficient budget, among other challenges, related to the incorporation of resilience practices at the planning, engineering, management, policy, and administration levels (Delaware Flood Avoidance Workgroup, 2016).

In addition, DelDOT emphasized the 3D approach the internal work related to risk and resilience is taking and how it better supports decision making by confirming assessments and trends. The 3D approach can be summarized by the following:

- The government approach: FEMA Hazus;
- The academic/scientific approach: currently working with the University of Delaware on a few projects; and
- The market approach: re-insurance industry modeling approach (Croope, 2017).

Many of the existing models today still have a great level of uncertainty; DelDOT emphasizes the importance to "support data-based-decision making plus professional experts input" (Croope, 2017).

Port Authority of New York and New Jersey Case Example

PANYNJ has developed and implemented resilient practices in different areas of the agency, including planning, engineering, operations, and policy as well as at different modes (e.g., transit, port, highway, aviation). Information for the PANYNJ Port Department's resilience initiatives was obtained through an interview with Stephan Pezdek, senior project manager for port planning, resiliency, and sustainability, and Bethann Rooney, assistant director, both from the Port Department. Further information for other agency departments is based on a literature review and published sources. The case example summarizes the work and contributions done not only by PANYNJ's Port Department but also by the overall agency in terms of the implementation of resilience practices.

The PANYNJ is a bistate agency that oversees the design, building, operations, and maintenance of key infrastructure for the transportation network of the New York City (NYC) metropolitan region, which includes New York and New Jersey. PANYNJ is a multimodal agency that oversees 31 major facilities including two tunnels, four bridges, six airports, five marine terminals and ports, two major bus stations/terminals, two rail systems, and the World Trade Center (Adams, 2015). The Port Authority has different departments that vary vastly in terms of the type of assets to maintain and operate as well as population served. One of the major PANYNJ departments is the Port Department. This department operates as a landlord port, where most of their tenants manage their own equipment and facilities. However, it is the Port Department's responsibility to maintain the roadways, a large share of the railway infrastructure, water, sewage, stormwater, snow removal, and a number of other portions of the infrastructure that support the tenant operations. The Port Department is a freight, maritime, and transportation function of PANYNJ. The type of assets that the Port Department maintains is vastly different than some of the other Port Authority departments, such as Port Authority Aviation, PATH, and tunnels and bridges, which includes public transit and bridge and tunnel functions. The reach and effect of the Port Department is to over 127 million people in the United States and Canada. The Port Authority is responsible for only the waterways at their facilities (Pezdek and Rooney, 2017).

These important transportation facilities have been exposed to multiple natural and human-made hazards: The terrorist attack of 9/11 (2001), Hurricane Irene (2011), and Hurricane Sandy (2012) are some of the events that have caused major damages. New York had over 60 major disaster declarations since 1954, including Superstorm Sandy, and 22 emergency declarations since 1974, most related to flooding, hurricanes, severe storms, and high tides, followed by winter storms and terrorist attacks (U.S. Department of Homeland Security, Online, b). Similarly, New Jersey has had over 30 major disaster declarations since 1955 and 11 emergency declarations since 1974, with most related to flooding, hurricanes, severe storms, and high tides (U.S. Department of Homeland Security, Online, b). In recent years, the States of New York (NYS) and New Jersey as well as NYC, have introduced resilience, sustainability, and environmental practices into their policies and guidance to reduce the effects from these types of events.

Some of New York's and New Jersey's resilience efforts include the creation of the NYS Resilience Institute for Storms and Emergencies (NYS RISE), Climate Change in NYS Projections (ClimAID), Community Risk Reduction and Resiliency Act, Climate Smart Resiliency Planning assessment tool, Sustainable Jersey Resiliency Program, New Jersey's Coastal Community Vulnerability Assessment and Mapping Protocol, and Getting to Resilience: A Coastal Community Resilience Evaluation Tool.

One of the first resilience initiatives in NYC was initiated by the release of a long-term sustainability plan called PlaNYC (currently OneNYC), which was initiated in 2007 by the Bloomberg administration in response to the city's long-term challenges, including change in climate conditions and aging infrastructure. To help accomplish the goals outlined in PlaNYC, the City's mayor organized the first New York City Panel on Climate Change (NPCC) in 2008. The NPCC was composed of a body of leading climate and social scientists and risk management experts to give advice on issues related to climate change and adaptation. It produced a set of climate projections specific to NYC. In January 2013, following Hurricane Sandy, the second NPCC (NPCC2) was convened, and a report was published to provide up-to-date scientific information and analyses on climate risks for use in the Special Initiative for Rebuilding and Resiliency (New York City Panel on Climate Change, 2013). NPCC2 was followed by NPCC3 in a January 2015 publishing of the NPCC latest report: *Building the Knowledge Base for Climate Resiliency: New York City Panel on Climate Change 2015 Report* (The New York Academy of Sciences, 2015). The latest report provides climate change projections through 2100; new coastal flood risk maps; enhanced dynamic flood inundation modeling, including effects of sea-level rise; and a process for enhancing the city's resilience indicators and monitoring systems (City of New York, 2015b).

Followed by the updates of NCPP and PlaNYC, different commissions have been created to evaluate key vulnerabilities of the city's critical infrastructure, including energy, transportation, land use, insurance, and infrastructure finance. Recommendations made related to the transportation sector include the following (NYS 2100 Commission, 2012):

- Developing a risk assessment of the city's transportation infrastructure;
- Strengthening existing transportation networks;
- Expanding transportation networks to increase redundancy; and
- Creating enhanced guidelines, standards, policies, and procedures.

Based on these projections and models, the city was identified to be vulnerable not only to flooding from storm events and sea-level rise but also to heat waves, heavy downpours, and severe drought (City of New York, 2015b).

Along with New York's and New Jersey's resilience efforts, the Port Authority has also developed their own resilience and sustainability policies for over 20 years.

Figure 18 presents some of the most important timeline of policies, guidelines, and initiatives that reflect New York's, New Jersey's, NYC's, and PANYNJ's resilience efforts.

In July 2006 PANYNJ issued Administrative Instruction 45-2 (AI-45-2) in order "to reduce adverse environmental impacts of the design, construction, operation and maintenance and occupancy or leasing of new or substantially renovated buildings and facilities, reconstruction projects, and programs" (The Port Authority of NY & NJ, 2011). Because of these policies, a series of sustainable design guidelines and frameworks were created to help the agency meet the requirements of AI-45-2. Port Authority and tenants are required to implement the *Sustainable Building Guidelines* on capital projects, and Port Authority is required to implement the *Sustainable Infrastructure Guidelines* (The Port Authority of NY & NJ, 2011 and 2017).

In 2015, a new set of guidelines was established to address climate impacts such as increased precipitation, temperature, severe storms, and sea-level rise for all Port Authority's capital projects and includes a stepwise process for building flood resilience. These guidelines are captured in PANYNJ's *Engineering Department Manual* as the Climate Resilience Design Guidelines and are divided into two primary sections: climate resilience and flood resilience. The first section provides an overview of future climate conditions in the region and offers examples of how agency infrastructure could be modified to increase resilience specific to climate change (The Port Authority of NY & NJ, 2009 and 2015). The design guidelines also establish the flood protection criteria for projects and describe a series of 10 steps to follow by engineers and architects to increase the flood resilience of assets. These steps include

1. Identify flood risks to project scope,
2. Determine the influence of any area or systemwide strategy,
3. Identify if project is part of an emergency plan or enterprise risk plan,
4. Review current codes,
5. Determine funding source requirements/guidelines,
6. Identify critical infrastructure,
7. Determine life expectancy,
8. Determine flood protection level,
9. Perform benefit–cost analysis, and
10. Establish flood resilience criteria.

PANYNJ also evaluated the vulnerability of its infrastructure to a range of climate change events, specifically to sea-level rise, storm surges, increased precipitation, and higher temperatures. Currently, the Port Department has identified areas where climate change might affect their infrastructure and systems and have taken steps to reduce the risk of future damage of

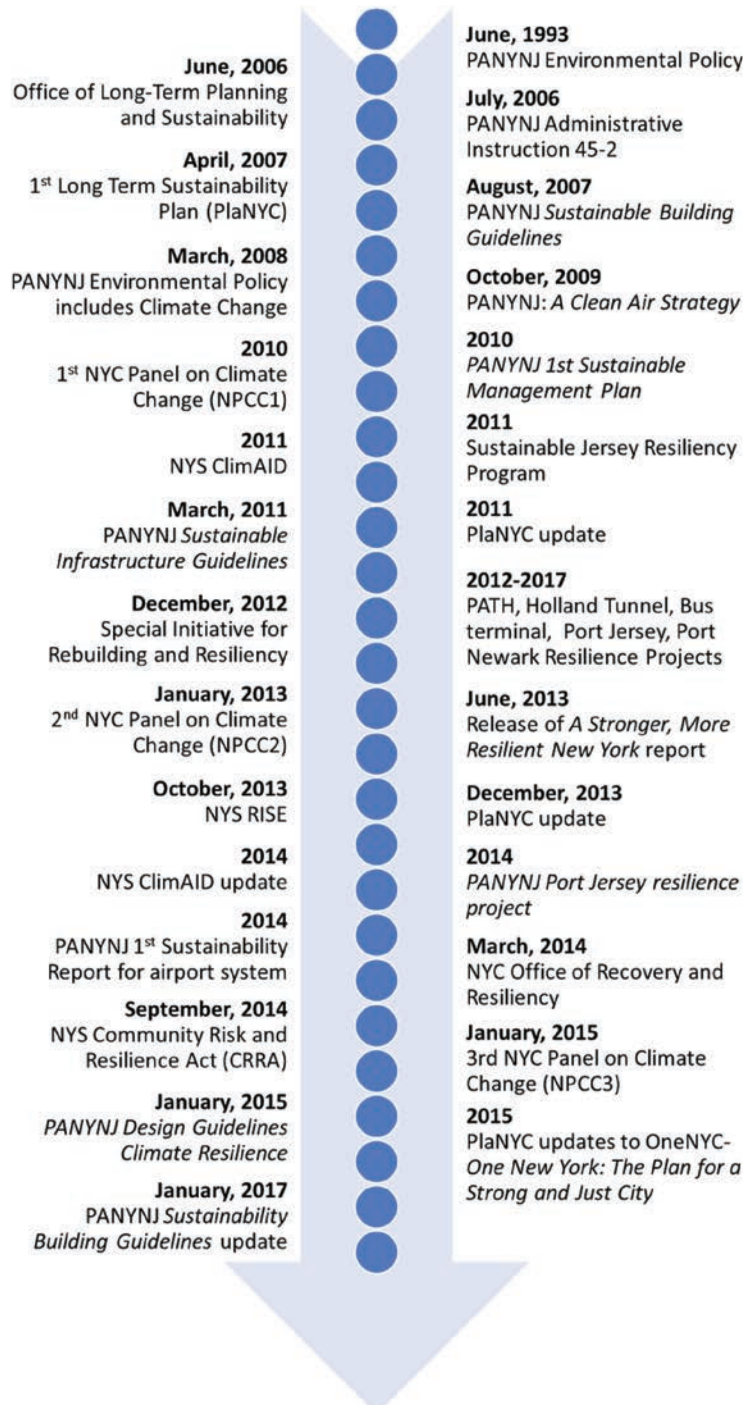

Figure 18. New York and PANYNJ resilience timeline.

their facility by elevating critical infrastructure, relocating equipment, wet-proofing applicable systems, and investing in systems to reduce system vulnerabilities. This has been in line with the PANYNJ's resiliency guidelines (Pezdek and Rooney, 2017).

To assess the long-term vulnerabilities of the agency's infrastructure to climate impacts, the Port Authority used the 50th percentile projections completed by the NPCC3, as recommended by the Office of Energy and Environmental Programs. These projections are generally applicable to a 100-mile radius around the NYC metropolitan area and are used as the benchmark for PANYNJ's resilience guidelines (Pezdek, 2016). PANYNJ analyzed climate-related vulnerability and level of risk for a wide variety of agency infrastructure, including airports, marine terminals, tunnels and bridges, rails, bus stations, and other facilities. The risk analysis was used to prioritize the highest risk assets and develop adaptation strategies for those assets. Furthermore, PANYNJ performed a quantitative and qualitative risk assessment based on the likelihood of particular threats during the asset's lifetime and the magnitude of the consequences of such events. The output of the analysis was used in a risk matrix and used for investment prioritization of adaptation projects in the immediate term.

One of the main lessons learned during the process of development vulnerability and risk assessment to the agency's infrastructure includes the importance of access to accurate data and information, including institutional knowledge. Accurate data were critical for vulnerability and risk analysis. In particular, reliable information in terms of asset topography and elevation was important to assess risks related to flooding caused by storm surges and sea-level rise and was used to develop more precise flood maps such as FEMA FIRMs.

Along with developing a risk assessment, PANYNJ has developed an adaptation program to increase the agency's infrastructure resilience, putting in place a wide variety of adaptation strategies. The adaptation program includes security, climate change, operational, and physical adaptation projects. This program includes internal projects as well as collaboration with other external agencies in the state. Some of the internal projects include asset inventory, multihazard risk assessments, creation of new sustainable design guidelines, and physical and operational projects, among others. In addition, PANYNJ has collaborated on climate change and sustainability projects with other state agencies, organizations, and projects such as NPCC, NY State Sea-Level Rise Task Force, NY State Climate Action Council, and NY State ClimAID. Some of the challenges of the programs include funding and budgeting, policies and regulations, geographical and operational boundaries, and aging infrastructure, among others (Zeppie, Online).

PANYNJ continues with the investigation of processes to evaluate project priority on the basis of multihazard resilience metrics. The tunnels, bridges, and terminal department of PANYNJ investigated the development of a resilience management framework for critical agency infrastructure that focuses on resilience to all disruptions, incorporates lessons learned, and upgrades based on multiple hazards. Using DHS Science and Technology Directorate's risk and resilience methodologies, the Port Authority completed a pilot program in which these existing resilience management methodologies were applied to the Holland Tunnel and the Port Authority Bus Terminal to evaluate their vulnerability and resilience to flood and storms hazards (Valletta et al., 2015; NYS 2100 Commission, 2012).

In 2014, a pilot project led by FHWA was developed for the Port Jersey facility to study the effects of storm surge and the long-term effect of sea-level rise, specifically the effect to the facility's electrical system. There was an effort to map future inundation levels using the Hurricane SLOSH Model, FEMA, and sea-level maps. This pilot was one of the 10 engineering-based vulnerability assessments focused on transportation assets in the region and helped to better inform and set the agency's climate change resilience guidelines for planning, design, and operations (Pezdek, 2016).

Another effort developed as a partnership of the PANYNJ's Port Department, the Engineering Department, and the Office of Environmental and Energy Programs was the evaluation of the potential effect and risk of possible future storm events, as well as the effect of sea-level rise over the next 40 years, at their Port Newark South Peninsula facility. Some of the critical infrastructure under study included facility buildings, container terminal and storage, dry and liquid bulk, rail yards, and a warehouse. The risk assessment evaluated the likelihood that a given event would affect an asset with a storm surge that would damage, destroy, or not affect that asset. To identify critical infrastructure and dependencies, an asset and operation database was developed using ArcGIS and web maps and later was integrated with heights to develop customized damage curves. Using USGS topographic data and FEMA flood insurance studies for still water elevations and starting wave conditions, an overland wave assessment and analysis was performed. The FEMA GIS-based model, Hazus, was used to determine the general cost effects to the different facilities including buildings and operational components. Some mitigation efforts, studied specifically at the port facilities, included the protection of electrical infrastructure and data centers, among other options (Pezdek, 2016).

Other projects at the Port Authority systems included the reconstruction and flood mitigation at some of its airports. La Guardia, Teterboro, Newark Liberty, and John F. Kennedy airports were affected by Superstorm Sandy and are part of the agency's Flood Mitigation and Storm Resilience Program (Transportation Resiliency Program) (New York State Governor's Office, Online). In 2014, PANYNJ published the first sustainability report covering the Port Authority's airport system, including a chapter on resilience. This chapter provides an overview of the airports' vulnerability to floods, sea-level rise, and storms associated with the effects of climate change (The Port Authority of NY & NJ, 2014).

In addition, PANYNJ has implemented resilience projects at their train system (PATH). The PATH system (tunnels, stations, and substations) was also severely damaged after Superstorm Sandy, causing failure to the power traction system, signals, elevators, escalators, and other electrical devices not only from flooding but also from salt intrusion and corrosion. The recovery effort after the storm event was mainly focused on the assets that were damaged during the event, however, further mitigations incorporate resilience practices to future climate conditions based on the new design guidelines (Adams, 2015).

As part of the OneNYC Plan, the Mayor's Office of Recovery and Resiliency developed an interactive map with the resiliency and recovery projects in the city, including PANYNJ resiliency projects (OneNYC).

The results from the agency's and city's vulnerability and risk assessments help the Port Authority to make better decisions in terms of adaptation options, which might include elevation, relocation, protection, or adaptation. In order to incorporate resilient practices into the agency at the project scoping, planning, design, construction, and operations levels, there has been extensive collaboration among different teams of experts, such as engineers, planners, emergency management, security personnel, and operations (DesRoches and Murrell, 2014).

In addition to the assessment of infrastructure resilience, PANYNJ is also looking at developing better operational plans for alternative methods of moving goods, supplies, and materials during emergencies when Port Authority infrastructure and facilities such as roads, rails, airports, and ports might be at risk or compromised. The Port Authority is sharing the results of the pilots with its tenants to be able to study not only the effects to their facilities but also the regional operations and incorporate the results into business planning (Pezdek, 2016).

Genesee Transportation Council Case Example

As mentioned previously, many state DOTs are including, or are beginning to include, the concept and practice of resilience into their agencies. However, not only are state DOTs incorporating these practices but also many transportation MPOs are developing vulnerability and risk assessments, developing climate change scenarios, and studying the resilience of their systems and assets, making resilience an important part of their transportation plans.

The Genesee Transportation Council (GTC) was chosen as an example of an MPO that has participated in a case example to incorporate resilience initiatives into their agency using FHWA's Vulnerability Assessment Framework. The information in this case example was gathered and compiled from published resources.

GTC is the MPO for the Genesee–Finger Lakes Region (Greater Rochester region) in upstate New York. The region consists of nine counties with a highway and bridge network of 27,000 lane miles of roads and approximately 1,600 bridges that carries over 30 million vehicle miles per day. The surface transportation network in the region is of vital importance for the movements of freight of major metropolitan areas, including New York City, Chicago, and Toronto.

GTC is responsible for transportation policy, planning, and investment decision making in this region, and its mission is to "maximize the contribution of the transportation system to the social and economic vitality of the Genesee–Finger Lakes Region." GTC is also responsible for producing and maintaining the Long Range Transportation Plan (LRTP) 2035, the Unified Planning Work Program, and the Transportation Improvement Program, among other mandated activities and programs (Genesee Transportation Council, 2016a, 2016b, 2017a, and 2017b).

As mentioned previously in the PANYNJ case example, NYS has experienced many disaster declarations due to the effects of major natural and manmade disasters. As a consequence of these catastrophic events, the state, its DOT, and its MPOs have been changing the way they plan, design, construct, operate, and maintain their infrastructure and systems. In order to evaluate and improve the resilience of their transportation system and infrastructure, and after the New York State 2100 Commission's recommendations for developing a risk assessment for the state's transportation infrastructure, GTC initiated a project to develop the first regionwide vulnerability assessment for the Genesee–Finger Lakes Region (NYS 2100 Commission, 2012). This project aligned with the state infrastructure program outlined in 2016 by Governor Cuomo, which established a $500 million extreme weather infrastructure hardening program to fund resilience projects to roadways that had been damaged by weather events. The GTC vulnerability assessment project was a collaborative effort among different stakeholders, including transportation, law enforcement, and emergency management. The project covered the nine counties in the region and had the major purpose of identifying systemwide and asset-specific strategies for hazard mitigation, including natural and manmade hazards, and proposed solutions for preventing or reducing the effects of such events. The vulnerability assessment included infrastructure such as roads (with functional classification of Minor Collector or greater), bridges (along regional roadway network), emergency response facilities, traffic and transit operation centers, highway garages, and fuel storage (Genesee Transportation Council, 2016a).

This assessment also builds on climate change adaptation initiatives as part of their regional sustainability plan (Bovenzi, 2015). The vulnerability assessment plays an important role in evaluating and improving the region's resilience, which is defined as the "ability to adapt to changing conditions and prepare for, withstand, and rapidly recover from disruption" with focus on "enhancing assets to a 'New Normal'" (Bovenzi, 2015). Figure 19 shows a representation of the GTC resilience view.

The GTC vulnerability assessment process has the following five major steps:

1. Identification of critical transportation assets with an inventory of the critical transportation assets across the Genesee–Finger Lakes Region and based on information collected from studies and evacuation plans and input from stakeholders.
2. Identification of natural and human-caused hazards, including a profile of hazard types and geographical extent based on historical records, emergency management and hazard mitigation plans, and stakeholder experiences.

Figure 19. GTC resilience diagram.

3. Understanding of consequences from threats to vulnerable and critical assets with the potential of occurrence.
4. Asset prioritization based on the critical transportation infrastructure vulnerability and developed using a Microsoft Excel scoring method joined with GIS data.
5. Development of strategies for preventing or mitigating the effects of the identified possible hazards (Genesee Transportation Council, 2016b).

Some of the natural hazards identified for the study include floods, winter weather, severe storms, landslides, seismic activity, sinkholes, extreme temperatures, and wildfire. In addition, the following human-caused hazards were also identified: structural failure, fire, hazardous material spills, roadway accidents, derailments, and sabotage/acts of terrorism. The vulnerability assessment was done on three geographical levels: macro (region), meso (municipality), and micro (neighborhood) (Bovenzi, 2015).

The vulnerability assessment is based on a qualitative analysis of the four key factors that define their system and asset vulnerability such as sensitivity of the asset, likelihood of the event, exposure of the asset to particular hazards, and the expected consequence or severity of the effect from such events. These four factors were each assigned scores from 1 to 5 and then added to calculate the total vulnerability score for each particular asset. The process to conduct the vulnerability assessment is based on the *FHWA Climate Change and Extreme Weather Vulnerability Assessment Framework* (FHWA, 2012a). The assessment also uses concepts from other sources such as the outcome of two studies from the Volpe National Transportation Center named *Beyond Bouncing Back: A Roundtable on Critical Transportation Infrastructure Resilience* and *Infrastructure Resiliency: A Risk-Based Framework* (U.S. Department of Transportation, 2013).

The Genesee–Finger Lakes Regional Critical Transportation Infrastructure Vulnerability Assessment final report was published in June 2016 (Genesee Transportation Council, 2016a). In order to perform the assessment, multiple data sources were compiled, including GIS data from various agencies such as New York State Thruway Authority, NYSDOT, and GTC, among other emergency management and planning agencies. Some of the GIS data included asset location, flood maps (FEMA), and other hazard maps.

The hazard identification was county specific; however, it was identified that flooding, severe storms, and hazmat in transit spills were the hazards that pose a significant risk to critical transportation assets across the region (Genesee Transportation Council, 2016a). In addition, the number of assets identified by the assessment to have high or moderately high vulnerability include 20 bridges, 91 roadway segments, and 18 facilities (Genesee Transportation Council, 2016a).

Table 4. GTC Mitigation Strategies.

Key Themes	Categories
• Prevention • Protection • Redundancy • Recovery	• Planning and policy • Communication, education, and awareness • Infrastructure and construction • Natural and land resource protection • Operations and maintenance

In order to mitigate these hazards, GTC developed a hazard mitigation strategy toolbox and placed their strategies into four key themes and five categories. These themes and categories are presented in Table 4. The report provides a toolbox with a range of options for mitigation strategies for each one of the five categories to help agencies to identify possible mitigation strategies (Genesee Transportation Council, 2016a).

Along with the mitigation strategies, a table with potential funding sources is included to help implement these strategies; the funding sources vary from FEMA grants to the FHWA ER program.

The major goal of the GTC vulnerability assessment was the development of a process to prioritize investments on transportation infrastructure projects that help to increase the resilience of the region. In addition, it looks to provide an Excel tool that can be used by different agencies to update or customize their database in order to conduct more localized vulnerability assessments (Genesee Transportation Council, 2016a).

Some of the GTC lessons learned during the vulnerability assessment process include the importance of

- Interagency and intermunicipal partnership and coordination,
- Integration of the vulnerability and risk assessment into the transportation infrastructure investment decision-making process, and
- Integration of the vulnerability assessment findings into the land use and policy decision-making process.

The GTC vulnerability assessment project was featured as one of FHWA's case studies on resilience planning (FHWA, 2016).

Summary

This chapter documented five case examples related to the incorporation of resilience practices by infrastructure agencies. The case examples were developed by using information from the survey, as well as in-depth interviews with staff. The case examples included information from the following agencies:

- ADOT,
- CDOT,
- DelDOT,
- PANYNJ, and
- GTC (MPO).

The three state DOTs included in the case examples began resilience analysis from different starting points. Two of the states were involved in FHWA climate change pilots and have continued their efforts beyond the pilots, and one state suffered a significant loss from a flood event that prompted the agency to begin a proactive assessment of system resilience.

ADOT was involved in the FHWA climate change pilots and has focused efforts on establishing a unique relationship with USGS to improve understanding of the potential flow and path of extreme rain events and how those flows may affect ADOT assets. CDOT is building on lessons learned from the devastating 2013 flood event, which damaged over $750 million in highway assets alone. Using the ASME RAMCAP Plus framework, CDOT is proactively conducting an all-hazards risk and resilience assessment of the I-70 corridor from border to border. DelDOT has focused their efforts on incorporating resilience into their policies and planning areas. Much of the focus of their resilience assessments is focused on sea-level rise and coastal flooding given the state has the lowest average elevation in the country and 381 miles of shoreline. While ADOT is seeking candidate sites for implementation of the information being generated by USGS and their resilience investment economic analysis process, CDOT is taking a systematic look at a specific corridor, I-70, and analyzing all applicable hazards on the corridor through their pilot project. DelDOT, being a coastal, low-lying state, has focused much of their attention on proactive identification of flood-prone areas and incorporating resilience into their planning and policies.

The case example developed for PANYNJ demonstrates how resilience can be incorporated into design policies. The development of guidelines to address climate impacts such as increased precipitation, temperature, severe storms, and sea-level rise provide an approach for state DOTs to begin to include such requirements in their design guides.

The GTC vulnerability assessment project was a collaborative effort among different stakeholders, including transportation, law enforcement, and emergency management. The project covered the nine counties in the region and had the major purpose of identifying systemwide and asset-specific strategies for hazard mitigation, including natural and manmade hazards, and proposed solutions for preventing or reducing the effects of such events.

Similar lessons learned from the case examples include the need for buy-in from management to support resilience analysis, the need for a range of staff to be engaged in assessments, reaching out to nontraditional partners to capitalize on needed and unique data and modeling capabilities, and seeking low-hanging opportunities to demonstrate the value of resilience assessment. Each of the highlighted agencies has experienced extreme weather events in recent years that may have contributed to leadership support; however, dedicated staff within each agency who seek to know more, to proactively manage better, have begun to benefit from lessons learned from recent events, which should help these agencies absorb, rebound, and recover more efficiently from future events.