ENHANCING INFRASTRUCTURE RESILIENCE: A PRACTICAL GUIDE FOR GEORGIA LOCAL GOVERNMENT IMPLEMENTATION

by

ELLA TERRELL

(Under the Direction of Stephan Durham)

ABSTRACT

This study develops a resource and decision guide to support Georgia’s local governments in enhancing infrastructure resilience, focusing on the barriers and needs unique to cities and counties within the state. Through a comprehensive literature review, an analysis of survey data from local government representatives, and structured interviews, this research identifies barriers to resilience implementation and infrastructure challenges experienced by small and large local governments. The resilience implementation barriers, including funding limitations, lack of data and technical expertise, and limited resilience planning resources, are explored to inform actionable strategies for addressing these issues. The resulting guide aligns with common local government needs, offering practical solutions for resilience planning, funding access, and technical support. By presenting resilience opportunities with different levels of cost and implementation efforts, the guide aims to equip Georgia's local governments with the tools to better withstand climate-related impacts and ensure the longevity of critical public services.

INDEX WORDS: Infrastructure resilience, Local government, Resilience implementation, Resilience decision matrix

ENHANCING INFRASTRUCTURE RESILIENCE: A PRACTICAL GUIDE FOR GEORGIA LOCAL GOVERNMENT IMPLEMENTATION

by

ELLA TERRELL

B.S.Env.E, The University of Georgia, 2024

A Thesis Submitted to the Graduate Facility of the University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2025

ENHANCING INFRASTRUCTURE RESILIENCE: A PRACTICAL GUIDE FOR GEORGIA LOCAL GOVERNMENT IMPLEMENTATION

by

ELLA TERRELL

Major Professor: Stephan Durham

Committee: Todd Bridges

Alysha Helmrich

Whitney Pagan

Electronic Version Approved:

Ron Walcott
Dean of the Graduate School
The University of Georgia
May 2025

ACKNOWLEDGEMENTS

This work has been made possible through the generous sponsorship of the Georgia Chapter of the American Public Works Association and through the support of the University of Georgia's College of Engineering and Carl Vinson Institute of Government. I extend my gratitude to Interim Dean Stephan Durham and Walt McBride for their guidance and direction in the creation of this work, and to my committee members, Dr. Alysha Helmrich, Dr. Todd Bridges, and Dr. Whitney Pagan. Thank you to my family and friends for your incredible love and support.

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

1.0 Introduction

1.1 Infrastructure and Resilience

The American Society of Civil Engineers (ASCE) defines critical infrastructure as the physical assets and associated social systems that are so crucial to society that their failure would have extreme consequences to the economy, national security, and/or public safety, health, and welfare (ASCE, 2021). The International City/County Management Association (ICMA) acknowledges that infrastructure can include both economic and social infrastructure assets (Chen & Bartle, 2017). Examples of economic infrastructure managed by a local city or county government include roads and bridges, water supply, sanitary sewer systems, and natural gas lines. Examples of social infrastructure managed locally are schools, hospitals, correctional facilities, government offices, libraries, and parks.

Resiliency in critical infrastructure refers to the capacity to plan for, prepare for, mitigate, and adapt to evolving conditions caused by hazards, allowing for the swift recovery of physical, social, economic, and ecological systems (ASCE, 2021). Enhancing resilience involves instilling the physical infrastructure and social systems with the capacity to change and adapt at a moment's notice while working interdependently with one another.

1.1.1 Comparing Sustainability and Resilience

Sustainability is often used synonymously with resilience, and while there is some shared meaning in the definitions, it is important to decouple their use. Sustainability in critical infrastructure is defined by ASCE as infrastructure that is planned, designed, and constructed in a manner that balances environmental, social, and economic benefits through the project's life cycle (ASCE, 2023). The three spheres of sustainability, environmental (planet), social (people), and economic (profit), combine into what is known as the "Triple Bottom Line". The Triple Bottom Line overlaps in ASCE's definitions of resilience and sustainability, but the two concepts are ultimately different from one another. Resilience is event-driven, focusing on the response to an event (preparation for the short-term), and sustainability is resource-driven, focusing on resource conservation and management (endurance for the long-term). Figure 1.1 shows the Triple Bottom Line and sustainability as a function of resilience, where the more sustainable system is the one that loses less critical functionality during an economic, environmental, or social disturbance.

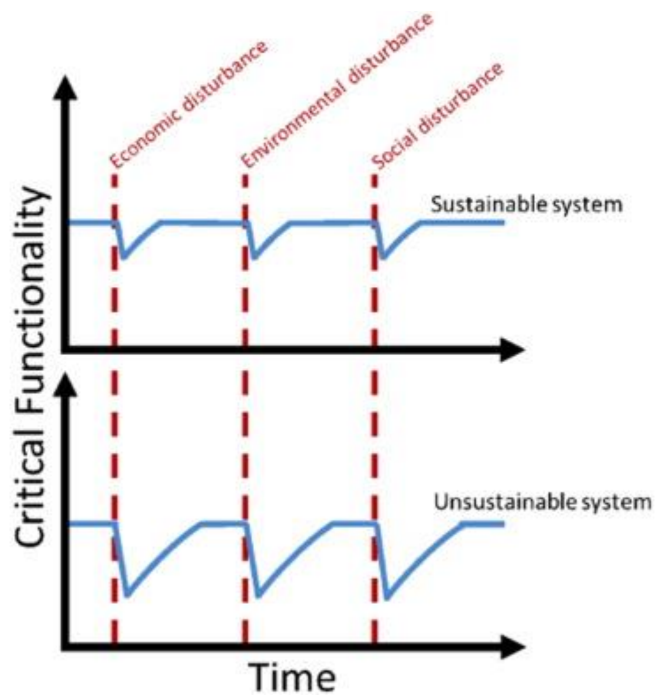


Figure 1.1. Sustainability as a component of resilience, from Marchese et al. (2018).

Posing resilience in this way puts functionality during and after a disturbance as the primary objective. Increases in economic, environmental, or social wellbeing will increase the resilience of the system's functionality. In this framing, increasing system sustainability will increase system resilience, but increasing system resilience will not necessarily increase system sustainability (Marchese et al., 2018).

1.2 Resilience and Non-Stationarity

Historically, if infrastructure has been designed with resilience in mind, it has been under the assumption that future conditions will be the same as the past. This "stationary" resilience approach has been implemented with well-researched, well-quantified hazards, such as earthquakes and large temperature fluctuations (Reid, 2022; Hill & Ayyub, 2019), and is aimed at enabling infrastructure systems to return to their previous state following a disruption or hazard. Designing, maintaining, and operating infrastructure to account for "non-stationarity" is addressing uncertain factors that are not fully quantified yet in a multidimensional context, like the increasing intensity of weather hazards, the acceleration of technology advancements and associated demand on natural resources, and urbanization (Sarhadi et al., 2018; Hill & Ayyub, 2019). Planning for non-stationarity allows infrastructure the flexibility to respond to varying conditions to be successful, which is what resilience demands (Chester & Allenby, 2019). The question that engineers, policymakers, city planners, and government officials continue to ask is which non-stationary factors or conditions, such as the level of climate change risk, should or can be considered when implementing resilience strategies.

1.3 The Significance of Resilient Infrastructure in Local Governments

Mayors across the U.S. have stated the importance of infrastructure improvements and developing plans for "climate-ready infrastructure" (National League of Cities, 2023), because infrastructure success directly relates to economic development, public health, and government budgets. The top three infrastructure areas that U.S. municipalities are most focused on are streets and roads, water, sewer, and reclamation systems, and finally, power utility systems (National League of Cities, 2022). In a 2019 national survey, researchers found that COVID-19 pushed local government officials to adopt an adaptive management approach that led to decisiveness and efficiency of government operations (Dzigbed et al., 2020). Weather-related natural disasters require an efficient emergency response and economic recovery, which necessitates financial resources and a disaster mitigation plan in place before disaster strikes. However, the research shows that local governments with a budget of less than $100 million are generally less prepared for weather-related disasters (3.1 out of 7) than governments with a budget greater than $100 million (4.8 out of 7).

1.4 Structure of Thesis Chapters

This thesis consists of seven chapters that explain the development of the Guide and Matrix for local governments in Georgia to use to incorporate resilience in their infrastructure portfolio. Chapter 2 provides background on the state of infrastructure resilience in Georgia. Chapter 3 contains a broader, national review of the current state of U.S. infrastructure, the state of resilience in infrastructure, and various guides and frameworks that support resilience implementation. Chapter 4 explains this thesis's research objectives and significance. Chapter 5 details the research methodology used to conduct and create the survey, interviews, and resource guide. Chapter 6 discusses research findings and outcomes, and Chapter 7 contains the conclusion and further fields of study within this research area. The appendices contain supplementary material used to develop this research, as well as the Guide and Matrix for the Georgia Chapter of the American Public Works Association (APWA) and Georgia's local governments.

2.0 Background

2.1 Economics of Infrastructure

It is important to distinguish between the different types of goods and services that the public sector provides, as each is financed differently. While private business and governments can offer similar types of goods and services, the management approaches of those products differ. For example, government services are difficult to assign direct value to, since, in most cases, the community does not complete a direct transaction for the service. On the other hand, the private sector must assign a price to their goods and services to derive a profit.

Economic goods can be measured in two dimensions: exclusivity and exhaustibility. An exclusive good requires consumers to pay for its use, whereas a non-exclusive good is available free of charge. An exhaustible good is one that comes in limited supply or capacity, whereas a non-exhaustible good can be used by all without restricting its core function. Table 2.1 presents the four types of economic goods with examples relevant to the scope of this document.

Table 2.1. Four Categories of Economic Goods in the Context of Infrastructure, Occupancy Considerations Forgone, adapted from “The Elements of Nonappropriability” from Mikesell, 2010.

	Exclusive	**Non-Exclusive**
Exhaustive	Private Good • Power • Residential Drinking Water from City Supply	Common Good • Groundwater
Non-Exhaustive	Toll Good • Toll Roads & Bridges • Sanitation Services • Stormwater System with Rates or Fees • Sanitary Sewer System with Rates or Fees	Public Good • Public Roads & Bridges • Public Parks • Public Buildings • Free-use Stormwater System • Free-use Sanitary Sewer System

Many different arguments can be applied to the categorization of infrastructure goods and services, such as public/private water use (Goodwin et al., 2023) and the production/provision dichotomy (Mikesell, 2011).

2.1.1 Accounting Mechanisms of Public Goods

Local governments operate using various types of funds: governmental funds, proprietary funds, and fiduciary funds (Reed & Swain, 1997). It is important to clarify these terms and mechanisms in order to gain a better understanding of the financial structures relevant to infrastructure projects. Governmental funds include the general fund, special revenues, capital projects, and debt service funds. Proprietary funds consist of enterprise funds and internal service funds. Fiduciary funds consist of agency funds and trust funds. Public infrastructure is typically financed/accounted for through governmental funds, like special-purpose local-option sales taxes (SPLOST), grants, the general fund, or proprietary/enterprise funds. Governments follow the Generally Accepted Accounting Principles (GAAP) as the financial reporting standard, but the way in which governments prepare their budgets varies from city to city, under the assumption that it is a legal process.

A local government does not seek to profit from direct user fees for non-exclusive, inexhaustible goods, like a public pool. While citizens might contribute indirectly to these public goods through income, sales, and property taxes, which are directed to the governmental fund, they are not paying directly for the operational costs of a public good. This structure creates competition for funding, which may come from federal infrastructure grants or be allocated amongst other public goods within the same government. Publicly provided “private goods”, like water, sanitary sewer, and storm sewer are usually accounted for in an enterprise fund. Enterprise funds have distinct financial reporting and accounting tools from other government expenditures, which outline direct and indirect costs to customers. This allows governments to set service prices that reflect the significant capital investments made in these systems (Reed & Swain, 1997).

2.1.2 Special-Purpose Local-Option Sales Tax (SPLOST)

Since 1985, Georgia counties can vote on the adoption of a special-purpose local-option sales tax (SPLOST) to fund specific capital projects in a district (ACCG, 2016). A SPLOST is a one percent county sales tax imposed on items in a special district, which is defined by the municipalities or counties that choose to participate and receive funding. All counties and eligible municipalities can receive SPLOST funds. SPLOST revenue can be used to fund long-term capital improvement plans (CIPs), such as road construction, bridge repairs, sidewalk installations, surface/stormwater drainage improvements, and public buildings or facilities, or to pay off general obligation debt. In addition, Georgia offers transportation-SPLOST (TSPLOST) and education-SPLOST (ESPLOST) as specialized options to fund transportation and educational infrastructure improvements within a special district. SPLOST funds can also be used to repair CIPs damaged by natural disasters, providing cities and counties with an infrastructure resilience opportunity.

2.2 Current State of Infrastructure in Georgia

ASCE publishes an infrastructure report card for each U.S. state that grades infrastructure based on the factors of capacity, condition, funding, future need, operation and maintenance (O&M), public safety, innovation, and resilience. In 2024, Georgia received a “mediocre” C+, which it maintained from the previous report card in 2021, meaning that the infrastructure within the system is in “fair to good condition” and shows “general signs of deterioration and requires attention”, with some elements exhibiting “deficiencies in conditions and functionality, increasing vulnerability to risk” (ASCE, 2021). Figures 2.1 and 2.2 show the 2024 and 2021 grades in Georgia broken down by category.

Figure 2.1. Georgia's 2024 Infrastructure Report Card by Category, from ASCE (2024).

Figure 2.2. Georgia's 2021 Infrastructure Report Card by Category, from ASCE (2021).

According to ASCE, Georgia's nearly 11 million residents continue to benefit from increasing infrastructure investments, attracting businesses due to expanding airports, improved road networks, and a diverse energy portfolio. Improvements have been made in the transit, port, and dam infrastructure categories, but rapid growth brings challenges. Atlanta is still the 10^{th} most congested city in the U.S., transit costs are higher than transit revenue, and utility rates have not kept up with national cost increases. Road fatalities have also increased, reflecting ongoing infrastructure and safety issues.

2.3 State of Resilience in Georgia

The Hazards Vulnerability & Resilience Institute at the University of South Carolina published the Baseline Resilience Indicators for Communities (BRIC) Index in 2010, 2015, and 2020 for the continental U.S. While multidimensional frameworks are a more accurate and nuance-permitting method to measure resilience over composite resilience indicators (South et al., 2018), the BRIC index is a mature and replicable methodology that makes the concept more digestible and easier to understand (Bakkensen et al., 2016). The BRIC Index (not affiliated with the BRIC funding program) quantitatively assesses community resilience across six categories: Human Well-Being/Social, Economic/Financial, Infrastructure/Housing, Institutional/Governance, Community Capacity, and Environmental (Cutter et al., 2014). The categories most associated with physical infrastructure assets are Housing/Infrastructure, which measures variables like sturdier housing types, high-speed internet infrastructure, and housing stock construction quality; Institutional/Governance, which measures variables such as mitigation spending, flood insurance coverage, and population stability; and Environmental/Natural, which measures variables like efficient energy and water use and pervious surfaces. The index data is sourced from federal databases and standardized to create the resilience scores (0 being low resilience to 6 being high resilience) for each county. Figures 2.3 and 2.4 show Georgia's BRIC indices in 2015 and 2020 in comparison with the nation and within the state.

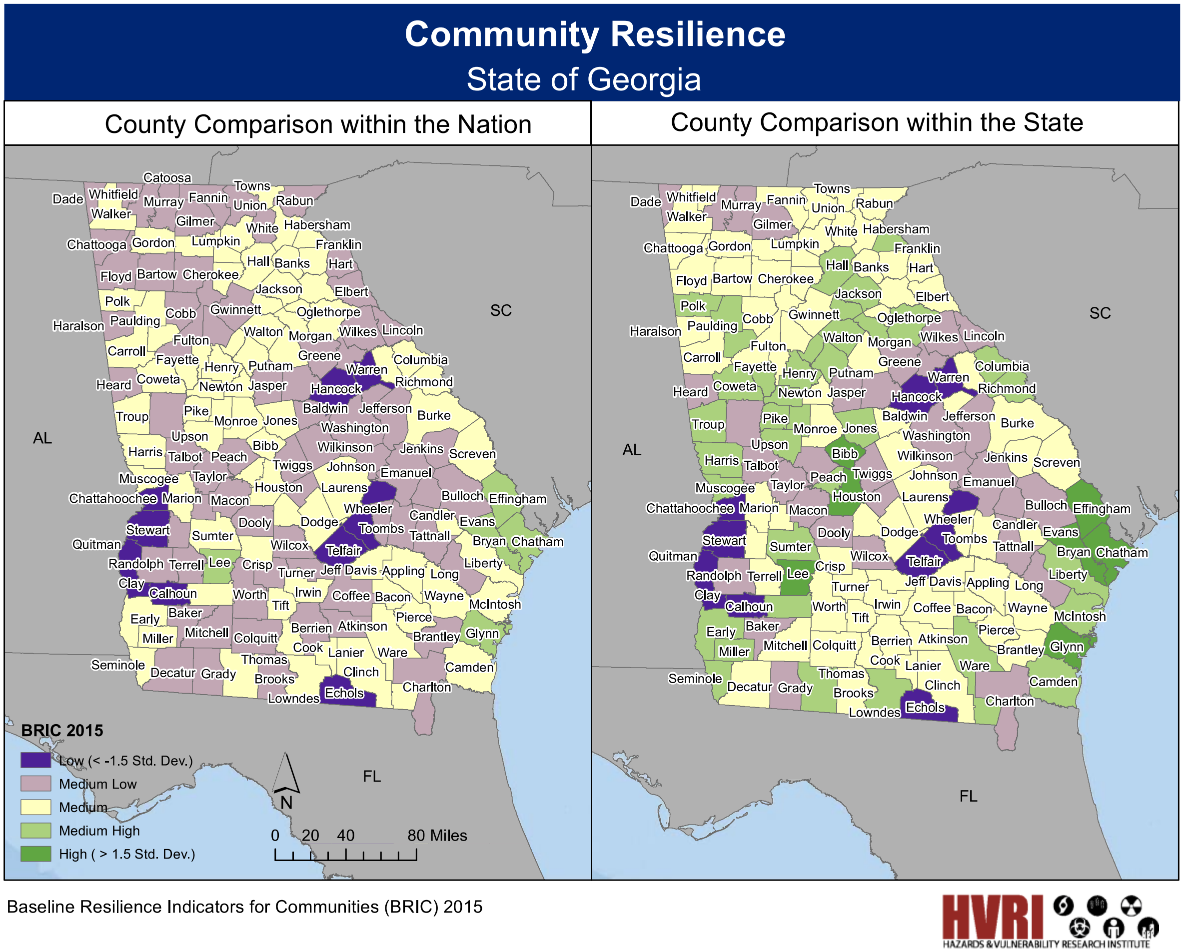


Figure 2.3. Community Resilience BRIC Indices for 2015 for each county in the State of Georgia, in comparison with the rest of the Nation and within the State, from the University of South Carolina (2015a).

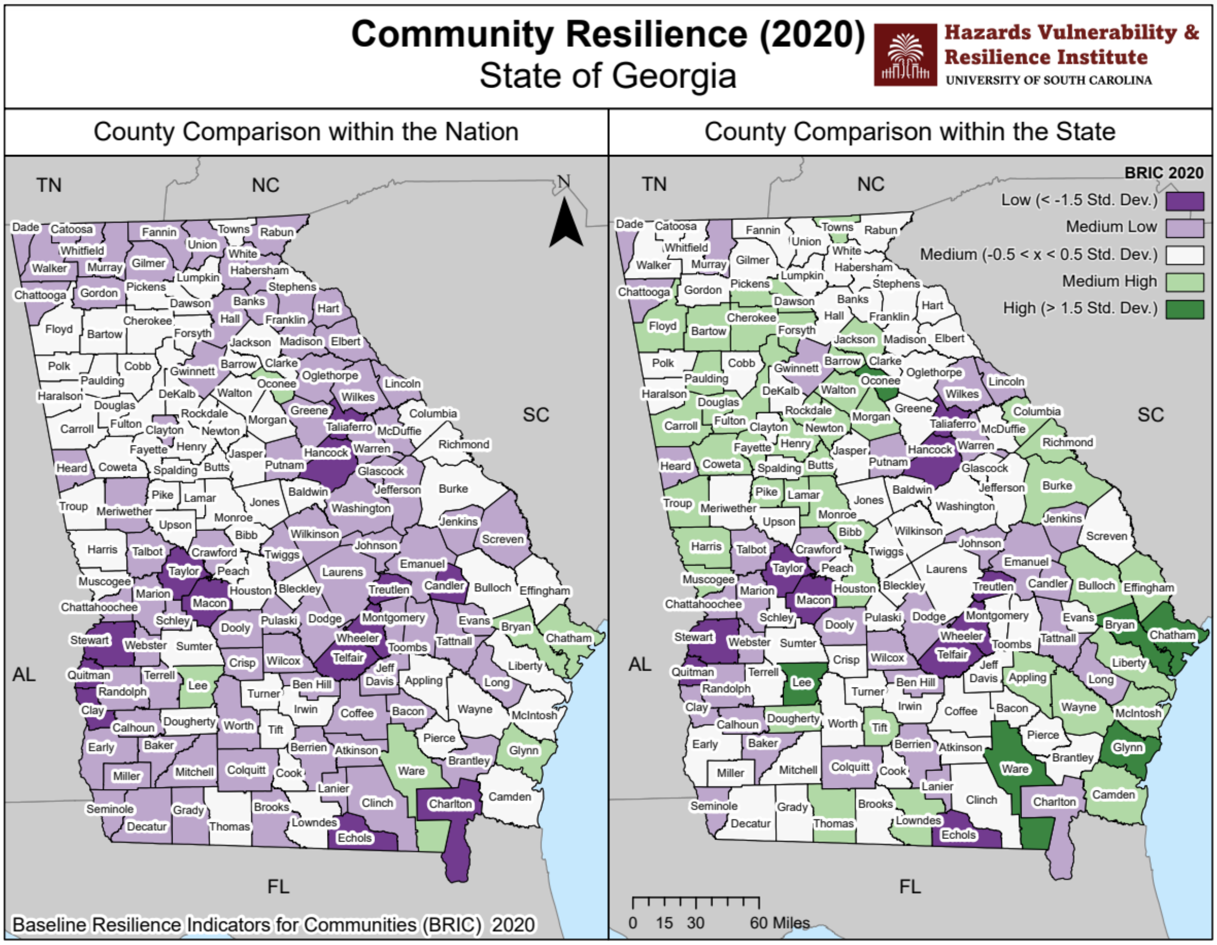


Figure 2.4. Community Resilience BRIC Indices for 2020 for each county in the State of Georgia, in comparison with the rest of the Nation and within the State, from the University of South Carolina (2020b).

Areas around Atlanta, Macon, and Augusta, have the highest BRIC indices. Coastal Georgia counties have high indices, which showcases the effectiveness of their infrastructure amidst the frequent and intense hazards they experience. When looking at the county comparison within the Nation, most of the counties in Georgia move down an index (High to Medium-High, Medium-Low to Low), demonstrating that, on average, Georgia's overall community resilience falls behind that of the rest of the country. When comparing the 2015 and 2020 BRIC Indices, twenty-six counties increased their index in the Housing/Infrastructure category, 13 counties increased their index in the Institutional Category, and only all but one decreased their Environmental index. Every county in Georgia, except for McDuffie County, decreased its overall resiliency score. When looking at the national BRIC scores between 2015 and 2020, 94.5% of counties decreased their total resiliency score. The average 2020 BRIC score in Georgia and the nation is 2.508 and 2.592, respectively.

Georgia's resilience to hazards like flooding, drought, and environmental stressors has declined in recent years, with many counties falling behind national averages in key areas such as infrastructure, governance, and environmental sustainability. While there have been some improvements in housing and institutional resilience, the overall trend points to a need for greater investment and coordination. Measuring resilience both quantitatively, through indices that assess infrastructure and environmental factors, and qualitatively, through stakeholder engagement, reveals the importance of bridging gaps between planning and implementation to strengthen the state's hazard preparedness.

2.3.1 State of Infrastructure Resilience in Georgia

2.3.1.1 At UGA

The UGA Institute for Resilient Infrastructure Systems (IRIS) expands the traditional definition of infrastructure to include natural infrastructure that provides public goods and services, like air and water purification from forests, flood storage and carbon sequestration from marshes and wetlands, and protection for communities against natural disasters from shorelines and barrier islands (Stanford et al., 2024). IRIS's action items include research, outreach, practice, education, and community partnerships to advance resilience through the integration of natural and conventional infrastructure systems. IRIS collaborates on research and implementation projects with a myriad of organizations, such as Ducks Unlimited, the U.S. Army Corps of Engineers (USACE), ASCE, and over a dozen local communities and military installations.

Recent research includes a 2023 IRIS collaboration publication in the Journal of the American Water Resources Association that offered recommendations for improving water infrastructure resilience along the I-85 corridor, addressing challenges despite reduced per capita consumption (Jackson et al., 2023). The research explored various strategies, such as enhancing water-use efficiency, implementing closed-loop systems like Clayton County's wastewater treatment for drinking water, adopting green infrastructure, and utilizing inter-basin transfers, while acknowledging the associated environmental, political, and social challenges. Additionally, a 2024 IRIS Legal, Regulatory, and Policy primer on levee setbacks explained their implementation in government agencies, various funding opportunities, and their regulatory considerations (Huang & Shudtz, 2023). IRIS has also implemented a natural stormwater infrastructure feature in Hinesville, GA's downtown park, which delivers extensive social, economic, educational, and environmental advantages (IRIS, n.d.).

2.3.1.2 In the State of Georgia

IRIS and the Pew Charitable Trusts hosted the Georgia Resilience Roundtable at the Atlanta Regional Commission in December 2023. The event brought together stakeholders from state agencies, city planners, Georgia Power, private companies, and the US DOT to discuss advancing resilience efforts across Georgia. Consensus points included the importance of engaging communities in hazard mitigation planning, bridging the gap between planning and implementation, and promoting cross-disciplinary partnerships, especially to address the challenge of organizational turnover (IRIS, 2023).

Georgia's progress in resilience demonstrates local support, various funding pathways, and evolving approaches to defining and implementing resilience. The Georgia Environmental Finance Authority (GEFA) and the Family of Companies are spearheading a $507 million initiative to enhance grid resilience and clean energy development in Georgia (DOE, 2023). This transformative project focuses on upgrading smart grid infrastructure, including the installation of 80 miles of new transmission lines to connect communities, advanced grid control systems, and substantial investments in battery storage and local microgrids, which will improve reliability and service in remote and underserved communities.

In 2013, St. Marys, Georgia, was selected for coastal flooding resiliency planning by NOAA's National Sea Grant Program, with support from the University of Georgia and Georgia Sea Grant (Gambill et al., 2017). The city had experienced severe flooding from tidal surges, highlighting the need for enhanced flood management. As part of its response, St. Marys joined the Community Rating System (CRS) in 2016—a voluntary FEMA program that rewards communities for exceeding minimum floodplain management standards, leading to reduced flood insurance premiums for high-risk areas. By October 2023, the city had improved its CRS rating from Class 7 to Class 6, increasing premium savings to 20% and saving residents nearly $87,000 annually, while also focusing on preserving open space, enforcing construction standards, and providing flood information. In 2024, 90% of Georgia's 655 communities participated in the National Flood Insurance Program, and 58% of those communities also participated in the CRS (ASCE, 2024).

Examples of projects in transportation resilience include August-Richmond County being awarded $1.7 million to plan a new bus transfer facility for August Transit, replacing the current facility and enhancing it with electric vehicle charging infrastructure and improved safety (Georgia Municipal Association, 2024).

2.3.1.3 Infrastructure Funding Opportunities in Georgia

In Georgia, infrastructure improvements are supported by a combination of federal, state, and local funding programs. The funding opportunities in this section were chosen to be highlighted based on their relevance to infrastructure resilience and their demonstrated impact in Georgia, particularly following the passage of the Infrastructure Investment and Jobs Act (IIJA). Priority was given to programs that provide substantial or targeted support for local governments, especially those focused on resilience adaptation and equity.

Since 1970, the share of U.S. state and local spending dedicated to capital investment in infrastructure has significantly decreased, dropping from around 24% to 16%, with the lowest point reached during the COVID-19 pandemic (U.S. Department of the Treasury, 2024). The passing of IIJA in 2021, which allocates $1.2 trillion of federal funding to energy, transportation, and climate infrastructure projects, has increased this share by 1.6 percentage points in the past two years. As of March 2024, $10.2 billion is being directed toward 473 specific projects in Georgia (The White House, 2024). The announced funding includes, but is not limited to, $5.6 billion for roads, bridges, and roadway safety, $486 million for water infrastructure improvements, $692 million for public transportation improvements, $706 million for clean energy, energy efficiency, and power, and $304 million for infrastructure resilience, including $96 million for flood mitigation through the USACE.

There are several federally funded programs specifically targeted at increasing infrastructure resiliency in America. The Building Resilient Infrastructure & Communities (BRIC) program was created through the Disaster Recovery Reform Act of 2018 and awards grants to communities through FEMA for capacity and capability building (Georgia Emergency Management and Homeland Security Agency). The Rebuilding American Infrastructure with Sustainability and Equity (RAISE) program splits its funding between rural and urban areas and has provided significant funding to persistently disadvantaged areas. The grant allocated $29 million dollars to six Georgia cities for various infrastructure projects, some projected to begin in 2026, at the earliest. Most of the projects awarded in Georgia are for neighborhood connectivity, street improvements, and transit efficiency (Georgia Municipal Association, 2024).

For large-scale capital improvements in stormwater systems, municipalities and state entities often rely on enterprise fund revenue, general obligation bonds, and federal resources (ASCE, 2024). One key federal resource is the Environmental Protection Agency's (EPA) Clean Water State Revolving Fund (CWSRF), which has been instrumental in financing over $2.2 billion in national stormwater projects since its inception in 1987. CWSRF funding has increased dramatically, from $58 million in 2012 to $387 million in 2019, with a growing focus on green infrastructure. The FY24 CWSRF allocated over $95 million to the state of Georgia. The EPA's Water Infrastructure and Finance Innovation Act is another critical federal mechanism, with significant loans provided to stormwater infrastructure projects. The Community Development Block Grant (CDBG) is a grant program through the Department of Housing and Urban Development that targets cities and counties to develop urban communities. This includes funding for the construction of water and sewer facilities that help expand the capacity of a growing city or county (HUD).

The Georgia Department of Transportation (GDOT) budget is funded through federal and state resources (ASCE, 2024). Federal transportation funding primarily comes from the Highway Trust Fund, which has benefitted from recent infusions from the IIJA. The IIJA will provide stable funding through 2026, ensuring the continuation of vital roadway projects. State funding is supported by the Transportation Funding Act of 2015 and the Transportation Investment Act, which have collectively provided billions of dollars for transportation projects across Georgia. GDOT's Statewide Strategic Transportation Plan and the Major Mobility Investment Program are key initiatives that benefit from this funding, helping the state to tackle critical projects like the I-285/I-85 bottleneck and the I-85 widening projects. The Local Maintenance and Improvement Grant (LMIG) is a state-level program that allocates funding based on total centerline road miles, providing financial assistance to 576 projects in FY23 (GDOT, 2024).

Wastewater infrastructure funding largely comes from sewer user fees and connection fees and is supplemented by federal programs like the CWSRF (ASCE, 2024). GEFA is also key in financing wastewater projects by offering low-interest loans and leveraging federal funds to support over $4 billion in stormwater and sanitary sewer improvements since 1985.

Bridge maintenance and replacement in Georgia are also heavily reliant on federal funding, primarily through the Highway Trust Fund and additional allocations from the IIJA (ASCE, 2024). The IIJA will direct, at a minimum, $45 million annually to each state for bridge replacement and rehabilitation, which will be distributed through the Bridge Formula Program (BFP). The Bridge Investment Program (BIP) is a competitive grant option for bridges on the National Bridge Inventory. The Promoting Resilient Operations for Transformative, Efficient, and Cost-saving Transportation (PROTECT) Program and Rural Surface Transportation Grants can also be used to fund bridge resilience projects.

Public buildings and facility improvements, such as those in parks and schools, can be funded from sources like SPLOST, federal grants, and state grants. Public parks in Georgia benefit from federal grants such as those from the National Land and Water Conservation Fund and projects funded by the Trust for Public Land. These programs have supported the development of public spaces, contributing to the state's commitment to preserving green spaces and providing recreational areas for residents. For K-12 schools, Georgia’s 2024 budget allocated $13.1 billion to the Quality Basic Education program, though inflation and cost-of-living increases present ongoing challenges. Local property taxes play a significant role in supplementing state funding, but disparities in local tax revenues can lead to varying levels of support across districts, impacting the quality and availability of educational facilities (ASCE, 2024).

Grid transmission and distribution (T&D) systems are undergoing significant upgrades to enhance reliability and resilience in Georgia. Georgia Power Company's recent Grid Investment Program, supported by $1.3 billion from 2020-22 and an additional $7 billion planned for 2023-25, focuses on improving distribution and substation assets (ASCE, 2024). The Inflation Reduction Act (IRA) of 2022 and federal programs like the Grid Resilience and Innovation Partnerships further support these efforts, offering loans and grants for renewable energy projects and grid improvements, particularly in disadvantaged areas.

3.0 Literature Review

This literature review began by examining the evolution of resilience in infrastructure and the increasing volume of resilience literature. The next step was to assess the state of U.S. infrastructure using the ASCE National Report Card and supporting resources. The review then analyzed resilience definitions and practices within each infrastructure sector, including real-world examples and case studies that display the efficacy of resilient infrastructure. Finally, an analysis of current resilience-focused guides and frameworks and the visualizations they provide to communicate resilience opportunities was conducted. Many papers were found based on searches in Google Scholar and UGA Libraries using the keywords *Resilient infrastructure, Local government, Infrastructure financing mechanisms, Resilience decision-making, Public works, and Climate change impact*. The case studies and resilience guides for this literature review were selected using local government websites and databases from reputable sources that apply engineering strategies to tackle climate resilience, such as the EPA's Creating Water Resilient Utilities database, American Society of Landscape Architects case study database, and the NOAA Climate Resilience Toolkit. The purpose of synthesizing this literature is to inform the development of a comprehensive resilience resource guide.

3.1 History of Infrastructure Resiliency in the U.S.

Infrastructure resilience in the United States began to evolve in the late 1980s (Fisher et al., 2018). Figure 3.1 shows the progression of the focus phrases during the resilience evolution in the U.S. The gradual thickening of the dashed line across the top of the figure represents the attention growing for infrastructure resilience through time.

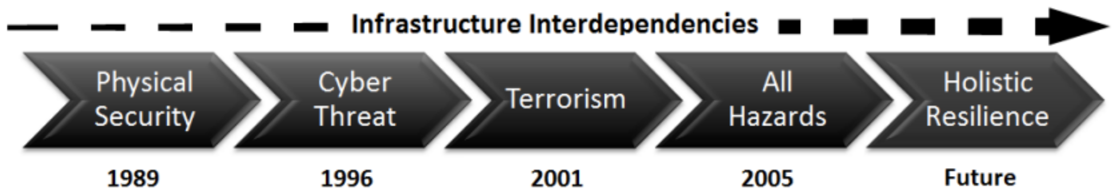


Figure 3.1. Progression of the Phrases of Focus in Resiliency in the United States, from Fisher et al. (2018).

U.S. resilience policies have evolved, starting with cybersecurity and critical infrastructure protection in the 1990s, and then expanding to include national disasters after 9/11 and Hurricane Katrina. The current "Holistic Resilience" period emphasizes a comprehensive approach, integrating community, organizational, social, and personal resilience perspectives. The U.S. formally recognized the importance of resilience in its 2010 National Security Strategy, expanding its focus from physical and cyber threats to a broader range of disruptions.

Liu et al. (2022), a comprehensive literature review of infrastructure research published on the Web of Science and Scopus, shows that the frequency of publications over infrastructure resilience dramatically increased from 2011 to 2021 (see Figure 3.2). Nearly half of all selected studies, drawn from a diverse array of journals, concentrated on the issue of resilience and how it pertains to critical infrastructure and interconnected systems broadly. The remaining half focused on specific infrastructure types, such as power systems, transportation services, and roadways.

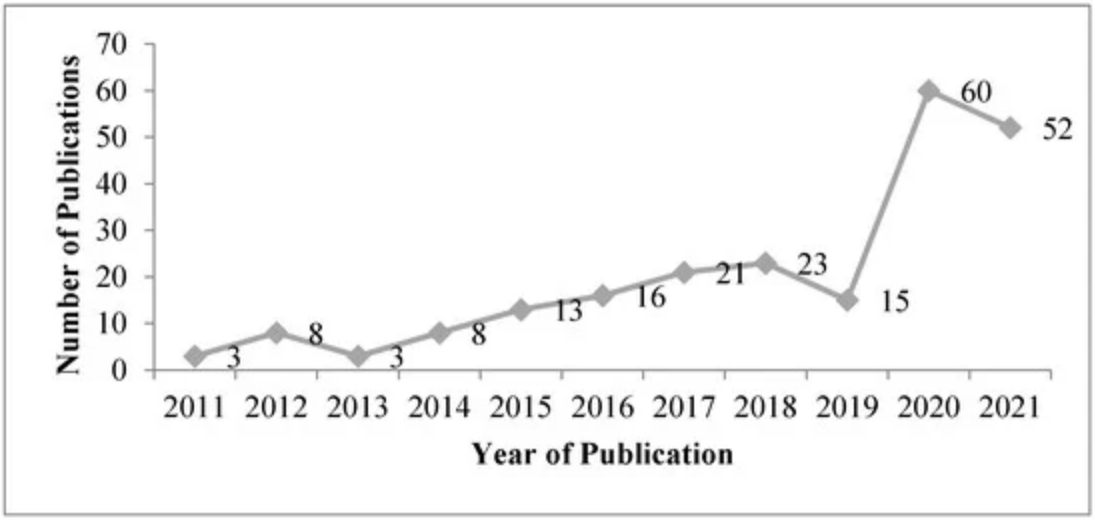


Figure 3.2. Number of Publications on the topic of Infrastructure Resilience over time, from Liu et al. (2022).

The paper notes that one of the most probable reasons for the large uptick in publications in 2020 is the large number of natural disasters that have sparked a frenzy of studies in the research community.

3.2 Current State of Infrastructure in the U.S.

ASCE publishes a nationwide scorecard every four years for each infrastructure sector. In 2021, the nation received an overall letter grade of C-, meaning the general state of infrastructure was "mediocre and showed general signs of deterioration that require attention". ASCE recommends a strong focus on resilience to raise the national infrastructure grade, The following sections explain the nationwide grades received by ASCE in 2021 for specific infrastructure categories that are generally provided, operated, and/or maintained by local governments (Chen & Bartle, 2017).

3.2.1 Stormwater Systems

ASCE graded stormwater systems a D, meaning "Poor, At Risk" and "approaching the end of their lifespan" (ASCE, 2024). Traditional concrete structures, like drains and ditches, green infrastructure, and natural riverine systems are examples of what ASCE classifies as stormwater infrastructure. ASCE estimated that there are 3.5 million miles of storm sewers and 270 million storm drains, though national stormwater system record-keeping is poor; only 40% of stormwater utilities had mapped their systems as of 2018. From 2004 to 2014, the average cost of damages from urban flooding was $9 billion in direct damages. The typical lifespan of detention and retention ponds ranges from 20 to 30 years, and conveyance systems range from 50 to 100 years. Systems that were constructed in 1970 or prior have met or exceeded their usable lifespan.

3.2.2 Drinking Water Distribution Systems

Drinking water infrastructure received a C- on the 2021 ASCE Report Card. ASCE's analysis covers drinking water distribution pipes but does not analyze the state of water treatment plants (WTP). The average American uses 82 gallons of water per day, totaling approximately 39 billion gallons of water withdrawn daily from surface water and groundwater bodies. Efficiency improvements are helping to reduce water consumption; from 2010 to 2015, water usage declined by 3% even with a 4% increase in the U.S. population. The U.S. distribution system includes over 2 million miles of pipe, much of which is aging and deteriorating, experiencing a water main break every two minutes. Water utilities have increased the annual rate of pipe replacement from 0.5% in 2015 to between 1% and 4.8% in 2019. However, the nation still loses at least 6 billion gallons of water daily due to leaks, which cost approximately $7.6 billion in 2019 (ASCE, 2021).

3.2.3 Wastewater Systems

Wastewater systems, including wastewater treatment plants (WWTP) and sanitary sewers, received a D+ from ASCE. Publicly owned WWTPs serve 80% of Americans, while the other 20% rely on smaller-scale services, like septic tanks. WWTPs across America are, on average and regardless of size, operating at 81% of their total capacity and 15% of plants are exceeding 81%.

Wastewater pipe maintenance is performed following a system failure 38% of the time, with the other 62% of maintenance performed preemptively before a failure. The average age of drinking water and wastewater pipes in the U.S. is 45 years, with some exceeding 100 years old. These aging systems, expected to last between 50 and 100 years, often experience problems like inflow and infiltration, which can result in combined sewer overflows (CSO). Spending on WWTP O&M nationwide has increased by 4% annually from 1993 to 2017, but the replacement of sanitary sewer pipes has remained steady since 2017 (ASCE, 2021).

3.2.4 Levees

ASCE gave the nation's coastal and inland levee system a grade of D. Twenty-three million people, seven million buildings, five million acres of farmland, and two trillion dollars' worth of property are protected by levees in the USACE (USACE National Levee Database). This does not include the estimated 10,000 miles of levees outside the purview of USACE, whose exact conditions and locations are unknown due to varying ownership. According to the National Levee Database, the average age of U.S. levees is sixty years old. As of March 2019, three-quarters of levees in the USACE portfolio have undergone risk assessments, revealing that while most levees are low risk, about 45% of the population lives behind high- or very high-risk levees, and approximately 30% of FEMA-accredited levees in the USACE portfolio are classified as moderate, high, or very high risk (ASCE, 2021).

3.2.5 Roads

The ASCE Report Card scored roads a D. With vehicle miles traveled surpassing 3.2 trillion in 2019, an 18% increase since 2000, these roads face the consequences of growing traffic volumes (ASCE, 2021). As displayed in Figure 3.3, 43% of public roadways are in poor or mediocre condition, which has remained steady over the past several years (TRIP, 2021).

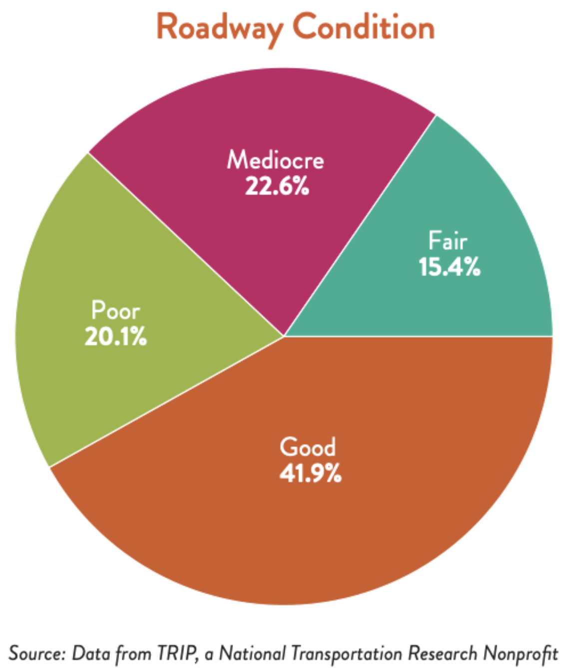


Figure 3.3. Proportion of Roadways Conditions of all U.S. Roads, from TRIP (2021).

This proportion of roadways tends to affect urban and rural collector roads more than the non-interstate system, which is in comparatively better condition. Additionally, vehicle miles traveled on roads in poor condition have increased from 15% to over 17% in the past decade (ASCE, 2021) Underfunded roadway maintenance and construction have caused a backlog of capital needs totaling $786 billion, including $435 billion for existing road repair and $105 billion for safety, operational, and environmental improvements. Current spending levels would have to be raised by 29% to close this investment gap.

3.2.6 Bridges

Bridges scored a C on the ASCE report card. Over the past decade, government efforts have significantly reduced the number of structurally deficient bridges in the U.S., at 7.5% in 2019 compared to 12.1% ten years ago (ASCE, 2021). A "structurally deficient" bridge is one that has a key element, either the deck, superstructure, substructure, or culvert, in poor condition. Despite this progress, nearly 231,000 bridges still need repairs, and the annual reduction rate has slowed to 0.1%. In 2023, there were 42,400 structurally deficient bridges supporting over 167 million daily trips. At the current pace, it will take over 50 years to repair all deficient bridges, which is currently unachievable given the increasing rate of deterioration and lack of sufficient funding.

Challenges in bridge maintenance vary across states, with structurally deficient bridges ranging from 1% in Nevada to 22% in Rhode Island in 2019. Additionally, 42% of the nation's bridges are over 50 years old, with 12% of bridges at 80 years or more of operation. Many bridges will soon need significant replacement or rehabilitation as they reach or exceed their 50-year service lifetime (ASCE, 2021).

3.2.7 Energy Systems

Energy received a C- in the ASCE Report Card, noting the need for more funding, planning, and reliability to match the growing demand from a constantly changing energy sector (ASCE, 2021). T&D systems in the U.S. struggle with reliability. The nation's grid is aging, with many components, including 70% of T&D power lines, creeping towards the end of their 50-year lifespan and in need of refurbishment or replacement. The aging distribution system is the source of 92% of all electrical outages and must face damage from weather events and vandalism. Increased use of renewable energy and natural gas sources requires T&D system construction and integration to connect the electricity to the customer.

Yearly transmission spending on high voltage lines surged by 40% from 2012 to 2017, from $15.6 billion to $21.9 billion. Meanwhile, yearly distribution spending increased 54% from 2001 to 2021, from $31 billion to $51 billion. The IIJA dedicates billions of dollars to programs within the Department of Energy that are focused on hazard hardening, grid resilience, and incentives for renewable energy generation (U.S. Department of Energy Grid Deployment Office).

Despite this funding, the investment gap for generation, transmission, and distribution continues to grow and tracks to reach $197 billion by 2029.

3.2.8 Public Facilities

Public facilities, such as parks, libraries, schools, government buildings, and community centers, are recognized by 83% of Americans as a part of a community's infrastructure, and in the same poll, 83% of survey respondents argued that investment in public buildings is as crucial as investment in bridges and roads (American Institute of Architects, 2017). Public parks and public schools both received a D+ on ASCE's 2021 Report Card (ASCE, 2021). Local parks and recreation facilities in America collectively generate hundreds of billions of dollars of economic activity, but in the past decade, public parks have seen a 9% increase in maintenance backlog due to aging facilities and limited resources. Schools are the second largest sector of public infrastructure spending, behind highways, and yet there is still a $38 billion annual funding gap that has caused over a third of the nation's schools to employ portable buildings/trailers due to capacity constraints. There is no formal database on K-12 public school infrastructure.

3.3 Resilient Infrastructure in the U.S.

3.3.1 Stormwater Systems

Cities and counties are incorporating resilience to increase the lifespan and efficiency of their stormwater systems. A resilient stormwater system, according to ASCE, can adapt to climate change effects by integrating grey infrastructure (pipes, drains, gutters, etc.) and green infrastructure (rain gardens, green roofs, permeable pavement, natural areas) that is supported by real-time data and innovative practices. Resilient stormwater infrastructure should be designed and maintained keeping in mind future growth, asset management protocols, and potential reuse of stormwater (ASCE, 2021).

Flood Action Alexandria is an initiative in Alexandria, VA as part of their resilience plan designed to protect residents from flooding through various programs and actions. It includes storm sewer capacity projects identified in a 2016 analysis, which prioritized the top 11 projects for funding to address significant flooding issues. "Spot improvement" projects are funded as part of the initiative to manage localized flooding and contribute to the resilience of the entire stormwater system. Additionally, the initiative focuses on public outreach, educating residents on best practices to prevent sewer backups, and includes an Emergency Operations Plan for major emergencies (City of Alexandria, 2021).

The Green City, Clean Waters initiative in Philadelphia is a comprehensive plan launched in 2011 to improve the city's stormwater management through green stormwater infrastructure (GSI) solutions and low-impact development. Since its inception, the program has successfully implemented over 10,000 green stormwater management practices, such as rain gardens, green roofs, and permeable pavements, which have collectively kept nearly three billion gallons of stormwater runoff and sewer overflow out of surface water bodies. This initiative uses decentralized, nature-based solutions that are adaptable, reduce flood risk, and improve water quality, therefore increasing Philadelphia's stormwater infrastructure resilience (Philadelphia Water Department, 2024).

GSI can also be used to reduce the need for traditional flow detention/retention methods. The EPA shows that green roofs on existing NYC building roofs had effective rainfall retention; vegetated mats, built-up systems, and modular tray systems demonstrated 37-60%, 49-66%, and 47-61% rainfall capture, respectively (U.S. EPA, 2015). Data from green roofs at Pennsylvania

State University demonstrated that a 3.5-4-inch-deep green roof can retain over half of the annual precipitation in the Northeast (U.S. EPA, 2015). A combination of GSI at Elmhurst College in Elmhurst, IL were designed together to help store flows for the 100-year storm event (ASLA, 2012). Performance analysis from the combination of porous pavement, a rain garden, a bioswale, and a 35,000-gallon underground shows that the ~$1,000,000 project successfully stores the 2-year storm event, where the water can infiltrate into the soil and become a source for the nearby Salt Creek. Similarly, after a devastating flood in 1999, Two Harbors, Minnesota, sought to reduce future flood damage and water pollution entering Lake Superior by implementing a resilient stormwater management plan. The city invested $80,000 in three flood control basins, two streambank stabilization projects, and a rain garden to manage runoff. As a result, Two Harbors sustained only minor damage during the 2012 "Solstice Flood" while surrounding areas faced $100 million in damage, and remained mostly unscathed during a 2018 storm that caused $18.4 million in damage to nearby communities (Alvis et al., 2024).

Another way to improve stormwater resilience is through floodplain reconnection and restoration. Nashville, Tennessee’s Metro Water Services’ Stormwater Division manages a voluntary Home Buyout Program that identifies flood-vulnerable homes and offers homeowners fair market value to relocate, returning the land to its natural floodplain and reducing flood risk. This program, funded by FEMA, TEMA, and USACE, saw increased participation after severe flooding events in 2010 and 2021. In total, the program has bought out 421 homes and 470 parcels to improve the community’s resilience (EPA Creating Resilient Water Utilities, 2024).

3.3.2 Drinking Water Treatment and Distribution Systems

Resilience within a drinking water system is essential to maintaining the most essential resource for public health, water, in both day-to-day operations and emergency situations. Water treatment and distribution systems should be able to withstand and quickly recover from emergencies while ensuring a level of water service suitable for human consumption (EPA, 2024). Examples of resilience measures in drinking water infrastructure are installing backup power at water treatment facilities, weatherizing residential water connections with meter keys and hose covers, deploying advancement metering infrastructure, and regularly servicing and checking equipment (Tiedmann et al., 2023). Following the Texas Winter Storm Uri, more than 50% of drinking water utilities noted frozen infrastructure, facility power outages, and generator problems as a gap in resilience at their plants. Fifty percent or more of water utilities identified backup power, treatment/operational changes (use of alternative chemicals for treatment, thoughtful adjustments to valves and pumps), Supervisory Control and Data Acquisition (SCADA) systems, and/or sufficient chemical inventories as a source of resilience at their plants. While many utilities did not observe significant effects on wastewater infrastructure, the resilience strategies could also be effectively applied to wastewater systems.

Resilience can also be implemented throughout stages of the treatment and distribution process. In South Burlington, VT, the Champlain Water District (CWD) provides drinking water to 83,500 people through 56 miles of distribution lines. With concerns over rising water temperatures in their sole water source increasing the presence of nitrifying bacteria in the distribution system, CWD has implemented and iterated on a Clean Water Resiliency Plan. This plan has included projects like increasing chloramine dosages during summer months to maintain a higher disinfection residual, increasing tank sampling frequency to detect nitrifying bacteria, and adjusting system operation and management to ensure more effective tank turnover (EPA Creating Resilient Water Utilities, 2023).

Supply chain resilience is also a way to ensure proper levels of treatment when certain treatment chemicals are not available. The Poarch Creek Indians Utility Authority in Alabama is frequently impacted by hurricanes, so increased chemical storage is necessary to ensure service in an emergency. During the COVID-19 pandemic, the utility faced the strain of chemical shortages in chlorine and soda ash. Through lessons from the pandemic and the threat of hurricanes, the utility enhanced its supply chain resilience by increasing storage even more, adjusting order frequency, and collaborating with neighboring utilities. During the pandemic, the utility was able to implement operational changes, such as leveraging UV disinfection to reduce chlorine use while still maintaining regulations (EPA Creating Resilient Water Utilities, 2022).

3.3.3 Wastewater Treatment and Collection Systems

According to the CWSRF, wastewater system resilience means the uninterrupted operation of collection systems, "integrity of the treatment train", and protection of the treatment facility during and after hazard events (EPA, 2021). Managing and building out system components to meet the projected needs of the community for the future is key to enhancing resilience in this sector while still ensuring environmental regulatory compliance.

Wastewater CSO abatement strategies improve water quality, reduce flows to treatment plants, and manage stormwater and wastewater more effectively. The Lick Run combined sewer system in Cincinnati, OH underwent a daylighting project from 2009 to 2021 to separate the stormwater and wastewater streams, improve water quality, and provide recreation and activity for a challenged community (ASLA, 2021). Along with the stream daylighting, the engineering team used a wide variety of GSI to eliminate 1.26 billion gallons of stormwater from entering the CSO and preventing 800 million gallons of CSO annually. The total project cost was $122 million dollars, significantly less than the alternative $245 million gray infrastructure project that planned to tunnel deep from the wastewater plant to the CSO outfall to convey large flows. A project in Indianapolis retrofitted an existing plaza with bump-out rain gardens, porous pavers, and curb cuts to reduce the effects of CSO. The site retains all water from the 2-year storm event and saves over 100,000 gallons per year from entering the flow of runoff. The $52,000 project was funded through the EPA Sustainable Skylines Grant and provides economic and social benefits to the community (ASLA, 2023).

3.3.4 Coastal and Riverine Protection

In 2020, every mile of the mainland Atlantic coast was subject to watches or warnings from tropical storms, tropical depressions, hurricanes, and major hurricanes. Nearly all coastal counties, except for five, experienced tropical-storm-force winds during that year (FEMA, 2023). Investing in resilience for coastal and inland communities can include projects such as updating zoning policies and building codes, incorporating natural infrastructure, reinforcing or elevating infrastructure, and improving floodwater storage (U.S. Climate Resilience Toolkit, 2020). These investments can speed up and strengthen the response of American coastal and inland communities to the devastating natural disasters experienced year after year, while saving significant sums in the process. For example, building new coastal homes 2 feet above the 100-year flood level saves $17 in losses for every $1 invested. Regarding nature-based solutions, a study found that natural shoreline protection in North Carolina was not damaged by Hurricane Irene, while 76% of bulkheads experienced damage from the storm. In Texas, buildings that were constructed using the most recent version of the International Residential Code and International Building Code were stronger in facing Hurricane Harvey and had insurance claims half of those of buildings constructed using previous codes (FEMA, 2023).

Grand Isle serves as a crucial barrier against coastal flooding for New Orleans and inland Louisiana cities, featuring a series of breakwaters installed just offshore, which absorb the impact of waves before they can reach the beach, providing effective protection for the area. The breakwaters and levees, built by the USACE, slow down major storms that brew in the Gulf before they make landfall in major Louisiana cities (U.S. Climate Resilience Toolkit, 2024). Pensacola, Florida, launched Project GreenShores in 2000 with a $6 million investment to enhance coastal resilience through living breakwaters and shorelines. The project involved constructing breakwaters with 14,000 tons of limestone and 6,000 tons of recycled concrete, creating five offshore islands, and planting 41,000 native cordgrasses, which provided significant protection against storm surges and effectively reduced storm damage to roads and buildings on Bayfront Parkway during Hurricanes Ivan and Dennis (Florida Department of Environmental Protection).

Inland flooding poses significant risks to inland community infrastructure. In 2011, Tropical Storm Irene caused severe flooding and damage in Vermont, but the town of Middlebury was largely saved due to its upstream floodplain and wetland conservation efforts. The town benefited from a network of 23 conservation easements protecting over 2,000 acres of wetlands, which reduced flood damage by an estimated $1.8 million during Irene and $126,000 to $450,000 annually from other flood events. The success at Middlebury sparked other cities to remove berms and increase natural floodwater storage, which contributed to nutrient filtration and ecosystem restoration in the area (Naturally Resilient Communities, 2017). The Johnson Creek Restoration project in Portland, Oregon, tackled chronic flooding in the Foster Road area by purchasing at-risk properties, removing berms, and restoring 63 acres of wetlands and floodplains. The $20 million project effectively mitigated flood damage during heavy rains in January 2012 when Johnson

Creek flooded two feet over the record stage and the restored floodplain protected Foster Road and its businesses from damage (Naturally Resilient Communities, 2017).

3.3.5 Surface Transportation

A "resilience improvement" for surface transportation projects, as defined by the PROTECT Grant program, involves using materials, structural or nonstructural techniques, or natural infrastructure to help a project better prepare for, withstand, and recover from weather hazards (U.S. FHWA). This includes ensuring the project functions throughout its lifespan, reducing the impact and duration of hazards, and enhancing recovery capabilities. Examples include building natural infrastructure, flood prevention for roads, stabilization, riprap installation, and bridge scour prevention.

3.3.5.1 Roads

The federal government has acted to incorporate resilience into roadway planning and maintenance. For example, the Federal Highway Administration mandates state-level roadway planners and departments of transportation to consider resilience in their planning and asset management plans. Additionally, every state must develop an asset management plan for their roads in the National Highway System to acquire federal funding; this requirement helps states establish priorities and timelines for roadway maintenance and construction.

A case study examined the rapid reconstruction of Iowa's interstates after two flood events in Spring 2019 undermined sections of the roadway and the shoulders (Bowers & Gu, 2021). Key innovations included using flexible concrete geomats anchored with an asphalt wedge to prevent overtopping (see Figure 3.4) and adding an extended shoulder to protect against future failures (see Figure 3.5). These measures helped reopen the roads quickly and enhance their resilience against future flooding.

Figure 3.4. (Left to right) Failed Flood Protection Geomats, Asphalt Wedge Working to Maintain Geomat Stability, from Bowers & Gu (2021).

Figure 3.5. Additional Shoulder to Bear Most of the Damage and to Leave the True Shoulder Unaffected, from Bowers & Gu (2021).

A 2023 case study from the Asphalt Pavement Alliance highlights how the Alaska DOT incorporated resiliency into road design to address challenges with thawing permafrost. To restore Chena Hot Springs Road, which had been repeatedly patched since 1998, ADOT used a polymer-modified binder and geogrid layers to improve pavement flexibility, which reduced thermal cracking and maintenance needs in the face of future permafrost thawing (National Asphalt Pavement Association, 2022). Temperature changes due to climate change will also impact the future of roadway design. Marath et al. (2023) researched modified asphalt mixtures to enhance pavement durability in New Jersey. Their study revealed that climate change led to a 43% increase in rutting for flexible pavements and a 10% increase for composite pavements. The research found that using modified asphalt mixtures, including fiber-reinforced asphalt, binder-rich intermediate course mix, and 9.5 ME Superpave mix, improved rut resistance in both flexible and composite pavements. Additionally, the 9.5 ME Superpave and fiber-reinforced asphalt mixtures helped reduce reflective cracking in composite pavements.

Permeable pavement is a green roadway infrastructure practice that can reduce stormwater runoff and vehicular hydroplaning and increase groundwater infiltration and driver safety. Porous asphalt pavement (PAP) is one of the most common types of permeable pavements and has many case studies that show its efficiency and practicality as a surface for vehicles and pedestrians. Case studies from New Hampshire and Minnesota concluded that, generally, PAP has a lower risk of frost damage compared to impervious pavement due to shallower frost penetration and a quicker response to warming temperatures (Zhang & Kevern, 2021). In regions with a high risk of frost damage, the PAP thickness should be equal to the local frost penetration depth and frost heave. In regions with a low risk of frost damage, the PAP thickness should be 65% greater than the local frost penetration depth. The same case studies also found that snowplowed PAP requires 64-77% less salt for de-icing than plowed typical asphalt concrete requires to maintain the same or better surface conditions, measured by traction and the surface area of snow and ice.

3.3.5.2 Bridges

Bridges are essential to transportation systems and face various hazards throughout their lifetime, such as deterioration due to aging, flooding, seismic activities, and vehicle-induced disasters. Resilience improvements to bridges enhance their structural safety, economic performance, environmental sustainability, and longevity.

In April 2018, severe flooding on Kauaʻi damaged three historic bridges along Kūhiō Highway, including scour and debris buildup that compromised their structural integrity. In response, the Waikoko and Waipā bridges were replaced to meet the current HDOT load and hydraulic standards and the Waiʻoli bridge was refurbished and reinforced with new concrete, rebar, and fiber-reinforced polymer. These resilience measures have since protected the bridges from damage during subsequent storms, maintaining community safety and emergency access (FHWA, 2018). The Guy Ford Road Bridge in Watauga County, NC, was severely damaged by floods in 2004, with nearly $700,000 in estimated repair costs to the bridge surface, securing cables, and asphalt scours. The county used FEMA Public Assistance to receive emergency funding to repair, restore, and re-open the major roadway. To prevent future damage, the bridge was reconstructed with redesigned approaches to allow water flow and a concrete overlay to replace the asphalt, completed in 2005. These mitigation efforts are estimated to have saved over $1 million in potential future repair costs (FEMA, 2021).

A study in the Journal of Structural Engineering presented a multi-hazard resistant concrete-filled fiber-reinforced polymer tube (CFFT) column system as a more resilient alternative to the conventional reinforced concrete (RC) system (Echevarria et al., 2016). The CFFT and RC systems both endured blast, fire, and seismic hazards, and the results show the performance favorability of CFFT during and after the hazards. The restoration time and repair costs as a percentage of bridge replacement costs were much less for CFFT than for RC. The column performance data is shown in Figure 3.6.

Table 8. Estimated Highway Bridge Restoration Time and Cost Based on Column Performance

		RC columns			CFFT columns		
Hazard type	Intensity	Column damage	Restoration time[a] (days)	Repair cost[b] (%)	Column damage	Restoration time[a]	Repair cost[b] (%)
Blast	$Z > 1.0$ ft/lb$^{1/3}$	Moderate/extensive	2–75	5–25	Slight/minor	<1 day	2
	$Z < 1.0$ ft/lb$^{1/3}$	Extensive/complete	75–225	25–100	Moderate	2 days	10
Fire	1-h duration	Moderate	2	10	Slight/minor	<1 day	2
	2-h duration	Complete	225	100	Slight/minor	<1 day	2
Earthquake	PGA < 1.0 g	Moderate/extensive	2–75	5–25	Slight/minor	<1 day	2
	PGA > 1.0 g	Extensive/complete	75–225	25–100	Moderate	2 days	10

[a]Estimates are based on Hazus (2012) highway bridge information.
[b]As a percentage of bridge replacement cost.

Figure 3.6. Bridge Restoration Time and Repair Cost Based on Hazard Type and Column Performance, from Echevarria et al. (2016).

Eighty percent of failure for bridges over water in the United States is due to scour, which is caused by scouring vortices that erode sand and sediment from bridge or pier footings (Simpson & Byun, 2019). Research from Simpson & Byun (2019) demonstrates that scouring vortices can be prevented with a stainless-steel retrofit that changes the approach and tail flow patterns, which is more economical and less burdensome on the existing structure than concrete. Additionally, the research found that the present value of cost savings over the useful life of the bridge with the vortex-prevention devices is an order of magnitude cheaper than the commonly used scour countermeasures (Simpson & Byun, 2017). Effective scour countermeasures to reduce the effects of scour include armoring bridge piers with partially or fully grouted riprap, articulated concrete block systems, and gabion mattresses (Lagasse, 2007). While modifying the channel/field of flow upstream of a river crossing is an effective measure, this method brings about many environmental concerns and does not inherently contribute to the resilience of the bridge or river infrastructure.

3.3.6 Energy Systems

A resilient power system can withstand disturbances and continue delivering energy, with specific emphasis on high-impact, low-frequency events. Resilience before this kind of event can be achieved by hardening infrastructure, such as using stronger poles or underground cables, and adopting pre-emptive strategies like increasing distances between conductors, vegetation management, and routine distribution inspection programs. Additionally, redundant designs like parallel circuits and backup transformers can enhance resilience, although these solutions are costly and require a longer implementation horizon.

Transmission hardening and distribution hardening are both important aspects of creating more resilient infrastructure. A transmission-related outage, however, affects significantly more customers than a distribution outage does (Hanus, 2023). Transmission hardening in Florida Power & Light (FPL) reduced line section outages in the aftermaths of Hurricane Wilma (2005) to Hurricane Irma (2017) by 38%, transmission structure failures by 95%, and de-energized transmission substations by 62%. FPL's goal with transmission hardening was to replace all wooden transmission structures (70%) with steel or concrete structures and to implement an effective transmission inspection program (FPL, 2022). The program requires all transmission structures to be inspected on a six-year cycle and wooden and steel structures to undergo climbing inspections on a six and ten-year cycle, respectively. FPL's distribution hardening program, which focused on undergrounding laterals and feeders, has had enormous success in the wake of the devastating hurricanes Matthew and Irma (see Figure 3.7).

Storm and Facility	Laterals Out	Total Laterals	% Out
Matthew OH	3,473	82,729	4%
Matthew UG	238	101,892	0.2%
Irma OH	20,341	84,574	24%
Irma UG	3,767	103,384	4%

Figure 3.7. FPL analysis of overhead (OH) and underground (UG) lateral line outages following hurricanes Matthew and Irma, from Florida Power & Light (2022).

The distribution hardening program also includes an inspection program, where poles are inspected on an eight-year cycle.

Microgrids can enhance community energy resilience and reliability by allowing independent operation during outages and reducing strain on the main grid. Kaiser Permanente’s Richmond, CA, Medical Center, the West Coast's second-largest renewable energy microgrid, has generated 153 MW off-site, 30 MW on-site, and reduced peak loads by 20-25%, saving an estimated $394,000 annually. With hospitals' high energy demands, this setup decreases environmental impact, provides three hours of backup power, and minimizes care disruptions. Supported by a $4.77 million grant from the California Energy Commission, the project aligns with state energy resilience and climate goals. (U.S. Department of Energy).

Advanced metering infrastructure for distribution systems allows utilities to record live power consumption data and manage services remotely. Benefits of advanced metering include reduced meter reading costs, improved customer support, better and more resilient distribution management, potential for dynamic pricing, and remote service management capabilities (MIT, 2011). Conservation Voltage Reduction is a way to reduce peak electricity demand, decrease overall power consumption, delay capacity expansion projects, and enhance the efficiency of the system using advanced metering. Conservation voltage reduction is accomplished through voltage control sensors on the line, which lowers feeder voltage within the minimum acceptable range. Thirteen utilities in the Pacific Northwest, serving 30,000 customers, yielded 2% annual savings in energy delivered by substations when maintaining the voltage service level between 114 – 120 volts every other day (Massachusetts Institute of Technology, 2011). The Electric Power Board of Chattanooga used federal grant funding to also implement smart grid improvements, such as automated circuit switches and sensors, which reduced its system average interruption duration by 45% and system average interruption frequency by 51%. The estimated value of service reliability to these improvements was about $26.8 million annually (U.S. Department of Energy Office of Energy Policy and Systems Analysis, 2016).

3.3.7 Public Buildings

FEMA defines the goal of a disaster-resilient structure as the capability to withstand and limit the effects of disasters, like erosion, high winds, flooding, or fire, on the structure beyond the minimum standards (FEMA, 2023). This definition can be expanded on by being resilient during less dramatic effects like aging and general use.

FEMA advocates for modern building codes as a low-cost method of incorporating resiliency into building design. As of 2020, 65% of cities, towns, and counties in the U.S. had not adopted up-to-date building codes. The added cost of resilient building features, such as roof tie-downs and coverings, strengthened walls, and window protection, makes up, on average, 1-2% of total construction costs on a building, and with every $1 invested in construction under new codes, $11 is saved in recovery and repair costs (FEMA, 2023). A custom builder in Louisiana shared his experience with Hurricane Ida’s impact on roofing and structural resilience. Roofs over five years old suffered significant damage, leading him to install an “ice and water shield” and waterproof tape on decking joints to prevent water infiltration. He noted improvements in structures built to post-Katrina codes, which resisted structural damage in Ida (National Association of Home Builders).

Hurricane Sandy had drastic impacts on cities close to the ocean. Many buildings could not withstand the flooding, costing owners billions of dollars to repair the damage. Buildings that complied with building code requirements for flood-resistant construction, like the Seagate Rehabilitation & Nursing Center in Brooklyn, NY, were able to still perform and carry out their function without any disruption. Seagate's building was raised thirty feet above the ground and the vital areas and power equipment were elevated, as well, to protect from floodwaters (U.S. Climate Resilience Toolkit, 2024). The Spaulding Rehabilitation Center in Boston had similar design considerations and decided to promote flood resilience by raising their first-floor elevation thirty inches above the FEMA 500-year floodplain, which exceeds code requirements. The building will avoid major flooding consequences since its mechanical and electrical equipment is located on the roof and all critical patient care functions are located on the upper floors (U.S. Climate Resilience Toolkit, 2024).

3.3.8 Public Parks

Without the integration of resilient infrastructure practices, public parks are vulnerable to the relentless forces of nature. However, by implementing strategies like green stormwater infrastructure, parks can play a vital role in fostering climate-resilient communities. They can mitigate the urban heat island effect and enhance stormwater management, contributing to a healthier and more sustainable urban environment.

Hoboken, NJ received $10 million in BRIC funding to help design and construct ResilienCity Park, a multi-functional space that mitigates flooding while providing public amenities. Retrofitted from an old industrial site, the park includes athletic fields, playgrounds, community spaces, and a basketball court that also serves as a stormwater detention area, along with underground stormwater storage tanks. A 30-million-gallon-per-day pump helps control stormwater discharge and prevents combined sewer overflows. During Tropical Storm Ophelia in September 2023, the park successfully managed heavy rainfall by pumping 17 million gallons of stormwater out of the city, demonstrating its effectiveness in reducing flood duration (Accelerator for America, 2023). South Waterfront Park in Queens, NY also tolerated and attenuated the storm surge brought by Hurricane Sandy using green stormwater infrastructure. The Park produces a myriad of co-benefits like wildlife habitat, water quality improvements, and social enjoyment (National Recreation and Park Association, 2017).

3.4 Economic Significance of Resilient Infrastructure

Resilient infrastructure can hold significant inherent economic value by reducing the long-term costs associated with natural disasters, system failures, and climate impacts. Benefit-cost ratio (BCR) is a metric commonly used in infrastructure project evaluation, measured by the fraction of the economic value of outcomes from an infrastructure project, such as safety, travel time, health benefits, wildlife impacts, and effects on other infrastructure systems, over the economic value of building or maintaining a new or improved infrastructure asset over the course of the project (U.S. DOT, 2024). A benefit-cost analysis (BCA), which produces a BCR score, is a common requirement in applications for hazard mitigation and infrastructure grant programs to demonstrate a project's cost-effectiveness. For FEMA grant applications, a project is considered economical if the BCR is greater than or equal to 1.0 at a 3.1% interest rate (FEMA, 2024).

The World Bank published policy research that gives a BCR analysis of strengthening exposed infrastructure assets in developing countries. Using 3,000 compiled scenarios and the uncertainty demonstrated from each scenario, the research found that 96% of scenarios had a BCR greater than 1, 77% of scenarios had a BCR greater than 2, and 50% of scenarios had a BCR greater than 4 (Hallegatte et al., 2019). When climate change is considered, the median BCR doubles, and the percent of scenarios that make infrastructure more resilient is non-profitable reduces from 14 to 4%. The net present cost of these investments in 75% of scenarios, if they were to be made now, is greater than $2 million (see Figure 3.8), and the cost of waiting to make these investments until 2030 increases in 93% of scenarios (see Figure 3.9).

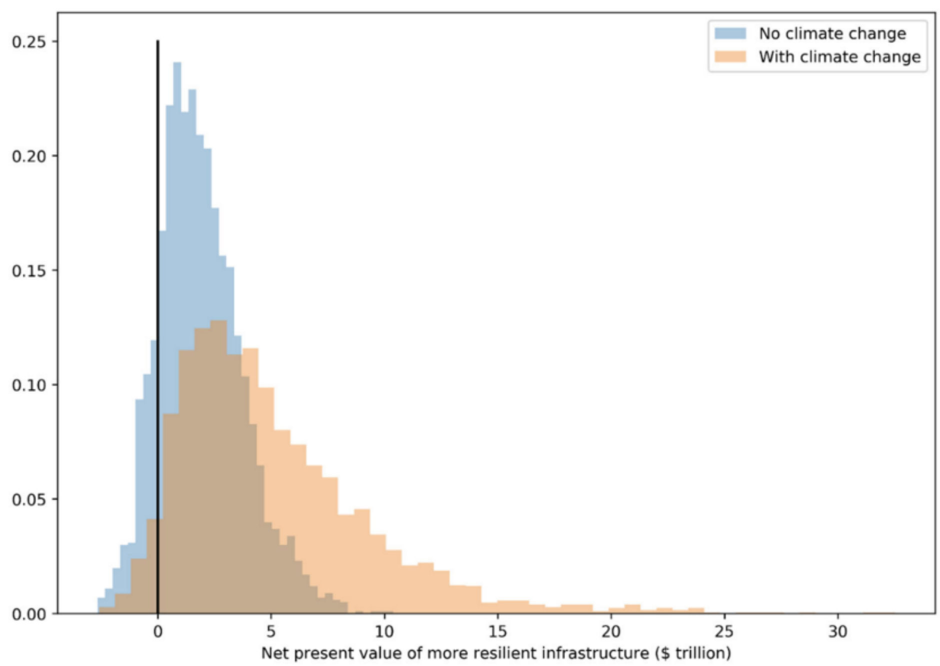


Figure 3.8. Histogram of the net present value of investing in resilience with infrastructure in developing countries now, from Hallegatte et al. (2019).

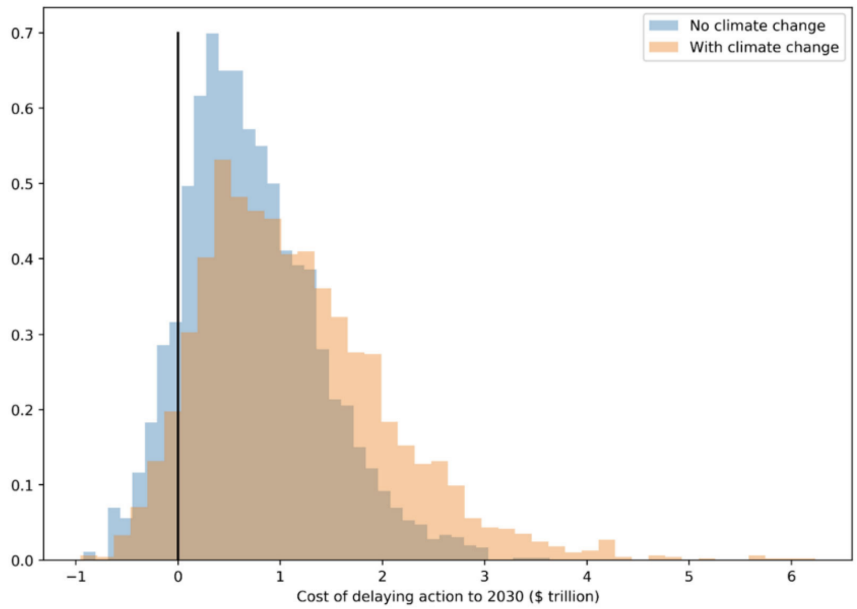
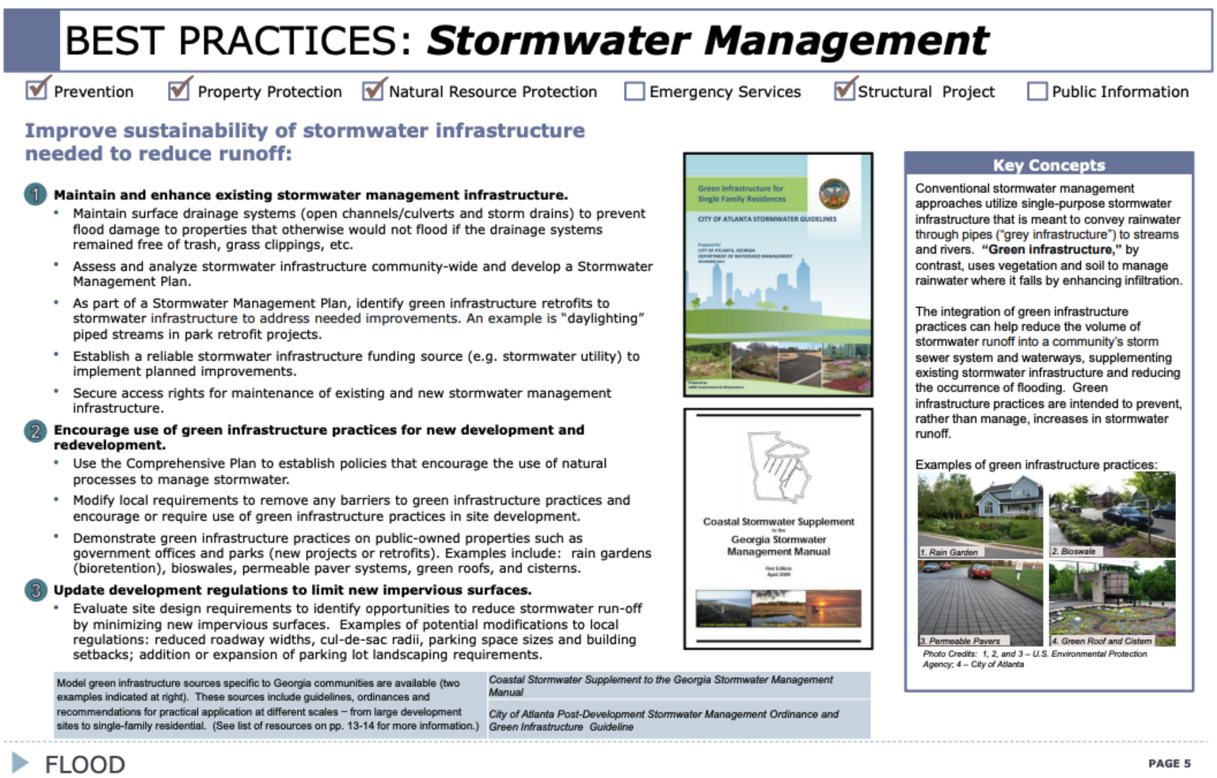


Figure 3.9. Histogram of the net present value if investing in resilience with infrastructure is delayed until 2030 in developing countries, from Hallegatte et al. (2019).

Many project awards and proposals are influenced by BCA. USACE plays a significant role in providing public engineering services that bolster national security and reduce natural disaster risks. In coastal resilience planning, for instance, the assessed value of a project—often calculated by comparing the cost of construction to the value of the structures it protects—tends to favor higher-value properties, such as million-dollar homes, over those valued at hundreds of thousands of dollars (Bresette et al., 2023). This approach can overlook the social justice implications of project selection. Using equity-weighting in BCA, which adjusts benefits and costs relative to the incomes of the community, would promote equitable distribution of benefits in USACE projects (DeJong et al., 2024).

3.5 State and Federal Resilience Guides and Toolkits

The GA Department of Community Affairs' (GA DCA) guidebook (2014) provides best practices for ensuring community resilience through disasters like flooding, severe storms, and tornado events. The best practices are categorized by types of hazards, and the recommendations for policies, maintenance procedures, and engineering design are based on hazard mitigation. The guidebook also contains a resource guide with a compiled list of technical and planning references. The cards used in GA DCA (2014), as seen in Figure 3.10, synthesize the best management practice (BMP) benefits effectively while also providing key concepts and example infrastructure modifications.



BEST PRACTICES: ***Stormwater Management***

☑ Prevention ☑ Property Protection ☑ Natural Resource Protection ☐ Emergency Services ☑ Structural Project ☐ Public Information

Improve sustainability of stormwater infrastructure needed to reduce runoff:

1. **Maintain and enhance existing stormwater management infrastructure.**
   - Maintain surface drainage systems (open channels/culverts and storm drains) to prevent flood damage to properties that otherwise would not flood if the drainage systems remained free of trash, grass clippings, etc.
   - Assess and analyze stormwater infrastructure community-wide and develop a Stormwater Management Plan.
   - As part of a Stormwater Management Plan, identify green infrastructure retrofits to stormwater infrastructure to address needed improvements. An example is "daylighting" piped streams in park retrofit projects.
   - Establish a reliable stormwater infrastructure funding source (e.g. stormwater utility) to implement planned improvements.
   - Secure access rights for maintenance of existing and new stormwater management infrastructure.
2. **Encourage use of green infrastructure practices for new development and redevelopment.**
   - Use the Comprehensive Plan to establish policies that encourage the use of natural processes to manage stormwater.
   - Modify local requirements to remove any barriers to green infrastructure practices and encourage or require use of green infrastructure practices in site development.
   - Demonstrate green infrastructure practices on public-owned properties such as government offices and parks (new projects or retrofits). Examples include: rain gardens (bioretention), bioswales, permeable paver systems, green roofs, and cisterns.
3. **Update development regulations to limit new impervious surfaces.**
   - Evaluate site design requirements to identify opportunities to reduce stormwater run-off by minimizing new impervious surfaces. Examples of potential modifications to local regulations: reduced roadway widths, cul-de-sac radii, parking space sizes and building setbacks; addition or expansion of parking lot landscaping requirements.

Green Infrastructure for Single Family Residences

CITY OF ATLANTA STORMWATER GUIDELINES

Coastal Stormwater Supplement to the Georgia Stormwater Management Manual

Model green infrastructure sources specific to Georgia communities are available (two examples indicated at right). These sources include guidelines, ordinances and recommendations for practical application at different scales – from large development sites to single-family residential. (See list of resources on pp. 13-14 for more information.)	*Coastal Stormwater Supplement to the Georgia Stormwater Management Manual*
	City of Atlanta Post-Development Stormwater Management Ordinance and Green Infrastructure Guideline

Key Concepts

Conventional stormwater management approaches utilize single-purpose stormwater infrastructure that is meant to convey rainwater through pipes ("grey infrastructure") to streams and rivers. **"Green infrastructure,"** by contrast, uses vegetation and soil to manage rainwater where it falls by enhancing infiltration.

The integration of green infrastructure practices can help reduce the volume of stormwater runoff into a community's storm sewer system and waterways, supplementing existing stormwater infrastructure and reducing the occurrence of flooding. Green infrastructure practices are intended to prevent, rather than manage, increases in stormwater runoff.

Examples of green infrastructure practices:

1. Rain Garden *2. Bioswale* *3. Permeable Pavers* *4. Green Roof and Cistern*

Photo Credits: 1, 2, and 3 – U.S. Environmental Protection Agency; 4 – City of Atlanta

FLOOD

PAGE 5

Figure 3.10. Recommended Practices for Flood Resilient Stormwater Management, from GA DCA (2014).

The condensed format (17 pages total) is likely intentional to hold the attention of the intended audience, emphasizing brevity without sacrificing substance.

The Resilient Design Guidelines document from the Department of Energy & Environment in the District of Columbia (2021) focuses on enhancing the resilience of buildings and site/landscape design. The guide aims to equip DC city planning teams with strategies to incorporate future climate conditions into urban planning, surpassing baseline codes and regulations for climate readiness. It organizes strategies by design themes (flooding, heat, outage, waterfront), project type (new construction or existing building), cost, O&M impact, and relevant regulations. Figure 3.11 displays a matrix within the guidebook that compares each resilient design strategy for extreme heat using the project consideration categories. Tennakoon (2023) produced similar matrix visualizations for a climate adaptation guidebook for transportation but categorized resilience opportunities by “failure mechanisms” and “adaptation options”.

	RESILIENT DESIGN STRATEGIES MATRIX	COST CONSIDERATIONS		O+M	BENEFITS							
	BUILDING STRATEGIES			Impact	Benefit Description	Reduce Economic Impact	Reduce Environmental Impact	Enhance Durability	Reduce Damage	Reduce UHI	Promote Continued Operation	Enhance Wellness
DESIGN FOR EXTREME HEAT												
1	Avoid Development in Flood Hazard Areas	$		Low	Keeping new buildings out of flood hazard areas will eliminate or reduce the costs and environmental impacts of repairs and renovations resulting from flooding.	x	x	x	x		x	x
2	Keep Occupied Spaces Above the Sea Level Rise Adjusted Flood Elevation	$	$$$	Low	Damage to occupied spaces as a result of flooding is far more costly, dangerous to occupants, and carries a greater environmental impact than damage to unoccupied spaces.	x	x	x	x		x	x
3	Integrate Exterior Dry Floodproofing Techniques	$$ - $$$		High	Dry floodproofing aims to keep floodable spaces entirely dry, eliminating the need for costly cleanup and dewatering following floods.	x		x	x		x	x
4	Improve Drainage Control and Prevent Intrusion into Buildings	$	$$ - $$$	Low	Keeping bulk water away from the foundation exterior can reduce the risk of flooding, as well as unwanted indoor humidity from water diffusing through foundation walls or floor slabs.	x		x	x		x	x
5	Use Wettable Systems/ Finishes At and Below the Lowest Occupiable Floor	$	$$	Low	Using materials that are resistant to water damage can help avoid the expense and environmental impacts from flooding. Such materials are also usually far less prone to mold growth, offering a health benefit.	x	x	x	x		x	x
6	Provide Rainscreen Detail for Siding/ Cladding	$ - $$	$$ - $$$	Low	Vented rainscreen construction details enhance durability and help prevent mold growth.	x		x	x			x
7	Reinforce Building Corners and Exteriors	$	$	Low	Installing features to protect buildings from floating debris is a simple measure that can offer significant resilience and environmental benefits.	x		x	x		x	
8	Specify a Resilient Elevator	$$	$$$	Low	Specifying the proper type of elevator in a flood-prone location can significantly reduce costs from flood damage, as well as prevent environmental contamination from spilled hydraulic fluid.	x	x	x	x		x	
9	Protect Mechanical and Electrical Equipment from Flooding	$	$$	Medium	Protecting equipment from flooding avoids both the expense and environmental impacts of repairs or replacement while reducing interruptions in service.	x	x	x	x		x	x
10	Install Sewer Backflow Preventers	$ - $$	$ - $$	Medium	Installing relatively simple, passive, sewer backflow valves (or backwater valves) can prevent sewage Sewage backflow that can cause water damage, contamination, and health risks.	x	x	x	x		x	x
11	Consider a Vegetative (Green) Roof	$$	$$$	High	Vegetative, or green, roofs provide two primary benefits: capturing and retaining stormwater during rain events and reducing the urban heat island effect in urban areas.		x	x		x		

Figure 3.11. Resilient Design Strategies Matrix compares the merits of many building strategies to design for extreme heat, from the Department of Energy & Environment in District of Columbia (2021).

The use of pictograms and recognizable symbols in the matrix format makes the document understandable and clear for the audience.

The coastal resilience guide authored by GADNR, NOAA, & UGA Carl Vinson Institute of Government (CVIOG) (2020) focuses on mitigating flood and wind impacts in coastal Georgia using modeled flood and wind scenarios from Hinesville and Tybee Island to select effective green infrastructure practices and advise communities on changing or adopting certain flood-related policies. It provides clear guidance on implementing these strategies, including how to earn credits from the Community Rating System and how to use the Georgia Stormwater Management Manual.

The guide also includes "policy and BMP summary cards," outlining specific actions, related ordinances, and technical resources (see Figure 3.12).

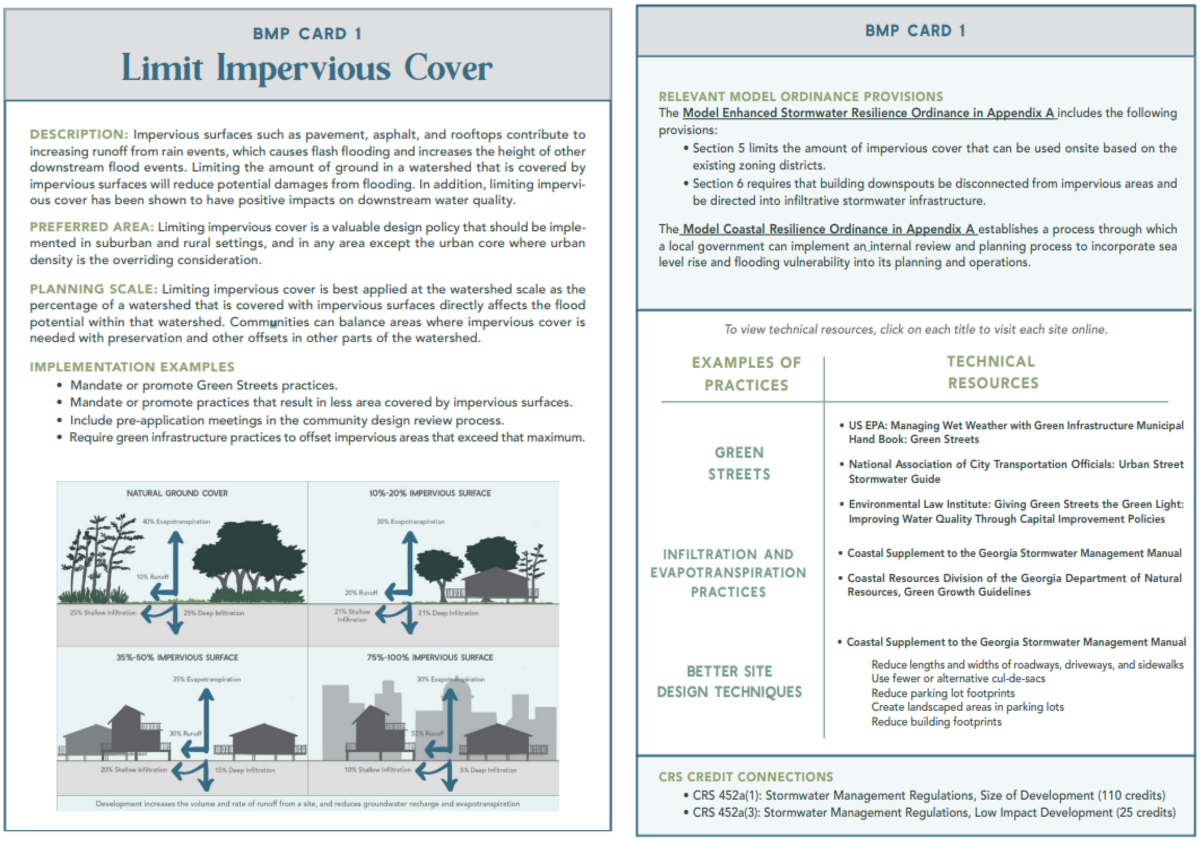


Figure 3.12. BMP Card for Limiting Impervious Cover with site design considerations and relevant references, from GA DNR, NOAA, & CVIOG (2020).

The guide addresses the concept of non-stationarity and helps communities factor changing environmental conditions into their planning. The effect of urbanization and imperviousness is reflected in the BMP Cards through before and after visuals, which is a useful way to communicate the benefits of resilience implementation.

The U.S. Climate Resilience Toolkit is a comprehensive database that provides guidance on resilience planning, implementation, reporting, training courses, and over 1,000 specific options for building community and asset resilience against hazards (Climate.gov, 2024). Information in the Toolkit is categorized by geographical regions and topics, which enhances site navigability and clarity for the user. An economic analysis of the Toolkit's efficacy in the southeastern U.S., performed by the National Environmental Modeling and Analysis Center found that the Toolkit has a BCR of 5.44, primarily through loss avoidance and capacity building (Fox et al., 2020). This BCR estimate is based on case studies from cities like Asheville, Charleston, and Tallahassee, where resilience planning helped mitigate the financial and operational impacts of climate-related disasters, such as flooding. A similar database developed by the EPA called Creating Resilient Water Utilities (CRWU) provides tools, technical assistance, and training to enhance resilience in water, wastewater, and stormwater utility's approaches to planning, design, construction, and maintenance. The "Resilient Strategies Guide" within the database breaks down resilience practices by funding opportunities, assets, population size, planning stages, and types of strategies (planning, operational, and capital/infrastructure). The database also contains a map of case studies of utilities in the U.S. that used technical assistance from the CRWU program to advance their resilience, as well as a training and engagement center, a climate resilience evaluation and awareness tool, and a list of federal funding opportunities for adaptation and resilience (CRWU, 2024).

A resilience planning guide developed by the U.S. Department of Energy in 2016 provides detailed direction to power system planners and decision-makers in assessing vulnerabilities in their current electrical infrastructure and providing them with specific resilient solutions to prepare for and adapt to hazard events. The guide helps to scope their resilience plan, develop and execute a vulnerability assessment, estimate costs, implement resilience measures for energy systems such as system hardening or risk mitigation actions, analyze costs and benefits of implementation, and evaluate and reassess their resilience portfolio. The guidebook is not tailored to a specific area of the U.S. but contains several case studies that support many of the recommendations. Risk categories, shown in Figure 3.13, were used to analyze hazards and their effect on infrastructure. The categories are broken down into the likelihood of a climate condition and the consequence of that condition, each with a low, medium, and high risk.

	Likelihood	Consequence
High	Once in 2 years or less	Cost of $100 million or more
Medium	Once in 2 to 25 years	Cost of $1 - 100 million
Low	Once in 25 years or more	Cost of less than $1 million

Figure 3.13. Categories of Risk by Likelihood and Consequence, from U.S. Department of Energy (2016).

This method of risk categorization could be expanded upon in the development of the framework to include avoided risk, which would help with "making the case" for resilient infrastructure. Another method of visualizing hazard risk is on a graph, as shown in Figure 3.14. Northern Powergrid in the UK developed a risk graph/matrix that assessed the likelihood of a climate event and the corresponding severity of the consequence (Northern Powergrid, 2015). The utility created 13 assessed risks and plotted them on the graph to have a visual understanding of their priorities. Examples of risks include overhead power line conductors having reduced rating and ground clearance due to temperature rise (AR1) and overhead power lines being affected by ground movement due to drought (AR2).

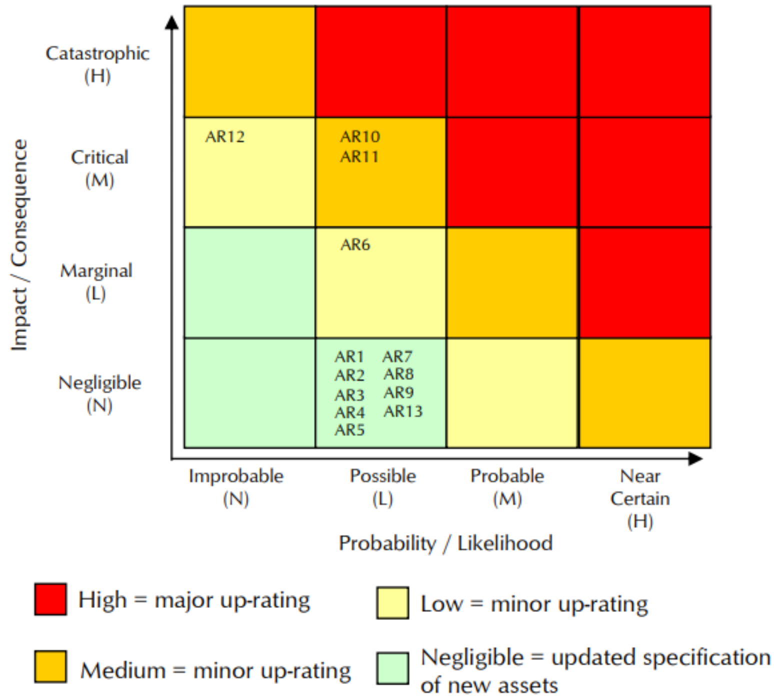


Figure 3.14. Risk Assessment Graph for Northern Powergrid (2015).

Giunta (2017) highlights the need to jointly assess sustainability and resilience when choosing rehabilitation alternatives following an extreme event that impacts critical road infrastructures. The approach quantifies the net present value of sustainability and resilience for each rehabilitation alternative and sums their score to determine the most effective alternative. Important considerations when using this approach are determining the probability of occurrence of an extreme event, which depends on the structural integrity and design of the infrastructure, as well as identifying the scope of environmental effects to include in each calculation, such as carbon dioxide emissions and/or loss of habitat. Resilient environmental costs are costs specific to reconstruction, and sustainable environmental costs are those associated with the construction and maintenance of the alternative. This mathematical approach, as seen in Figure 3.15, could be an option for local governments as a decision-making method for resilience opportunities, evaluating multiple realms of cost, including environmental and construction costs.

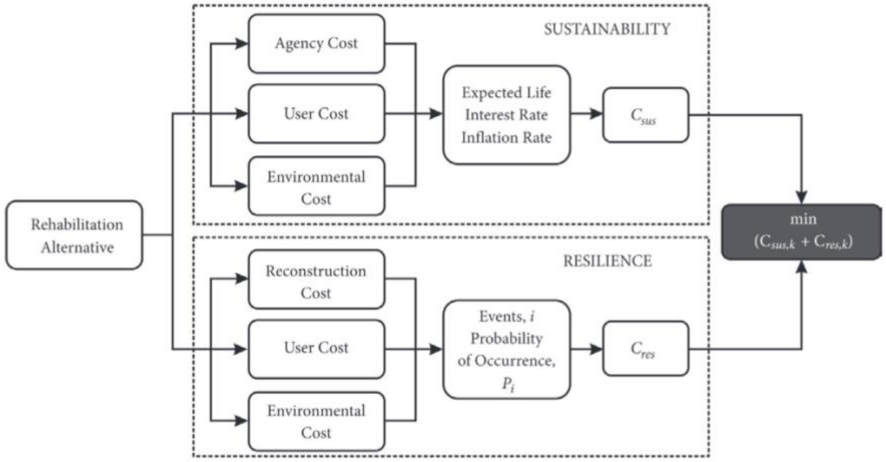


Figure 3.15. Diagram of Approach to Determining Optimal Rehabilitation Alternative based on Costs Associated with Sustainability and Resilience, from Giunta (2017).

BCR was used by Entergy Corporation when creating a study that compared solutions to make the U.S. Gulf Coast more resilient. The study identified cost-to-benefit ratios, factoring in both social and environmental co-benefits, and plotted them (see Figure 3.16) where the width of each bar is how much cost in losses that measure expects to avert by 2030, and the height is the cost/benefit (Entergy, 2010). BCR must be carefully considered in resilience decision methods due to cost savings inaccuracies and uncertainty from quantifying the economic impact of environmental co-benefits.

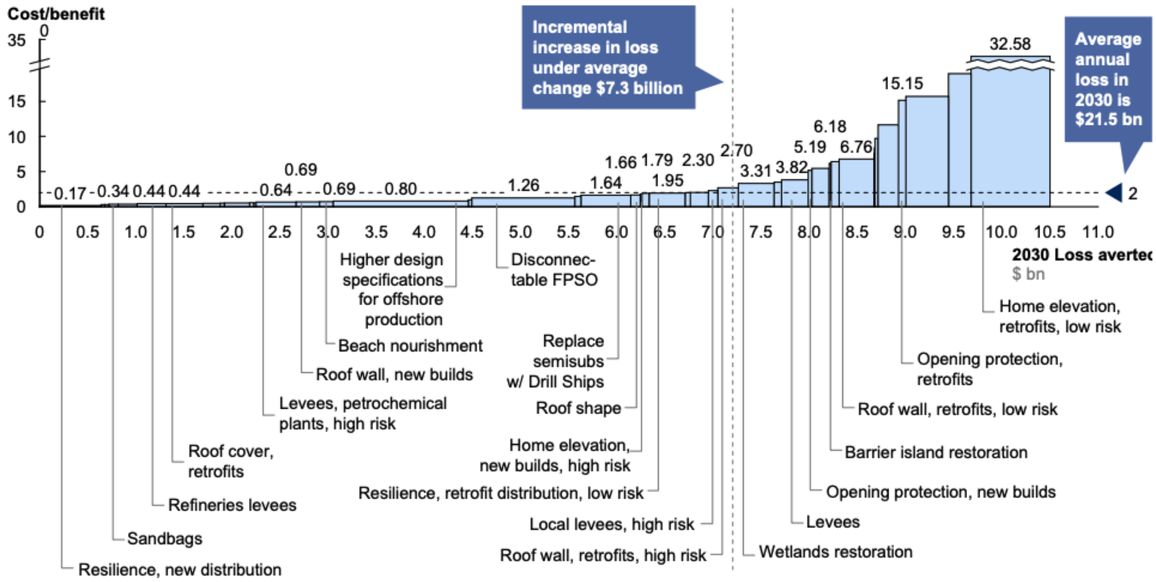


Figure 3.16. Economic Benefit/Cost Ratio of Resiliency Measures in the U.S. Gulf Coast, from Entergy (2010).

The Department of City Planning of NYC published a guide in 2014 titled "Retrofitting Buildings for Flood Risk" directed toward building professionals, architectural and structural communities, and citizens that provides a step-by-step method to approach retrofitting buildings for flood resiliency in order to reduce hazard risk and qualify them for reduced National Flood Insurance Program premiums (NYC Department of City Planning, 2014). The guide covers a range of buildings, from bungalows to mixed-use buildings, with strategies like elevating critical systems (mechanical, electrical, and plumbing systems) in each building and installing flood vents for wet floodproofing. The guidebook uses images that are highlighted to physically demonstrate where the resilience improvement is taking place on the building, as seen in Figure 3.17 (NYC-DCP, 2014).

ADAPTATION CONSIDERATIONS

CRITICAL SYSTEMS

It is important to consider the weight of the mechanical equipment on the building structure when elevating equipment to a higher floor. The additional load may require structural reinforcement of the space where the equipment is being relocated.

Oil- or gas-fueled boilers, furnace and water heaters require adequate combustion air and venting of exhaust gases. Venting and fire-rated enclosure requirements may affect if and how equipment can be elevated.

Before relocating equipment, ample consideration must be given to minimum clearances required for equipment, conduits, piping and duct work in order to maintain the horizontal and vertical clearances as required by building code, the National Electric Code and as recommended by manufacturers. Designing for the minimum clearance is important to maintain air circulation; to meet insurance or code requirements related to the equipment's requirements; and to maintain distance from combustible building materials. The use of heat shields as specified by code may reduce clearance requirements. Failure to maintain clearances can result in safety issues, such as fire, and can void equipment warranties.

ACCESS & STREETSCAPE

Figure 3.17. Resilience Improvements with Mechanical Equipment Relocation in NYC, from NYC-DCP (2014).

Arup, RPA, & Siemens (2022) recognize that in cities with mature infrastructure networks, actions will generally focus on retrofit and renewal that overlay resiliency components to the existing infrastructure, such as leak detection sensors that alert the appropriate personnel to mitigate the issue. Similarly, this guidebook also shows images with certain parts highlighted to show where the resilience improvements are taking place, like general locations of sophisticated fire safety systems components. This could be used in the development of the guide to create visual representations of a physical end-to-end infrastructure system, like a water treatment and distribution system, and to identify resilience opportunities in the image.

3.6 Knowledge Gaps

This research contributes to the infrastructure resilience discourse by creating a Georgia-specific framework that moves beyond traditional disaster response approaches. It will recognize that resilience is not merely a reaction to crises but can be integrated into the everyday infrastructure planning and funding processes of Georgia's cities and counties. Case studies from around the U.S. have demonstrated various ways resilience can be incorporated into infrastructure. While there is guidance on integrated planning methods and engineering techniques that promote resilience, many public works employees, city managers, and county administrators in the State of Georgia lack resources catered to their roles that identify potential roadblocks and strategies to overcome them during resilience implementation. Guidance on navigating the funding landscape to secure financial support for projects that further infrastructure resilience is lacking, particularly given the challenge of organizational turnover in both the public and private sectors. Developing a framework that considers these roadblocks and local stakeholder dynamics would enhance the relevance and applicability of existing guidance available to Georgia cities and counties.

4.0 Problem Statement

4.1 Research Objectives

This research seeks to create a practical and scalable guide for local governments to implement resilience in their infrastructure design, construction, and maintenance processes. The research will focus on resilience opportunities for infrastructure that has the greatest impact on community safety, operations, economics, and public services, including, but not limited to, storm and sanitary sewer systems, WWTP and WTP, roads, bridges, public buildings and parks, and energy systems. The guide will categorize resilience opportunities based on factors like cost and value, hazard, and ease of implementation, and will provide a decision-making tool to help governments prioritize investments.

The approach includes a comprehensive literature review of resilient infrastructure case studies and frameworks/manuals/guidelines on resilient infrastructure design, construction, and maintenance, a survey of Georgia local governments to gather data on current practices and challenges involving infrastructure resilience, interviews of government employees that manage their city/county's infrastructure portfolio to investigate and expand on their survey responses, as well as an evaluation process to gain feedback and improve upon the resulting guide. The literature review analyzes the gaps in this research area and evaluates the effectiveness of various resilience strategies by analyzing performance data from existing infrastructure projects. The main goals of the survey and interviews are to identify common challenges that many local governments face across their infrastructure portfolio and to gauge the uncertainty, willingness, and/or capacity to incorporate resilient design, maintenance, and construction into their infrastructure.

4.2 Research Significance

This research helps to bridge the gap between the planning process and implementation of resilient infrastructure. There are many extensive, process-oriented guidelines on the method of designing and implementing resilient infrastructure. The research field on stakeholder management and the importance of interdisciplinary collaboration regarding infrastructure improvements is well-established. However, there often lies a disconnect between the principles, mandates, and research published by public and private organizations, and the understanding of the specific actions, resources, and/or resilience opportunities that are achievable, impactful to communities, and proven to be resilient in local contexts. There is also a gap in understanding the roadblocks that cities and counties in Georgia experience when pursuing resilience opportunities.

The recent increase in available funding for resilient infrastructure projects, particularly from the Infrastructure Investment and Jobs Act, presents a significant opportunity for local governments to enhance their infrastructure assets. Georgia's infrastructure is aging and susceptible to damage from natural hazards, and, in this moment of need, Georgia's cities and counties need to weigh their options on infrastructure improvements to maximize the impact of available funds in addressing these challenges. The framework will be organized into a decision-making tool based on the type of infrastructure and city/county size, and will provide information on resources for resilience implementation. This will provide more flexibility to the end-user, since every organization has different budget allocations and methods of funding. The framework may provide small governments with the foundational knowledge to navigate integrating resilient practices into their normal infrastructure practices and large governments the insights into achieving advanced resilient design and practices that will strengthen their infrastructure systems even further.

5.0 Research Methodology

To develop a guide for improving infrastructure resilience in Georgia's cities and counties, it was essential to first gain a thorough understanding of their unique challenges. These challenges differ based on factors such as population size, budget, geography, and political climate, all of which are interconnected. Smaller cities often have limited budgets and government resources, which can hinder their progress in advanced infrastructure improvements. In contrast, larger cities and counties tend to have more complex infrastructure strategies in place. The political climate of a community can significantly impact budget decisions, particularly during election years, and influence tax policies that fund local infrastructure. Geographic differences also lead to varying infrastructure priorities. Given these considerations, data collection methods included a survey on resilience and follow-up interviews to accurately reflect these diverse factors in the resilience guide, as well as an evaluation survey and discussion process to assess the effectiveness of the guide.

5.1 Survey

A survey was developed using Qualtrics to collect quantitative and qualitative data from local governments of various sizes and geographical regions in the state of Georgia. A full list of the survey questions is located in Appendix A. The survey questions were created within certain categories: general information, infrastructure budget/financing, resilience preparedness, and specific infrastructure issues. The survey began by asking the respondents questions regarding their role and their city. One of the main grouping factors for cities and counties was four brackets of population sizes. This methodology was informed by the research from Caroline Dickey's

Thesis in 2019 from the University of Georgia, "Effective Approaches to the Development of Asset Management Programs for Small Scale Local Governments". This bracket method maintains the continuity of previous theses completed at UGA in partnership with CVIOG and APWA:

- Rural: <2,500 people
- Small: 2,500 – 20,000 people
- Mid-Sized: 20,000 – 75,000 people
- Large: >75,000 people

Within the budget/financing categories, respondents were asked about their annual government budget allocated for infrastructure design, maintenance, and construction. Another important question explored was whether respondents received funding grants related to infrastructure resilience. This set of questions aims to identify budget trends among cities and projects receiving funding, assess whether external funding is supplementing their annual budgets, and determine which cities are actively pursuing projects related to resilience.

Another key category was whether the respondents' cities and counties currently have a resilience plan and feel equipped to manage resilience in infrastructure. This question was essential in selecting respondents for follow-up interviews, ensuring a representative sample of those with and without resilience plans. The survey also captured the hurdles communities face in incorporating resilience, which will help pinpoint focus areas for the final framework.

The survey also addressed the top issues each respondent encounters within their infrastructure sectors, if any. This question identified the common challenges among cities and counties with similar budgets or levels of resilience integration. The ranking options were based on a thorough literature review and background research on common themes they face in each infrastructure sector. However, bridges were excluded from the ranking options because the primary concern highlighted in the ASCE report card was the large number of bridges in "poor condition" or classified as "structurally deficient." The emphasis is on bringing these bridges up to GDOT standards, which are defined by the percentage of deficient bridges.

The survey was sent out using several methods. The survey was distributed three times through email to the Georgia APWA Chapter contact list, which was received by public works employees, city and county leaders, and private vendors. The survey was emailed once to the UGA Archway Partner communities and promoted once through the Georgia City-County Management Association (GCCMA) newsletter, which is distributed to Georgia city and county managers and administrators, directors of regional development centers, and representatives from the Association of County Commissioners of Georgia and the Georgia Municipal Association. The devastation caused by Hurricane Helene on Friday, September 27th, resulting in loss of life, power outages, internet disruptions, and widespread structural damage across Florida, Georgia, and North Carolina, likely contributed to a slow survey response rate. For this reason, the survey was sent individually to local officials, requesting their participation in the survey, with careful consideration given to Georgia cities impacted by Hurricane Helene. These individual emails were sent to individuals from cities and counties whose population brackets were underrepresented in survey responses at that point in time, as well as individuals and governments recommended by employees of CVIOG and members of APWA. Follow-up emails were sent to individuals who had begun but not finished the survey, inviting them to complete their initial responses. The individual email addresses were compiled through online research and through the GCCMA Directory.

5.2 Interviews

The interview questions were developed to build from the survey responses and provide more context using the general interview guide approach, ensuring that similar lines of questioning are followed in each interview (Patton, 2002). The interview questions were aimed at gaining more background on the governments' infrastructure issues, views and challenges surrounding resilient infrastructure, financial structures, motivations for pursuing certain funding opportunities like SPLOST or state/federal grants, and current or projected infrastructure projects. The questions were proofed and edited by individuals from CVIOG and the College of Engineering. The full list of interview questions is located in Appendix B.

The interviews were conducted within the sample of survey respondents and selected based on ensuring diversity in population size, resilience preparedness, government structure (city versus county), and infrastructure funding sources. Some officials that were interviewed were recommended by individuals from CVIOG and APWA. Their recommendations focused on officials who were likely to be responsive and cities and counties that represented a range of governmental sophistication and geographic regions across the state. The same number of interviews were conducted between rural/small government sizes and medium/large government sizes.

Each interview was scheduled for 30 minutes on Zoom. Interview scheduling was done both via email and phone call. Due to persistent scheduling challenges with rural and small governments, the final interview was conducted well outside of the initial data-collection window, in March 2025. These challenges were compounded by the requirement that governments complete the survey before the interview, and the disproportionately low response rates from smaller governments necessitated numerous follow-up emails and calls to many different governments.

Responses from the survey and planned interview questions were distributed to each interviewee 1-2 days prior to the scheduled interview time to allow them to prepare and to create a fully transparent interview environment. Each meeting was recorded for transcription purposes with the interviewee's permission.

5.3 Product Development

The first drafts of the *Resilient Infrastructure Resource and Decision Guide for Local Georgia Governments* and the associated *Resilience Decision Matrix Excel Spreadsheet* were developed to address the key challenges and roadblocks that local governments indicated that they experienced in their efforts to strengthen infrastructure resilience based on the survey and interviews conducted. Certain infrastructure sectors were focused on more closely as dictated by feedback elucidated from survey questions. Financing and funding tools were included based on information gathered in the interviews on reliant and novel resources, as well as through discussions with the EPA Resource for Assistance and Community Training in Region 4 (REACT4), a Thriving Communities Technical Assistance Center (federal initiative). Formatting for Chapter 2 and Chapter 4 of the Guide was influenced by the Coastal Resilience Guide BMP cards, seen in Figure 3.12, authored by GA DNR, NOAA, & CVIOG (2020), and from the Guide for Retrofitting for Flood Risk, seen in Figure 3.17, authored by the NYC Department of City Planning (2014). The resilience strategies within the Guide (see Appendix E) were compiled for each infrastructure category based on the most significant issues that survey respondents identified. The formatting of the strategy tables was influenced by the Climate Ready DC Resilient Design Guidelines, seen in Figure 3.11 (Department of Energy & Environment in District of Columbia, 2021). The Decision Matrix was developed using Microsoft Excel and was aimed at quantifying resilience in a way that made it comparable to more traditional and well-established strategies. The Matrix was influenced by the rehabilitation alternatives matrix from Giunta (2017), as seen Figure 3.15, and its ability to effectively quantify resilience.

5.4 Product Evaluation Survey

Upon completion of the Guide and Matrix, a survey was created to assess the Guide's usability, ability to address gaps in resilience, and novel information. The survey questions were influenced by the thesis "Development Of An Asset Management Framework For Local Roadway Maintenance And Repair Within The State Of Georgia" by Natalie Branand from the University of Georgia (Branand, 2024) and were proofed and edited by a representative in the College of Engineering. Interest in the survey to evaluate the Guide and Matrix was assessed via QR code during a presentation to local officials at the Public Works Winter Conference on January 31, 2025, in Athens, GA. Survey questions are located in Appendix C.

5.5 Product Evaluation Discussion

Using results from the evaluation survey, two respondents were selected for a meeting to discuss their survey answers, how the Guide can be improved upon, and to provide use case validation for the Matrix spreadsheet. The participants were selected to gain perspectives from both city and county officials, and from those who had provided in-depth feedback in the survey, because they were likely to have stronger opinions when sitting down for an interview. The discussions were conducted for 30 minutes via Zoom, and guiding questions were developed and distributed to the interview participants before the interview (see Appendix D), along with their survey answers. The guiding questions were developed based on gaining more information from the survey responses received and were intended to walk through a use case of Matrix with the participants to assess its organization and usability.

5.6 Product Iteration

Insights from the evaluation process were used in the refinement of both the Guide and Matrix into their final forms. Chapter-specific feedback was incorporated to enhance the clarity, relevance, and applicability of the content within the Guide. Findings from the evaluation discussions directly informed improvements to the Decision Matrix, ensuring that the tool is intuitive, accessible, and well-suited for use by local government officials across Georgia.

6.0 Research Findings

This chapter summarizes and analyzes results from resilience survey responses, interviews with local government officials, Guide evaluation survey responses, and evaluation discussions with local government officials. The findings from all four research methods were used to inform and develop the Guide for Georgia's local governments.

6.1 Survey Results

The survey responses were collected for 67 days, from September to November 2024, and within that time, the survey received 66 total responses. Forty-six responses were incomplete when they were submitted, which is primarily because the survey settings were set to automatically record responses after one week of the response start. Two complete responses were received from the same city, Marietta. In this case, the two respondents were contacted to find out how to proceed, at which point the Public Works Director indicated that his response should be the sole response on behalf of Marietta. After these corrections, nineteen responses were deemed acceptable to include in the final sample size, all with 100% completion and with uniquely represented Georgia governments, resulting in a 28.8% completed response rate out of the 66 responses started. The responses received from each population category can be seen below:

- Rural (<2,500 people): 2 responses
- Small (2,500 – 20,000 people): 4 responses
- Mid-Sized (20,000 – 75,000 people): 10 responses
- Large (>75,000 people): 3 responses

The survey results were statistically analyzed and graphically represented in RStudio using the R programming language.

6.1.1 Summary Statistics

The top three categories that respondents ranked as their governments' most critical infrastructure, as seen in Figure 6.1, were roads, stormwater and sanitary sewer systems, and WTP & WWTP.

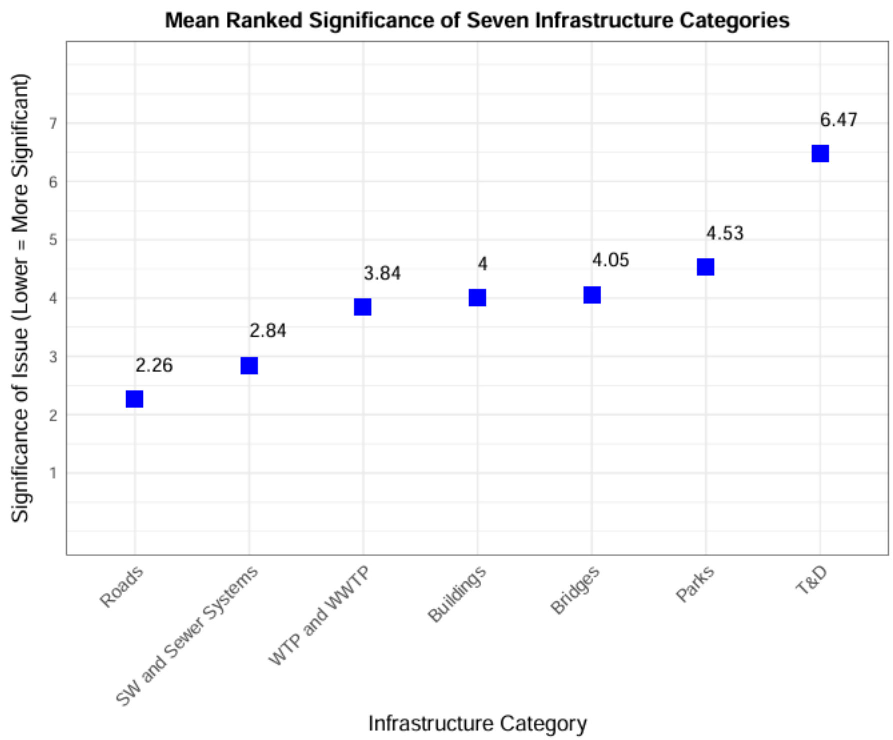


Figure 6.1. Average Value Rankings.

While most cities and counties are responsible for maintaining their own roadway systems, they may not all manage or maintain their bridges. Some cities, especially rural and small cities, do not have their own dedicated WTP or WWTPs. T&D was ranked last in priority, likely due to the privatization of electrical services in most areas, leaving project oversight in the hands of Georgia Power or a local EMC.

Every respondent, except for Dawson County and Gainesville, both with mid-sized populations, indicated funding limitations as their main roadblock for implementing resilience to their infrastructure systems, ranking this limitation more significant than the others by more than 2 points on average. Lack of data/information of resilience strategies and lack of technical expertise on resilience implementation were the two roadblocks that followed funding. Figure 6.2 summarizes these resilience roadblock data points.

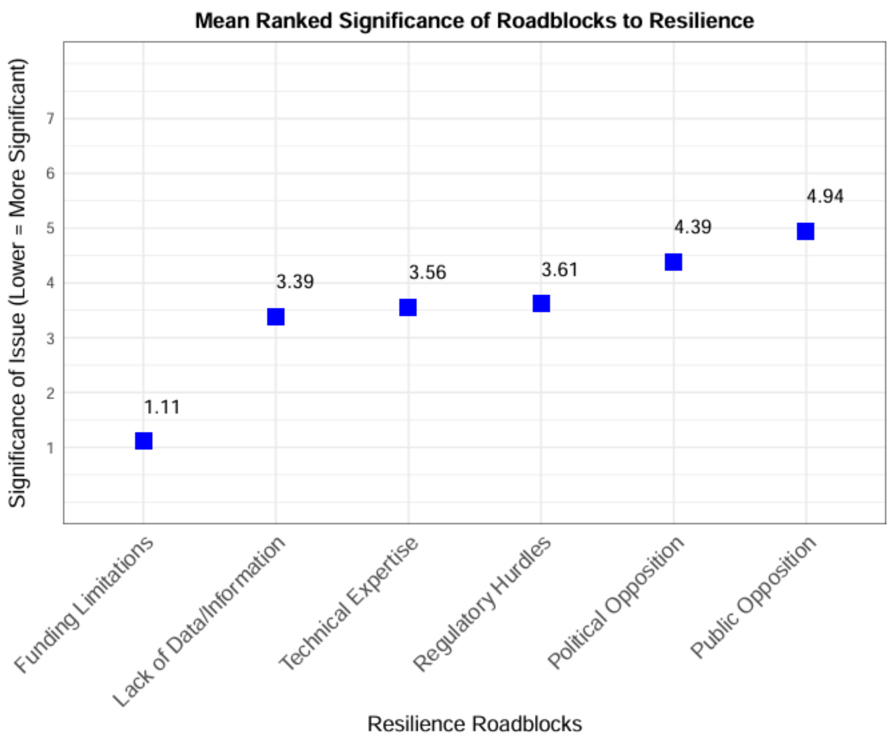


Figure 6.2. Average Value Rankings.

Four survey respondents out of 19 (21%) said that their government did have a plan for resilience, and all who had a plan said the plan did not receive regular updates. The average ranking of how informed the respondents felt their government was on how to incorporate resilience to their infrastructure was 5.1/10, with no significant difference found in the distribution of those values amongst the difference in city/county size.

Figures 6.3, 6.4, 6.5, and 6.6 display the mean rankings of the significance of challenges that cities and counties face with certain physical infrastructure systems. Figure 6.3 displays the top three issues faced by local Georgia governments in their stormwater and sanitary sewer systems as insufficient funding for repairs, outdated systems, and inflow and infiltration.

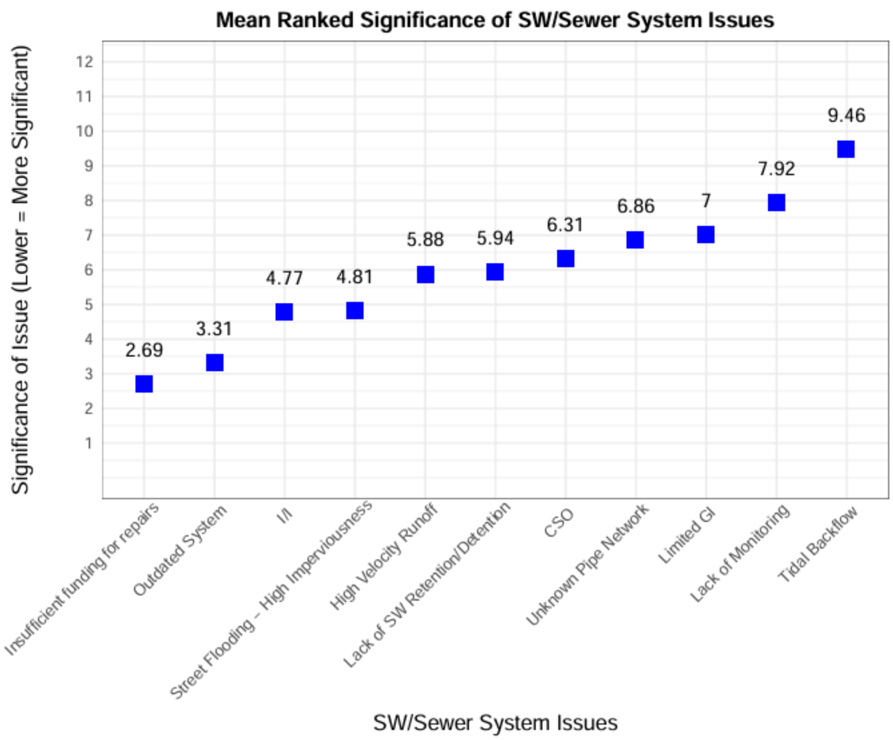


Figure 6.3. Average Value Rankings.

Tidal backflow was ranked last due to low representation from coastal communities in the survey. Insufficient funding for repairs directly aligns with the top ranked resilience roadblock, funding limitations, which in of itself stresses the importance of presenting diverse and accessible funding opportunities in the resource guide.

Figure 6.4 shows that the top three issues faced by local Georgia governments with their WTP and WWTP systems were aging systems, handling peak flows, and deteriorating drinking water distribution pipes. These issues can be addressed in the guide by presenting resources for cost-effective modernization opportunities in WTPs/WWTPs and demonstrating the cost effectiveness of various storage solutions to handle peak flows.

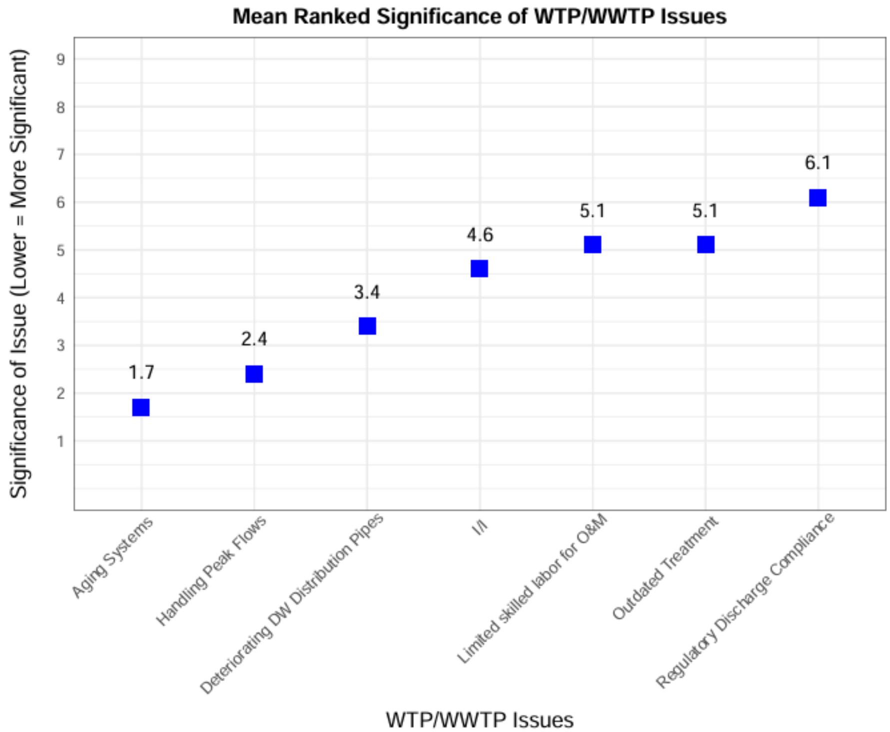


Figure 6.4. Average Value Rankings.

Figure 6.5 displays cracked pavement and potholes equally as the top two issues, which were ranked almost 2 points lower, and therefore more significant, than the rest of the issues. These issues can be reflected in the resource guide with recommendations for resilient strategies that solve these issues while providing co-benefits to other infrastructure sectors or roadway assets. Insufficient lighting will take less focus in the resource guide since respondents ranked this issue as the least significant.

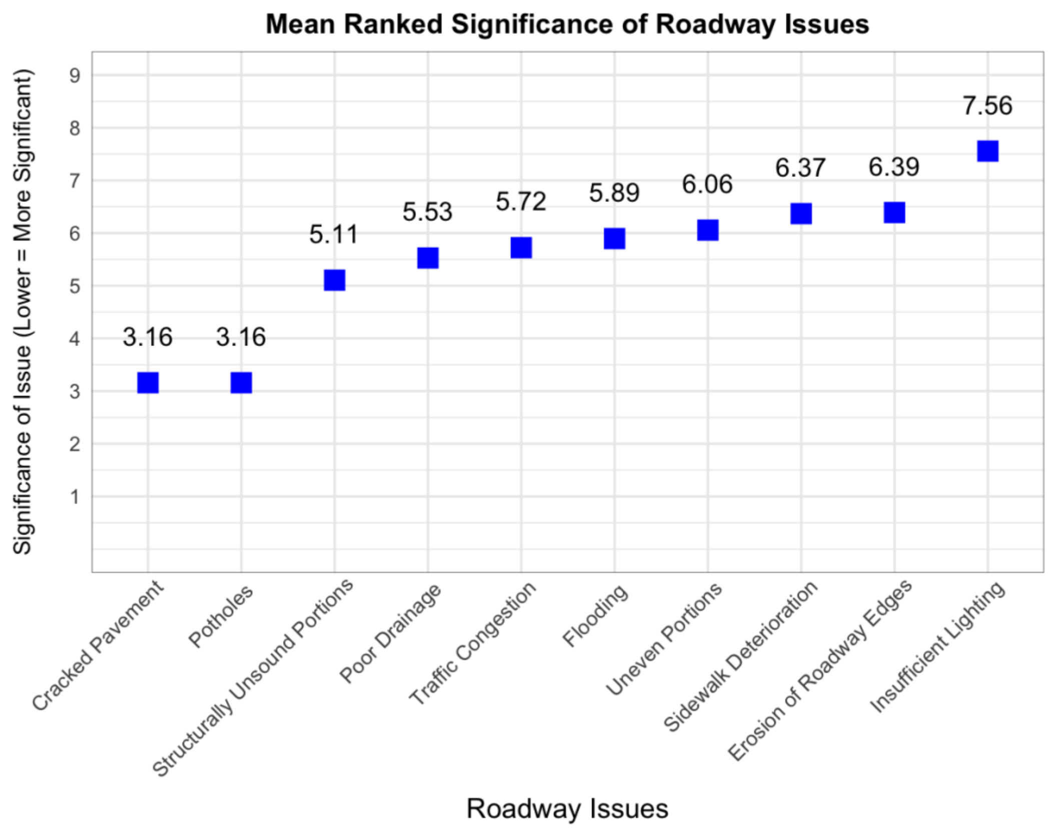


Figure 6.5. Average Value Rankings.

Figure 6.6 indicates that leaky roofs and windows, insufficient space, and outdated HVAC/electrical plumbing units are the top three issues respondents face within their public buildings. References for incorporating resilience into facilities management maintenance practices, and how to create a resilience plan for public buildings, are strategies that can address these issues in the resource guide.

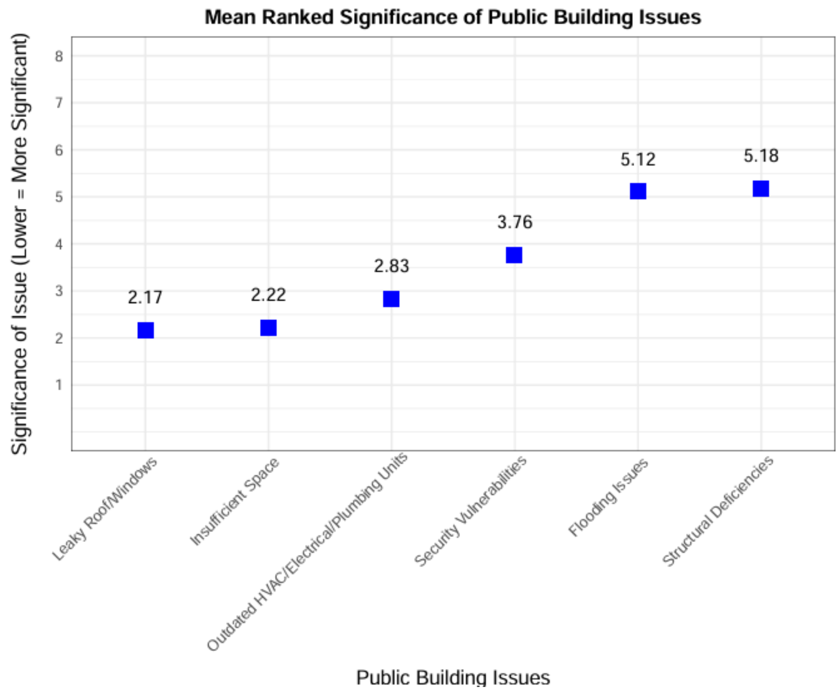


Figure 6.6. Average Value Rankings.

Figure 6.7 shows the ranked significance for issues experienced in public parks, with poor drainage in wet conditions being the most significant issue, followed by aging amenities and insufficient lighting. Strategies to alleviate these issues can be recommended in the resource guide, coupled with images that showcase examples of the strategies in action.

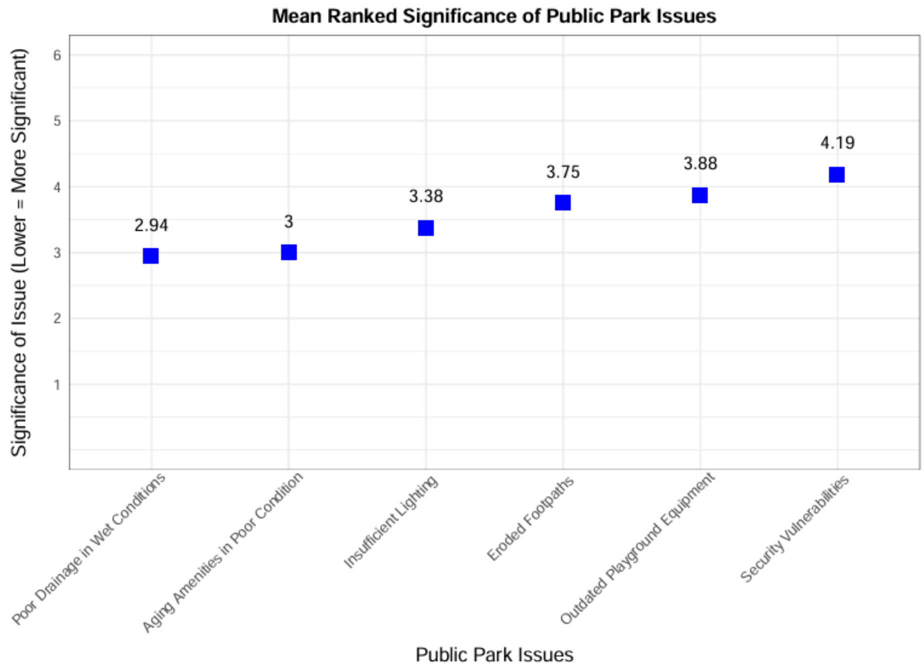


Figure 6.7. Average Value Rankings.

The main issues faced by local governments in each infrastructure sector can only be tended to when the resilience roadblocks are addressed first. If the resource guide's aim is to identify resilience opportunities, then those opportunities should align with the issues they experience most. For example, identifying easily accessible and diverse grant opportunities for roadway resilience, while explaining its benefits towards fixing cracked pavement would help local governments address their most significant issue in their top-ranked infrastructure category. This would also help to close the gap in the top-ranked resilience roadblock, funding. Providing technical examples and resources for helpful organizations would help to close the gap on the technical expertise roadblock.

6.1.2 Wilcoxon Rank Sum Test

The Wilcoxon Rank Sum Text, also known as the Mann-Whitney U Test, was conducted to determine significant relationships between two groups of independent qualitative values and their associated quantitative values amongst the non-normally distributed survey data. This non-parametric test assumes a small sample size, independent sampling, and continuous data (LaMorte, 2017). In this case, data has already been ranked by the respondents to become discrete, which completes the first step in the analysis process. The Wilcoxon test produces a test statistic, W, that represents the number of times observations from one group precede observations from another group when ranked across both groups. It measures whether the ranks of one group tend to be higher or lower than the ranks of the other group, testing for differences in their distributions. If the resulting W test-statistic value is less than or equal to the corresponding W value in the table, then the null hypothesis can be rejected. The following are the general null and alternative hypotheses used for the Wilcoxon Rank Sum Test (LaMorte, 2017):

H_0: There is not a difference between the two populations.

H_1: There is a difference between the two populations.

1. **Infrastructure Challenges vs. Population Categories**

Due to the low survey response rate, there was an insufficient number of responses to warrant each population bracket being analyzed against one another. For this reason, the two lower and two upper brackets were combined to encompass the "Rural-Small" category (<20,000 people) and the "Mid-Large" category (>=20,000 people). The rural-small category had 6 total responses (n = 6: rural = 2, small = 4) and the mid-large category had 13 responses (n = 13: mid-sized = 10, large = 3).

Every infrastructure challenge that respondents were asked to rank in the survey was analyzed based on their groupings into the two new population categories. In addition, the ranking of infrastructure categories in need of rehabilitation and the scoring of the respondents' level of knowledge regarding resilience implementation were both analyzed in these population categories. The Wilcoxon Rank Sum Test found one significant relationship.

One significant relationship ($p = 0.003547$, $W = 5$) was found between the ranked urgency of potholes on roadway infrastructure and rural-small and mid-large sized governments (1 = high priority issue; 8 = low priority issue). All respondents provided rankings for this question in the survey, making a total sample of 19 for this analysis. The critical W value for $n_1 = 6$ and $n_2 = 13$ at an $a = 0.05$ significance is 16. Figure 6.8 displays this relationship graphically using a boxplot.

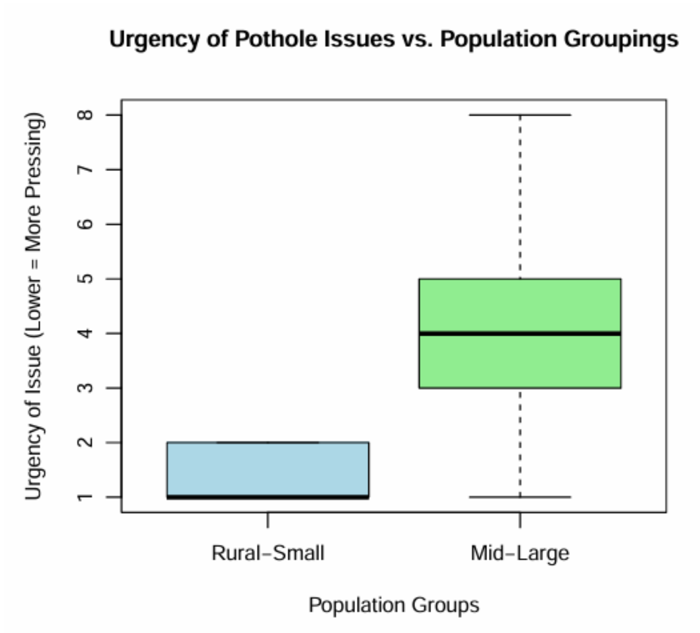


Figure 6.8. Wilcoxon Rank Sum Test Results.

Since the p-value of 0. 003547 is less than the $a = 0.05$ significance level, and $W = 5$ is less than the critical value of 16, H_0 can be rejected in favor of H_1. This indicates a significant difference in the urgency regarding the issue of roadway potholes between rural-small governments and mid-large governments, indicating that rural-small governments hold potholes at a higher priority compared to larger governments. This is likely due to their lower budget and fewer staff available at their disposal. To reflect this finding in the resource guide, recommendations will be tailored to fit each group's needs. Rural-small governments may benefit from an abundance of resilient pothole repair and mitigation strategies in the guide that are cost-effective, whereas mid-large governments might benefit from purely preventive maintenance strategies.

2. Infrastructure Challenges vs. Resilience Contact

Every infrastructure challenge that respondents were asked to rank and the barriers to incorporating resilience were analyzed against whether the respondent left contact information for someone knowledgeable about their government's approach to resilience, or a "resilience representative", at the end of the survey. The Wilcoxon Rank Sum Test found one significant relationship.

The significant relationship ($p = 0.\ 04167$, $W = 11$) was found between the urgency of aging stormwater and sanitary sewer pipe infrastructure (1 = high priority issue; 8 = low priority issue) and the mention of a resilience representative. Three respondents did not rank the storm and sewer issues, dropping the sample size to 16 for this analysis. After eliminating those responses, six respondents whose governments employ resilience in their infrastructure left contact information, and ten governments did not leave contact information. The critical W value for $n_1 = 6$ and $n_2 = 10$ at an $a = 0.05$ significance is 11. This relationship is shown graphically in Figure 6.9.

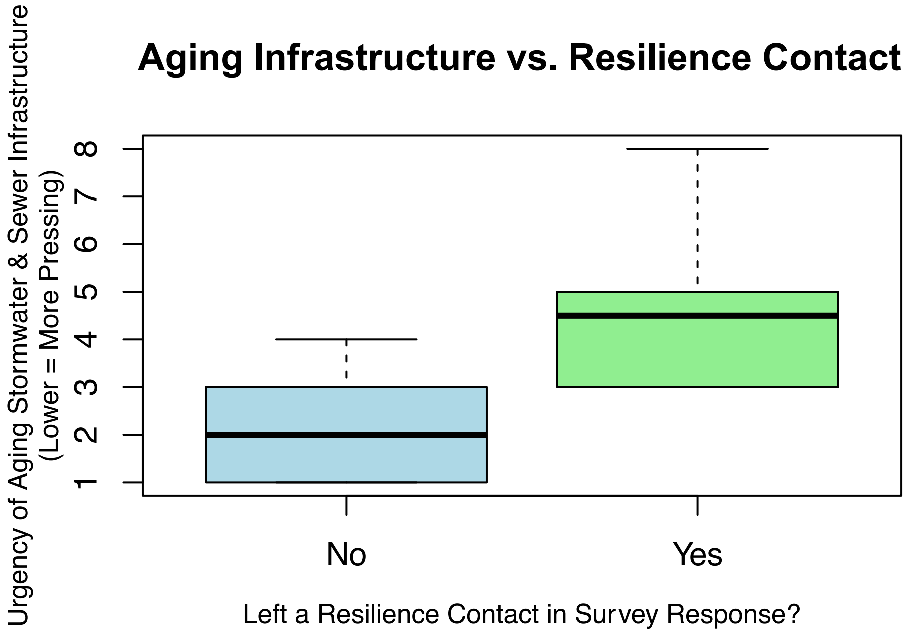


Figure 6.9. Wilcoxon Rank Sum Test Results.

Since the p-value of 0.04167 is less than the a = 0.05 significance level, and W = 11 is equal to the critical value of 11, H_0 can be rejected in favor of H_1. This indicates a significant difference in the urgency of aging stormwater and sanitary sewer infrastructure and whether the respondent left contact information for a resilience representative, demonstrating that respondents who did not provide contact information for a resilience representative perceived aging stormwater and sanitary sewer infrastructure as a significantly more urgent concern. This suggests that without a designated resilience contact, local governments may lack the critical oversight needed to keep their maintenance and rehabilitation strategies up to date. The guide will include organizational contacts that can serve as external resilience representatives, ensuring that local governments have the necessary resources to maintain and upgrade their critical infrastructure effectively. Delegating an external representative is important in the context of high organizational turnover within local governments.

3. Priority of Infrastructure Categories vs. Grant Applications

Priority rankings of the seven infrastructure categories were analyzed against whether those governments had applied to specific grant opportunities. The Wilcoxon Rank Sum Test found two significant relationships.

The first significant relationship found ($W = 2$, $p = 0.002464$) was between the priority ranking of a city/county's water and wastewater treatment plants (1 = high priority; 7 = low priority) and whether the city/county had applied for funding through the Community Development Block Grant (CDBG) distributed by the Department of Housing and Urban Development (HUD). Fifteen total responses contributed to this analysis. Two responses listed "I don't know" as to whether their city/county had applied for resilience funding and one response was unsure of the specific grants their city/county had applied to. Seven cities and counties had applied to receive funding through CDBG, and eight cities/counties had not. The critical W value for $n_1 = 8$ and $n_2 = 7$ at an $a = 0.05$ significance is 10. Figure 6.10 displays this relationship between the two variables graphically.

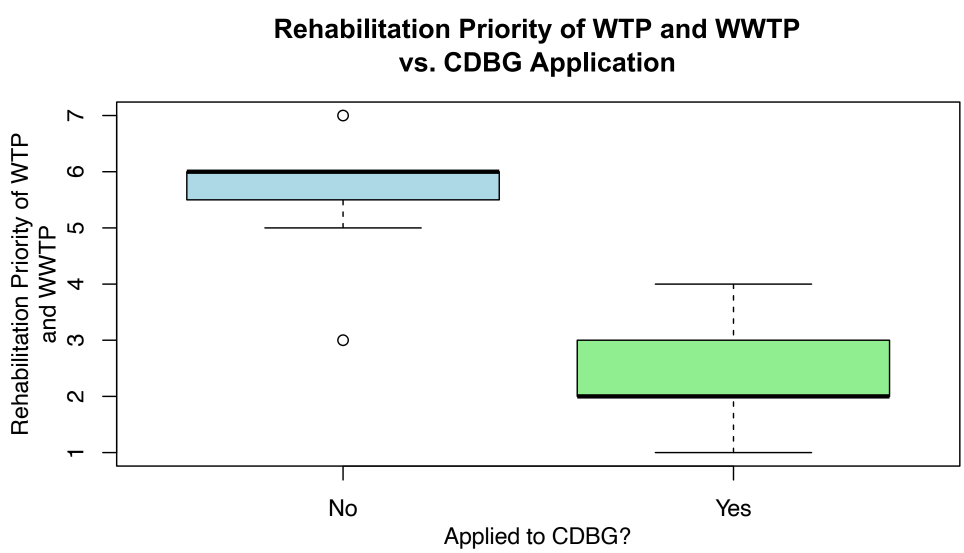


Figure 6.10. Wilcoxon Rank Sum Test Results.

Since the p-value of 0.002464 is less than the a = 0.05 significance level, and W = 2 is less than the critical value of 10, H_0 can be rejected in favor of H_1. This indicates a significant difference between the ranked priority of WTP/WWTP and whether the city/county has applied to funding through CDBG, indicating that those who ranked rehabilitation of WTP/WWTP as a high priority were more likely to have applied to the CDBG. This insight will inform the resource guide by focusing on targeting recommendations for access to funding opportunities, especially for cities/counties focused on upgrading critical water infrastructure. Strategies will include guidance on navigating the CDBG application process, resources on incorporating resilient practices to CDBG funding awards, identifying other potential funding sources that might be easy to apply to and/or receive for water infrastructure, and resources to help grant applicants attract financial support within a grant application lifecycle.

The second significant relationship found (W = 7, p = 0.01522) was between the priority ranking of a city/county's stormwater and sewer collection systems 9 (1 = high priority; 7 = low priority) and whether the city/county had applied for funding with CDBG. Again, the critical W value for n_1 = 8 and n_2 = 7 at an a = 0.05 significance is 10. Figure 6.11 displays this relationship.

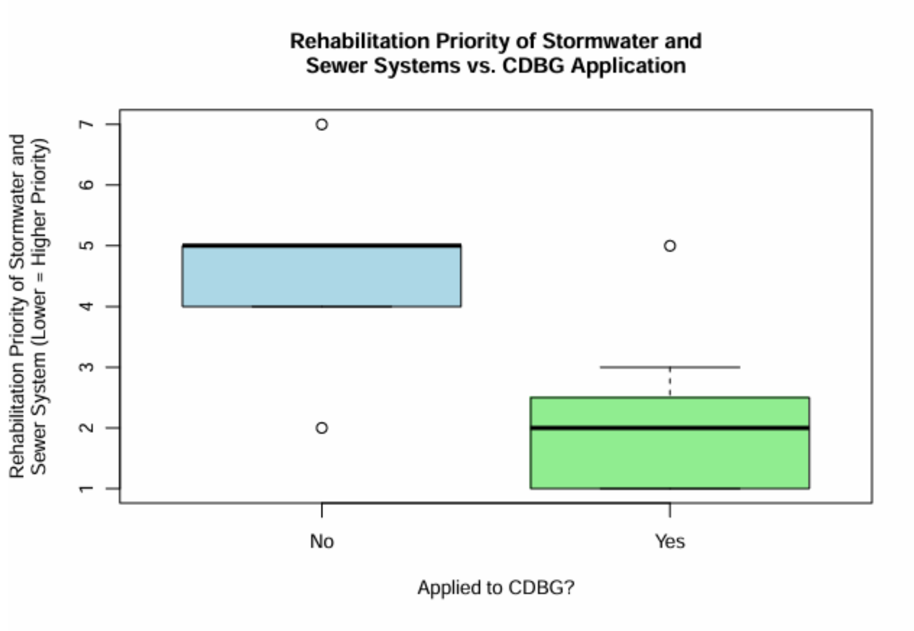


Figure 6.11. Wilcoxon Rank Sum Test Results.

Since the p-value of 0.01522 is less than the a = 0.05 significance level, and W = 7 is less than the critical value of 10, H_0 can be rejected in favor of H_1. This indicates a significant difference between the ranked priority of stormwater and sewer systems and whether the city/county has applied for funding through CDBG, indicating that those who ranked rehabilitation of stormwater and sewer systems as a high priority were more likely to have applied to the CDBG. This furthers the point of highlighting grant and other funding opportunities in the guide that are targeted towards critical water and wastewater infrastructure and providing resources to assist with the CDBG and HUD application and administration process.

6.1.3 Key Survey Findings

The survey results reveal key priorities and shared challenges amongst local Georgia governments in furthering resilient infrastructure. Priority infrastructure sectors identified by respondents include roads and stormwater & sewer systems, indicating a focus on transportation and essential conveyance infrastructure. A lack of funding emerged as the top roadblock to resilience, while gaps in information on resilience opportunities and technical expertise also limit planning efforts. One response was received from a coastal community, indicating that their most pressing issues in coastal infrastructure were flooding during high tides and storm surges, tidal backflow into storm and sewer systems, and a loss of natural buffers, in that order.

Significant differences were found amongst the categories of government size, designation of a resilience representative, and storm/sewer and WTP/WWTP grant applications. Smaller governments placed a higher priority on pothole maintenance, likely due to lower budgets and fewer staff. Respondents without a dedicated resilience representative indicated that aging stormwater and sewer infrastructure was a higher priority than those who did list a representative, suggesting that resilience-focused expertise plays a role in educating others and promoting resilience in their government's infrastructure design, construction, and maintenance. Governments that prioritized the rehabilitation of stormwater & sewer systems and WTP/WWTPs were more likely to have applied for CDBG funding, highlighting the importance of specific grant guidance in the resource guide and guidance on incorporating resilient practices with the allocated CDBG funding.

These survey findings will drive the creation of a resource guide aimed at equipping Georgia's local governments with the tools to help overcome their financial, technical, and data-related barriers to resilient infrastructure.

6.2 Interview Responses

As of March 2025, eight interviews were completed out of sixteen total requests sent to survey participants. These included representatives from one rural city, three small cities, three mid-sized cities, and one large county.

1. Rural Governments:

a. **City of Wadley**

Wadley was recommended to participate in the interview process due to their involvement with GCCMA. Their representation of rural governments also made Wadley an excellent interview candidate. The representative's survey response demonstrated the city's experience with grant writing and prioritized government buildings third when ranking infrastructure sectors, which was a unique prioritization from the rest of the survey respondents.

2. Small Governments:

a. City of Hawkinsville

Hawkinsville was selected to participate in interviews due to the government's established partnerships with UGA as an Archway Partner Community through CVIOG and the College of Engineering. The city was one of six rural and small cities to respond to the survey, so their participation was essential to a well-represented rural-small community category. The survey response noted the city had applied to grants specifically for resilience, but did not have a resilience plan and did not list contact information for a resilience representative, making Hawkinsville a unique interview candidate.

b. City of Alma

Alma was recommended by a representative from the APWA, which highlighted their potential interest in participating in APWA-funded research. In their detailed survey response, the Alma representative expressed a strong interest in resilience and provided contact information for a resilience representative when most respondents did not. As previously mentioned, the rural and small cities/counties were a much smaller sample than the mid-sized and large cities/counties, meaning their participation was vital in the interview process.

c. **City of St. Marys**

St. Marys was the only coastal government to respond to the survey. While one city cannot represent all coastal communities, its participation provided valuable insight and ensured that Georgia’s coastal region was represented in the interview process. Due to scheduling issues, the initial survey respondent recommended another St. Marys representative to participate in the interview process. The survey response indicated St. Marys’ pursuit of a variety of resilience grant funding opportunities and noted their in-house bridge management operations, making the city a unique candidate.

3. Mid-Sized Governments:

a. City of Statesboro

Statesboro was one of the first responses to the survey, signaling responsiveness to email and a proactive interest in resilience topics. The response noted that the Statesboro Public Works Department has applied for numerous grants with a high success rate, indicating the department’s capability to secure funding. An interview would have been able to further understand their grant writing process and how it is so effective, a skill that would be useful for the resource guide. The respondent provided a resilience contact in their response and rated the department's resilience knowledge as a 7 out of 10, which demonstrates a great foundational understanding that could serve as a benchmark for others.

b. City of Dalton

Dalton was recommended for participation by a representative from CVIOG. The city also operates its own utility company, setting it apart from other Georgia cities and counties.

Dalton is geographically unique by being at the foothills of the Appalachian Mountains. After the initial email correspondence with the survey respondent, they recommended including two additional public works officials from the city in the interview conversation to provide a more comprehensive insight.

c. City of Gainesville

Gainesville was selected to participate in the interview process due to the survey respondent's wide-ranging involvement in the city's infrastructure operations that would a comprehensive overview of many infrastructure sectors. Gainesville also represented a unique geographic region of northeast Georgia that had not been interviewed yet. Gainesville's representative scored their resilience understanding a 2 out of 10, which was lower than the average score from the total response pool and contributes a unique perspective that would help cater the guide to those in government with a lower understanding of resilience.

4. Large Governments:

a. Fayette County

Fayette County was recommended for an interview due to its history with stormwater infrastructure financing, transitioning from a dedicated stormwater fund to SPLOST. The respondent's position in the Environmental Management Department would have provided diversity in the response pool, which primarily consists of city managers, city administrators, and public works directors. Fayette County was one of four counties to respond out of the nineteen total respondents, making their feedback particularly valuable in this process.

6.2.1 Interview Summaries

1. *City of Hawkinsville* – In October 2024, the City Manager of Hawkinsville was interviewed to understand resilient infrastructure from the perspective of a small-sized city. Hawkinsville is the seat of Pulaski County and has a population of 3,980 as of 2020 (U.S. Census Bureau, 2021). The physical infrastructure assets and systems managed by the city, as described by the City Manager, include two wastewater and two water treatment facilities, an animal control facility, a public works facility, stormwater systems, sanitary sewer systems, roads, sidewalks, a natural gas facility and associated gas infrastructure, community buildings, a horse track, and various small parks. The City Manager explained that while there is no regular maintenance schedule for public works infrastructure like roads, stormwater, and sanitary sewer systems, their water and wastewater facilities, as well as associated pump stations and lift stations, are inspected and maintained regularly. This is due to the city's recent decision to outsource these services to a third-party contractor. The motivation for this switch from in-house to contracted maintenance was due to a lack of internal staff with proper operational training and expertise.

When asked to define a resilient infrastructure asset, the City Manager described it as "infrastructure that's able to sustain the needs of the community without interruption." They noted that a big challenge is convincing elected officials to approve long-term investments for infrastructure that may not provide immediate, visible benefits, such as stormwater and sanitary sewer, which makes it difficult to prioritize these projects. This is reflected in the 35% of Hawkinsville's budget that is dedicated towards infrastructure, generally for maintenance and repairs. The city typically allocates funds for infrastructure based on immediate needs or specific, anticipated events. For instance, since 2020, Hawkinsville has been under a consent order from the Public Service Commission to replace two miles of steel gas mains each year. These types of required projects are included in the budget. Recently, the city received a grant from the U.S. Department of Transportation to complete the remaining gas main replacements at no cost to the city.

Hawkinsville's preparedness for disasters has improved significantly since the hurricanes of 2018. The city nearly ran out of water during one storm due to a lack of backup power, prompting the installation of generators at essential facilities. The City Manager shared that through funding from the American Rescue Plan and SPLOST, the city was able to invest in generators, emergency pumps, and communication systems that have improved its ability to maintain essential services during hurricanes and other natural disasters.

The city is proactive in seeking external funding through grants to address water, sanitary sewer, and stormwater challenges. Hawkinsville relies on the Middle Georgia Regional Commission to write grant applications for projects like CDBG, which they have received over $1,800,000 from in the past five years. Currently, the city is pursuing a Congressionally Directed Spending grant to fund a new water tower and additional water plant capacity. The City Manager described this expansion as necessary to accommodate current residential growth and future industrial expansion in Hawkinsville that is currently limited by its existing infrastructure capacity. Hawkinsville has implemented an enterprise fund supported by its gas, water, sanitary sewer, garbage services, and mosquito spraying, but all profit from this revenue is being allocated toward the general fund, further limiting the availability of funds for infrastructure improvements.

2. *City of Alma* – Alma's City Manager was interviewed in October of 2024. The city falls into the small-sized bracket with a population of 3,433 as of 2020 (U.S. Census, 2021). The physical infrastructure assets and systems managed and maintained by the city include water distribution,

stormwater and sanitary sewer systems, a WWTP, five parks, 15 acres of cemetery, a solid waste collection service, streets, sidewalks, right-of-ways, government buildings, and a theater.

The City Manager defined resilient infrastructure as a multi-layered approach, starting with a solid foundation of a comprehensive database of infrastructure assets. Updates in Alma include recently digitizing maps of water and sanitary sewer lines from the 1970s to align with modern geographic standards. This foundational information supports effective planning, the use of high-quality construction materials, and sustained funding. Without this solid knowledge base, resilience becomes unstable, akin to a "honeycomb base—taking shortcuts makes things sticky." The City Manager has prioritized material selection in Alma's infrastructure projects, noting that resilient infrastructure depends on using quality materials and changing outdated construction standards, as older materials like asbestos cement pipes are prone to brittleness. They noted that a main barrier to implementing resilience is getting "buy-in" from elected officials, whose shorter-term outlooks prevent them from focusing on long-term success. Their strategy for educating these officials includes using APWA resources to familiarize board members with resilience priorities and taking officials to field sites to see infrastructure challenges first-hand.

Alma's infrastructure has grown gradually, adapting to modernization needs, including a $1 million CDBG award in 2023 used to slip-line and seal the aging terracotta sewer lines to improve resilience by reducing inflow and infiltration. Alma's funding model includes Local Option Sales Tax (LOST) and SPLOST initiatives, which help to fund capital improvements. SPLOST has enabled the city to invest in vital transportation projects, water and sewer upgrades, and other community infrastructure. Alma's 8% sales tax allocation has significantly supported improvements, including urban park developments and a "linear park" along the former railroad line, which reflects Alma's move towards urban renewal.

Alma’s experience with natural disasters, particularly hurricanes, has led to critical investments in emergency preparedness. In 2018, the city used funds from the general fund and water fund to switch to a central generator with a three-day fuel supply for backup power and emergency preparedness, as well as fiber optic for communications. Hurricane Helene’s eye came within 35 miles of the city, resulting in widespread power outages and severe damage to forests. However, the city did not lose access to its water supply due to investments and planning done six years ago.

3. *City of Wadley* – The City Administrator of Wadley was interviewed in March of 2025. Wadley lies in Jefferson County, roughly 50 miles southeast of Augusta, and falls into the “rural” community size with a population of 2,050 people as of 2020 (U.S. Census Bureau, 2020). The local government manages ten lift stations, two water wells, and an oxidation pond that discharges treated water into a nearby creek. The city is actively transitioning from the aging oxidation pond system to a modern MBR-style wastewater treatment plant, a move driven by the growing needs of local industry. In addition to water infrastructure, Wadley is responsible for maintaining local roads, streets, and public facilities, including an elementary school and a recreation department. With recurring challenges such as inflow/infiltration issues and significant water main breaks (which, when fixed, have saved over 100,000 gallons per month), proactive maintenance is crucial. For example, when valve malfunctions were identified at lift stations, the city implemented a structured maintenance program to replace three valves in lift stations every year to ensure consistent reliable water infrastructure operations.

Disaster resilience in Wadley is built on the premise of being perpetually ready to act, because “if something fails, we overcome it immediately.” The City Administrator’s approach is preventative and draws on experiences from past emergencies, such as Hurricane Helene which led to a complete water outage for 13 days. Helene was an “eye-opener” for many in Wadley’s government operations and led to more buy-in for resilient infrastructure. The cost of waiting until systems break down far outweighs the investment in regular, preventive maintenance. Routine exercises, such as testing every valve and lift station board and having clear maintenance cycles in place, help ensure that the city's water and wastewater systems remain operational. This proactive mindset extends to all areas of the city's operations, emphasizing that resilient infrastructure is as much about long-term planning and preparedness as it is about immediate fixes.

Funding remains one of the toughest challenges for Wadley as the city works to balance essential repairs with limited local resources. To stretch its budget, the city has effectively tapped into available funds like American Rescue Plan money, which has been used for water meter and valve replacements. Additionally, Wadley actively pursues external funding through a mix of grant opportunities. The Regional Commission has been instrumental in securing CDBG awards in 2022 and is assisting the city with securing the next round of funds for stormwater and sewer improvements. The city also targets smaller, more accessible grants that are considered “low-hanging fruit” and can be secured without the Regional Commissions’ grant-writing assistance. Their needs-based approach to funding, like prioritizing water system expansions before applying for housing development grants, allows Wadley to address both immediate challenges and invest in long-term resilience.

4. *City of St. Marys* – In November 2024, the Assistant Director of Public Works was interviewed on behalf of St. Marys in coastal Georgia. St. Marys falls into the “small” community size, with a population of 18,469 as of 2020 (U.S. Census Bureau, 2021). St. Marys manages a diverse range of infrastructure assets including WTP and WWTPs (owned by the city but operated by contractors with daily coordination meetings), roads, bridges, stormwater systems, right-of-ways, city

buildings, and several parks. They use tools such as Cartograph for tracking routine and emergency work orders and use ArcGIS for underground mapping, though not without challenges of manually locating buried assets. Additional maintenance efforts also include, but are not limited to, an EPA-mandated lead service line inventory and pipe relining projects to address inflow and infiltration issues.

The Assistant Director defined resilience as having infrastructure that is designed for ease of maintenance, rapid repair, or quick replacement with minimal disruption to the community and the environment. An example in St. Marys is their WTPs, which are considered their most resilient assets due to built-in redundancy so that if one plant is offline, residents will not notice a drop in pressure or firefighting capability. Efforts to standardize equipment, like addressing the challenges posed by using three different pump models, further underscore their commitment to creating a robust, long-lasting system.

Given its coastal location, St. Marys must always be on alert during hurricane season, from March through November. The Assistant Director described a proactive approach where the city prepositions equipment like backhoes, chainsaws, and other essential tools at flood-prone areas such as the causeway and Cumberland Harbor development. The city has not experienced a catastrophic water loss, and its emergency response is coordinated, with clear teams from fire, police, and public works. For example, during Hurricane Helene, a pump failure was quickly mitigated with a portable generator. St. Marys often faces unique challenges like natural blockages; for example, beaver dams sometimes obstruct drainage, forcing crews to manually clear ditches.

Funding remains a challenge in St. Marys. The city transitioned from in-house management of its water and wastewater systems to contracting services around the 2008 recession due to staffing and budget constraints. Today, they actively pursue a range of external funding opportunities, including Transportation Alternatives Program grants, CDBG, ARP, and a relief grant that will fund an effort to increase the urban canopy. The Assistant Director notes that they and their Director of Public Works are “equal opportunists” when it comes to state or federal grants, and they usually search for grants that directly align with the city’s needs rather than chasing funding for its own sake. However, navigating cost-share requirements (often demanding 20–30% local contributions) and educating council members on the financial implications of bundling projects, like combined park maintenance and landscaping initiatives, continues to challenge their city.

5. *City of Statesboro* – In October 2024, the Public Works Director of Statesboro was interviewed to gain a better perspective on Statesboro’s infrastructure challenges, their approach to resilience, and their challenges with implementing resilience. Statesboro falls in the “mid-sized” range, with a population of 33,434 as of 2020 (U.S. Census Bureau, 2021). The physical infrastructure assets and services that fall under the Public Works & Engineering Department are streets, sidewalks, right-of-ways, street lighting, stormwater systems, cemeteries, solid waste collection systems, a transfer station, an inert landfill, the maintenance of passive parks, and mosquito control. The city manages government/public buildings and has a Public Utilities Division that manages the WTP, water storage, water distribution, sanitary sewer conveyance, a WWTP, and natural gas pipelines. Power is managed by Georgia Power and Excelsior EMC, and parks and recreation fall under Bulloch County's jurisdiction. The Director revealed that the city is preparing to be designated as a Municipal Separate Storm Sewer System (MS4) site by the Georgia EPD, which will require compliance with parts of the Georgia Stormwater Management Manual, or “Blue Book”. The Director stated that there has been resistance from local developers regarding the future development costs of implementing Blue Book practices to new development, but with the MS4

permitting, the Blue Book adoption will happen eventually. The city has encouraged developers to incorporate amenity areas and has amended ordinances to ensure long-term stormwater system maintenance by the city, which will relieve homeowner's associations of that responsibility.

The Director stated that in general, the government and academic community with Georgia Southern University supports and advances resilience in Statesboro. They defined resilience in terms of conscientious planning and sustainability and emphasized that providing community amenities such as green spaces and recreational areas contributes to overall resilience by enhancing neighborhood sustainability. In their view, resilience can involve minimizing disruption during construction, such as using perimeter roads to avoid the need for future demolition and reducing environmental impact by preserving natural features like trees.

Regarding disaster preparedness, the city has learned from past experiences. Statesboro's infrastructure faced minimal damage during Hurricane Helene, with the city's proactive planning playing a significant role in mitigating potential impacts. The Public Works Department had backup generators running continuously, handheld radios for communication when other systems failed, and a FEMA-certified contractor ready to collect debris. Lessons from Hurricane Matthew influenced the city's response to Helene in their ability to quickly convert traffic signals to four-way stops and to manage storm debris, ensuring that the city remained functional and safe during the event.

The Director expressed concerns about the process of securing federal grants, noting that they generally prefer to apply for state funding mechanisms, such as the Local Maintenance Improvement Grant through GDOT. They emphasized that state officials tend to be more conscientious of and responsive to local needs, while federal grants are often cumbersome to apply for and less receptive to local government feedback. Although the Director currently writes the grant applications for their department, they stressed the importance of having a dedicated grant writer—a role that Statesboro lacks. To support their infrastructure initiatives, the city has implemented a strategic funding plan, leveraging an enterprise fund to raise capital for essential projects. The city has developed a Long-Range Transportation Master Plan extending to 2045, and the TSPLOST passed for the 2023-2028 period is being managed by a recently hired consultant.

6. *City of Dalton* – In November 2024, an interview was conducted with the Dalton City Administrator, the Director of Public Works, and a Project Engineer in Public Works. Dalton is the seat of Whitfield County and has a population of 34,457 people as of 2020 (U.S. Census Bureau, 2021). The physical infrastructure assets that the city manages and/or maintains are the streets, sidewalks, traffic signals and signage, garbage and recycling collection, stormwater infrastructure, parks and recreation facilities, cemetery and chapel, airport, golf course, and government buildings. Electricity, natural gas, water, wastewater, internet, and cable television services are all provided by Dalton Utilities through an enterprise fund, which is managed by the Water, Light & Sinking Fund Commission. Regarding maintenance, the costliest item in the budget is the annual asphalt resurfacing, followed by curb and gutter maintenance, and then storm drain maintenance. The City Administrator highlighted Dalton's worker order/maintenance request system adopted in 2018 called "SeeClickFix", an online service that allows citizens to easily report maintenance issues with Public Works infrastructure.

According to the team, resilience refers to preparing infrastructure to withstand and quickly recover from catastrophic events, such as storms or hurricanes, by mitigating damage and ensuring continuity. For example, the city is incorporating nature-based solutions into stormwater projects and using in-situ pipe-lining techniques to rehabilitate critical pipes under roads. They prioritize sustainable materials for repairs, avoiding "band-aid" fixes to ensure long-term durability and reduce the need for frequent repairs. The city has been expanding its expertise with resilience through participation in APWA conferences and through meetings with industry practitioners. The City Administrator highlighted the creation of a 21st-century stormwater master plan, recognizing the city's historical lack of stormwater management (no ordinance until 2006). The city hired an outside engineering firm to create a comprehensive plan that includes flood abatement strategies and capital projects to help them "move the needle" in addressing stormwater management deficiencies. Now, traditional gray infrastructure is being supplemented with nature-based solutions, such as regenerative stormwater conveyance projects, streambank restoration, and floodplain reconnection. This shift also aims to manage Dalton's issue with steep slopes and high imperviousness that leads to high-velocity runoff.

Funding is a barrier to implementing infrastructure improvement projects, but Dalton has still managed to secure substantial resources, especially for stormwater initiatives. They emphasized that although more funding would allow for faster projects, their question is not "if" the projects will be implemented, but "when". Dalton has received a $20 million revenue bond to kickstart capital projects and has spent nearly $10 million on stormwater projects so far. Other grants from the IIJA, GDOT, and the Federal Aviation Administration have helped Dalton with upgrading infrastructure at their municipal airport, an asset that contributes significantly to the local economy. With the FY2025 SPLOST ballot referendum passing recently, funding for more public works and infrastructure-centric projects will become available. Dalton has made steady projects on the master plan project list, completing about a third of the items so far. The team stressed the importance of public support and involvement, as it influences future funding approval by elected officials.

7. *City of Gainesville* – In November 2024, the Deputy Director of Public Services in Gainesville was interviewed. Gainesville falls into the category of a "mid-sized" government with a population of 42,348 as of 2020 (U.S. Census Bureau, 2021). The participant's role falls within Gainesville's Public Works department, acting as the operations side of the division. Public Services includes solid waste, streets, sidewalks, cemeteries, public buildings, and vehicle services. The management of water and sewer falls under the city's Department of Water Resources, an enterprise fund distinct from Public Works. The Deputy Director explained that a proposed stormwater utility, an initiative that aimed at improving stormwater management, was considered but ultimately not implemented due to public opposition.

The Deputy Director described resilient infrastructure as assets that can withstand and recover quickly from disasters. They highlighted challenges in maintaining resilience, particularly with limited funding, and that this limits them from doing more preventative maintenance. For example, they noted that Gainesville's budget of $1 million annually for stormwater is insufficient, given the scope of maintenance needs. Another challenge is political pressure, especially regarding the allocation of resources for maintenance across different wards. While some stretches of roads might need more investment than others, in order to meet council member expectations, they do their best to ensure even distribution of investments. In terms of resilience planning, the Deputy Director rated their understanding of resilience low in the survey but acknowledged the city's improvements in mapping critical infrastructure, like water lines, storm sewers, and traffic signals, through the Department of Water Resources and other departments. After the discussion and gaining an understanding of the scope of this research, they rated their understanding as an 8 out of 10. They emphasized that Gainesville is committed to understanding and tracking its assets, improving preventative maintenance, and planning collaboratively for future challenges.

A dedicated program tracks the maintenance and replacement cycles for equipment, yet budgeting for upkeep is determined more reactively as assets wear down. Road maintenance involves evaluating conditions annually through services like “Roadbotics” and street scanning, focusing funding on the city’s most deteriorated roads. Funding for infrastructure upkeep often comes from grants, including the LMIG through the state. The Deputy Director said LMIG is relatively easy to secure and helps maintain the city’s 152 miles of paved roads. The budgeting for upkeep is not automated and is an “address it as it wears” approach. The city has a grant writer in the city’s Planning Department, but Public Works benefits from the funding they receive. The Deputy Director noted that federal funding requires more reporting and record-keeping, making it more difficult to acquire.

They added that the city’s streets and utilities have fared well in recent storms like Hurricane Helene. Gainesville’s Public Works team has emergency response plans for those types of events to ensure a rapid response after the fact.

8. *Fayette County* – In October 2024, the Director of the Environmental Management Department was interviewed. Fayette County was the largest government interviewed, with a population of 119,181 (U.S. Census Bureau, 2021). Their department handles stormwater infrastructure development and project management, including asset management for roads and assisting with water system needs. The department conducts a mandatory asset inventory every five years to assess stormwater management facilities and address issues like clogged culverts or failing pipes. They manage replacements, either in-house or through contractors, depending on the project's complexity.

The Director described their personal definition of resilient infrastructure, stating, “My predecessor and their predecessor won’t have to worry about it." They questioned whether the investments made today would last for the next 100 to 150 years. This includes future floodplain modeling, considering upcoming developments, and opting for durable materials like concrete over plastic or metal for underground pipes and culverts to prevent failures. Their department adopts GDOT standards and seeks innovative methods to enhance resilience while minimizing costs but does not use any formal resilience policies. The Director explained that internally, the commitment to resilience is a 5 to 6 out of 10 and noted that while it is not always a priority, federal grant funding is increasing their focus on the subject. The Director is the grant writer for their department and picked up the skill during their tenure with Fayette County. They focus on applying for federal grants distributed through the state and noted the State's helpful assistance in the application process by ensuring that all requirements are met and that everything is properly documented. They mentioned applying for the LMIG and Hazard Mitigation Grant Program (HMGP through FEMA), which are easy grants to apply for and receive. The Director went on to explain that Fayette County is proactive in identifying its infrastructure problems before a disaster so that they can include that cost in their hazard mitigation plan and receive funding through HMGP.

The Director noted the shift from a stormwater utility to a SPLOST funding model. The implementation of a stormwater utility in Fayette County faced challenges due to inadequate public education. The transition to SPLOST funding allowed for substantial investment in stormwater infrastructure, with ongoing capital projects supported by an annual maintenance budget.

The Director described Fayette County's preparedness for catastrophic events, specifically Hurricane Helene, and how prior flooding events in 2015 led to improvements in his department's inventory and mapping systems. They emphasized the importance of having a disaster response plan and tools to track potential emergencies. When asked about additional challenges in incorporating resilience into infrastructure management, the Director highlighted a general lack of public education on resilience, particularly in a rural-urban context. They noted that public interest in resilience measures often wanes during economic downturns when immediate needs take precedence.

6.2.2 Key Interview Findings

Interviews with local government officials provided key insights into how infrastructure resilience is currently understood and implemented at the local level. While officials often described resilience in terms of emergency preparedness and disaster recovery, their actions frequently aligned with long-term resilience strategies, even if they did not explicitly label them that way. Many officials noted recent investments in redundant systems, infrastructure mapping, and nature-based solutions and highlighted how these long-term measures had improved their ability to respond to short-term extreme weather events, like Hurricane Helene. However, funding constraints and limited technical expertise remained persistent barriers, particularly for smaller governments that struggle to implement proactive resilience measures beyond routine maintenance.

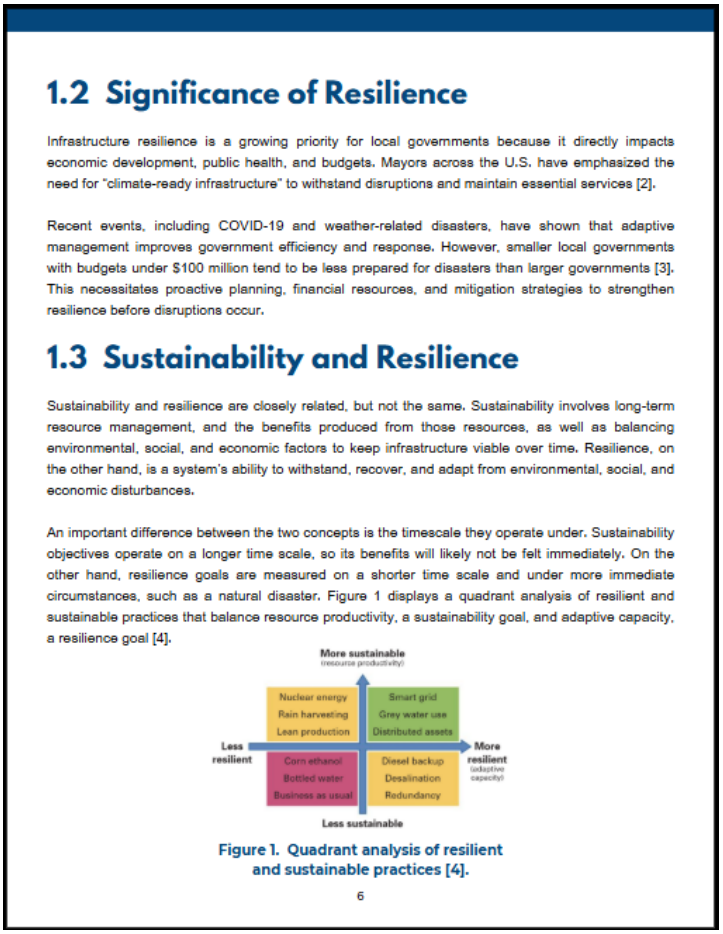
One of the most consistent themes across the interviews was the challenge of securing and managing funding for resilience projects. While federally administered grants were seen as valuable, some officials found them to be overly complex and restrictive, leading to a preference for state-level funding mechanisms such as LMIG from GDOT and locally funded SPLOST. Additionally, officials expressed concerns about political friction in securing funding for long-term infrastructure projects, which often results in deferred maintenance and missed opportunities for resilience improvements. To address these challenges, some governments have turned to external consultants for grant writing and project management, though this is not always feasible for smaller governments with limited budgets, who often rely on their Regional Commission.

Another key takeaway was that most local governments rely on a mix of engineering documents, state guidelines, and professional organization resources, and there is no single, widely adopted resilience planning framework. This lack of standardization has led to inconsistent implementation and a reliance on informal knowledge-sharing among public works professionals. Several officials emphasized the need for clearer guidance on resilience strategies, particularly those that could be incorporated into existing capital improvement plans with minimal additional costs.

6.3 Product Development

The development of the resource guide followed a structured, chapter-based outline approach. The four chapters and three appendices include a chapter introducing resilience, a chapter exploring resilience deeper within the context of eight infrastructure sectors, a chapter dedicated to resilience implementation, and a final chapter on financial and organizational resources to support resilience initiatives.

Chapter 1 establishes the purpose of the guide and underscores its significance in the face of climate change and the increasing frequency of natural disasters. A section of this chapter was designed to decouple the use of resilience and sustainability while acknowledging their areas of overlap (see Figure 6.12). Interview data revealed that these terms were commonly used interchangeably, leading to confusion on their use.



1.2 Significance of Resilience

Infrastructure resilience is a growing priority for local governments because it directly impacts economic development, public health, and budgets. Mayors across the U.S. have emphasized the need for "climate-ready infrastructure" to withstand disruptions and maintain essential services [2].

Recent events, including COVID-19 and weather-related disasters, have shown that adaptive management improves government efficiency and response. However, smaller local governments with budgets under $100 million tend to be less prepared for disasters than larger governments [3]. This necessitates proactive planning, financial resources, and mitigation strategies to strengthen resilience before disruptions occur.

1.3 Sustainability and Resilience

Sustainability and resilience are closely related, but not the same. Sustainability involves long-term resource management, and the benefits produced from those resources, as well as balancing environmental, social, and economic factors to keep infrastructure viable over time. Resilience, on the other hand, is a system's ability to withstand, recover, and adapt from environmental, social, and economic disturbances.

An important difference between the two concepts is the timescale they operate under. Sustainability objectives operate on a longer time scale, so its benefits will likely not be felt immediately. On the other hand, resilience goals are measured on a shorter time scale and under more immediate circumstances, such as a natural disaster. Figure 1 displays a quadrant analysis of resilient and sustainable practices that balance resource productivity, a sustainability goal, and adaptive capacity, a resilience goal [4].

Figure 1. Quadrant analysis of resilient and sustainable practices [4].

6

Figure 6.12. Sections 1.2 and 1.3 from Chapter 1: "Introduction" from the Resilience Resource and Decision Guide.

Chapter 2 examines resilience in the context of each infrastructure sector: roadways, stormwater, bridges, public buildings, public parks, drinking water treatment and distribution, wastewater treatment and collection, and coastal and riverine protection. Survey responses identified a lack of information on resilience opportunities and limited technical expertise as two of the top barriers besides funding, so specific engineering strategies are presented in Chapter 2 for all sizes of local governments. Based on survey feedback, the Transmission and Distribution category was eliminated from the original nine infrastructure categories, resulting in an analysis of eight sectors. Although stormwater and sewer systems were initially grouped together, they were later separated; sanitary sewer systems were combined with wastewater treatment due to their shared infrastructure, while stormwater was treated as an independent category. This decision reflects common local government practices, as many have dedicated stormwater departments, and recognizes that advancing stormwater resilience increasingly involves the separation of storm and sewer systems for improved environmental outcomes.

The interviews highlighted that many capital improvement plans and engineering designs incorporated resilient practices that were not explicitly recognized. To address this, the Resilience Strategy Tables were developed for Chapter 2. The initial Tables outlined six to ten strategies that address the top challenges identified by survey responses for each infrastructure category, focused on the planning, preparation, mitigation, and recovery tenants of the ASCE resilience definition (ASCE, 2021). Many of the strategies used in the Tables come from case studies located in the Literature Review, such as using "Green Infrastructure for CSO control" in the wastewater treatment and collection category (ASLA, 2023) and "Column reinforcement with glass FRP wrap" in the bridge category (Echevarria et al., 2016). Statistical analysis showed that smaller governments prioritize issues like pothole repairs, suggesting that larger governments might focus more on preventative maintenance. Therefore, the Tables offer differentiated strategies to address these distinct needs. Other strategies came from specific examples mentioned in the interview process that were noticed as resilience bright spots. For example, "Trenchless lateral repairs for stormwater pipes" was mentioned in the Fayette County interview as a resilience strategy used to avoid environmental and traffic disruptions. Another strategy, "Minor grading/re-grading of areas and trails with poor drainage in public parks", is used as a low-cost resilient nature trail rehabilitation strategy in National Park Service lands (National Park Service). Strategies were also adapted from state and federal organization resilience materials, such as the EPA's Flood

Resilience Guide for Water and Wastewater Utilities (EPA, 2014) and NOAA's U.S. Climate Resilience Toolkit (Climate.gov, 2024). Strategies were evaluated on factors of project cost, savings, construction, and O&M. Table 6.1 contains rationales for these four factors.

Table 6.1. Rationales and Methods of Development for Factors in Resilient Strategy Tables.

Factor	Rationale	Method of Development
Project Cost	**$:** Little to no cost. Can be completed with internal resources and staff without a contractor. **$$:** Moderate cost and intricacy. May require external funding and contractor assistance for implementation. **$$$:** High cost and intricacy. Requires significant funding and contractors to complete.	From EPA Flood Resilience Guide for Water and Wastewater Utilities (EPA, 2014).
Project Savings	**$:** Minimal cost savings. Any financial benefits are small or take a long time to materialize. **$$:** Moderate cost savings. Some reductions in long-term expenses, but upfront costs may still be significant. **$$$:** Significant cost savings. Leads to substantial long-term financial benefits, such as reduced maintenance, lower operational costs, or avoided major expenses.	Developed based on the expected lifespan of each given strategy in comparison with a traditional benchmark strategy. Considers the reduction in maintenance costs, frequency of new construction, and reduction in labor required.

Table 6.1 (Continued).

Level of Construction Required	Low: Minimal labor and expertise. Uses common technologies. Has little impact on the natural environment. Implementation is straightforward. Medium: Moderate level of labor that may require some specialized knowledge. Some natural disturbances. Remains feasible for most communities. High: Requires significant labor, advanced technologies, and specialized expertise. May involve major natural disturbances. Complex implementation with many potential challenges.	Adapted from construction rationales the Climate Ready DC Resilient Design Guidelines (Department of Energy & Environment in the District of Columbia, 2021). Considers levels of natural disturbance, community operations disturbances, and labor requirements.
O&M	Low**:** Minimal labor and routine maintenance using readily available materials or technologies. Low-cost and simple to sustain. Medium**:** Moderate upkeep with some specialized skills or materials. Maintenance is more frequent but manageable. High**:** Significant labor, expertise, and costly materials required. Maintenance is frequent and resource intensive.	Adapted from O&M rationales for resilience strategies from the Climate Ready DC Resilient Design Guidelines (Department of Energy & Environment in the District of Columbia, 2021).

Each strategy was accompanied by descriptions of its potential resilience benefits, with co-benefit check boxes on the right side of the table highlighting issues that were most pertinent in survey feedback, as seen in Figure 6.13.

Strategy	Level of Construction Required	O&M	Project Cost	Project Savings	Resilience Benefits	Reduces Pavement Cracking	Reduces Pothole Maintenance	Extends Asset Lifespan	Reduces Urban Heating Effect	Reduces Roadway Flooding
Using a rejuvenator for pavement preservation	Low	Low	$	$$	Restores the flexibility and durability of asphalt	X	X	X		
Permeable pavements	High	Medium	$$$	$$	Allowing water to pass through pavement to reduce runoff, prevent flooding, and replenish groundwater	X	X	X	X	X

Figure 6.13. Excerpt of Initial Resilient Strategy Table for Roadways.

Interviewees noted improvements to their community with investments in emergency preparedness, nature-based solutions, and durable/resilient building materials, so specific strategies from each of these categories were included in the Tables.

Chapter 3 focused on the implementation of resilience measures introduced in Chapter 2. A supplemental Decision Matrix Excel Spreadsheet is provided in Appendix E to assist the Guide's users in the resilience decision-making process. The Matrix was developed as a more concise alternative to a decision tree, offering a structured method to quantify resilience factors for local governments. The cover page of the Excel File is shown in Figure 6.14.

UNIVERSITY OF GEORGIA

Resilience Decision Matrix

Introduction

This tool allows the user to assess strategy options that could enhance resilience in their infrastructure systems and analyze their chosen options using a decision matrix.

Tool Authorship and Revision

Revision No.	Date	Reason	Author
A	2025	Original Authorship	E. Terrell

Instructions for using this tool:

1. View the "Table Key" sheet to understand the layout and rationales for each row and column within each table.

1. Analyze the infrastructure categories and their respective strategies by clicking on each sheet's tab on the bottom.

2. Navigate to the "Decision Matrix" tab to weigh resilience options and benchmark strategies. Select and input the required paramaters bas

Orange cells should be manually entered by the user.
Yellow cells are calculated scores - no input required.
Grey cells are automatically populated or calculated values based on the user's selection - no input required.
Light blue cells contain drop-down lists for user selection.

3. The calculated results will appear in the yellow cells. The final values may be used as an indicator for resilience strategies to pursue based on local conditions and individual city/county needs.

Figure 6.14. Cover Sheet of Resilience Decision Matrix.

The Matrix was designed with a numbering system to standardize assessments across up to five diverse resilience strategies in various sectors. Project cost and savings, categorized into low, medium, and high levels, were assigned numerical values (1, 2, or 3) to provide a direct comparison. The "time to implement" factor was segmented into three timeline categories (<1 year, 1–3 years, and 3+ years) with corresponding scores (1, 3, or 5), and "expected lifespan" was divided into 0–3, 3–10, and 10+ years with the same corresponding scores (1, 3, or 5). The options were designed to give the Matrix's users a chance to think of the strategy in terms of their government's operational capacity and its realistic timelines. These individual scores combine to form a cost-effectiveness score, which is the financial aspect of the Matrix. Figure 6.15 shows the formula and explanation of the score in the Guide.

Cost Effectiveness

The cost-effectiveness score assesses whether a project's financial benefits outweigh its costs, independent of resilience or co-benefits. This metric is calculated as:

(Project Savings x Expected Lifespan of Project) - (Project Cost x Time to Implement)

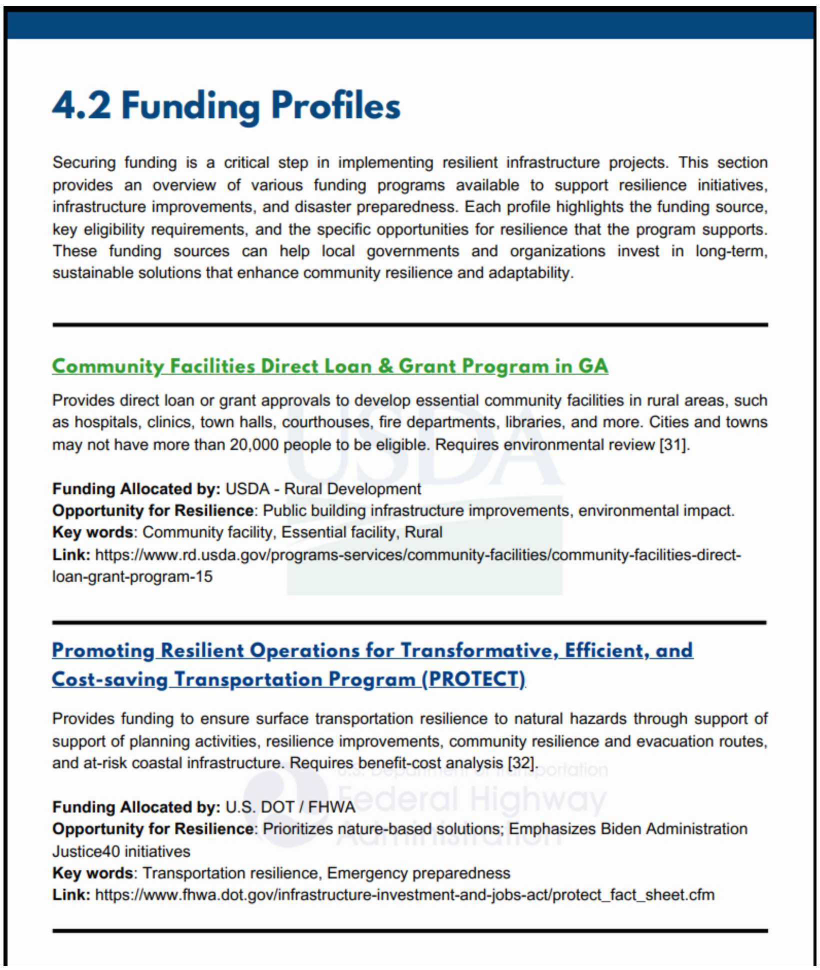
= Cost Effectiveness

A negative score (-8 to -1) indicates that the project cost exceeds its financial savings, making it a less viable investment from a purely economic standpoint. Conversely, a positive score (1 to 24) suggests that the financial savings surpass the project cost, demonstrating a favorable return on investment. This approach allows decision-makers to prioritize strategies that maximize financial efficiency while balancing other critical factors such as resilience and community benefits.

Figure 6.15. Cost Effectiveness Metric Explanation in the Guide.

To quantify the benefits of resilience and demonstrate its value, a Resilience Impact Score and a Community Impact Score were developed. The Resilience Impact Score enables users to assess the direct benefits and co-benefits of resilience strategies from the Tables, rating their potential effect on the community on a scale from low to excellent. Likewise, the Community Impact Score evaluates how both intended and unintended stakeholders are affected by a project, considering local conditions, implementation timelines, expected lifespan, construction complexity, and other relevant factors. Finally, a weighting system was developed to allow local governments to reflect their own priorities in the final decision, making the Matrix scalable and more relevant to a range of governments. The final score is calculated by multiplying each factor's score by its assigned weight, and then summing the weighted values. See Appendix E to see the Guide's example use case of the Matrix in detailed description.

Chapter 4 was developed to directly address the challenges and opportunities identified through the survey and interview research. Key findings, especially funding limitations, gaps in technical expertise, and the need for accessible resilience guidance, shaped the content of this chapter. For example, survey data consistently pointed to inadequate funding as the primary barrier to implementing resilient infrastructure. Interviews further revealed that federal grants can be seen as complex and state funding channels are viewed as more accessible and aligned with local needs. Based on these insights, organizational profiles, funding profiles, and training opportunities were compiled to directly target the barriers identified. Practical tools and actionable guidance, like both traditional and unique funding opportunities (see Figure 6.16), and funding training seminars, were compiled based on research and recommendations from members of REACT4.



4.2 Funding Profiles

Securing funding is a critical step in implementing resilient infrastructure projects. This section provides an overview of various funding programs available to support resilience initiatives, infrastructure improvements, and disaster preparedness. Each profile highlights the funding source, key eligibility requirements, and the specific opportunities for resilience that the program supports. These funding sources can help local governments and organizations invest in long-term, sustainable solutions that enhance community resilience and adaptability.

Community Facilities Direct Loan & Grant Program in GA

Provides direct loan or grant approvals to develop essential community facilities in rural areas, such as hospitals, clinics, town halls, courthouses, fire departments, libraries, and more. Cities and towns may not have more than 20,000 people to be eligible. Requires environmental review [31].

Funding Allocated by: USDA - Rural Development
Opportunity for Resilience: Public building infrastructure improvements, environmental impact.
Key words: Community facility, Essential facility, Rural
Link: https://www.rd.usda.gov/programs-services/community-facilities/community-facilities-direct-loan-grant-program-15

Promoting Resilient Operations for Transformative, Efficient, and Cost-saving Transportation Program (PROTECT)

Provides funding to ensure surface transportation resilience to natural hazards through support of support of planning activities, resilience improvements, community resilience and evacuation routes, and at-risk coastal infrastructure. Requires benefit-cost analysis [32].

Funding Allocated by: U.S. DOT / FHWA
Opportunity for Resilience: Prioritizes nature-based solutions; Emphasizes Biden Administration Justice40 initiatives
Key words: Transportation resilience, Emergency preparedness
Link: https://www.fhwa.dot.gov/infrastructure-investment-and-jobs-act/protect_fact_sheet.cfm

Figure 6.16. Funding Profiles from the Resilience Resource and Decision Guide.

The interview process demonstrated there is no "one-stop shop" for infrastructure resilience for local government use, so Chapter 4 acts as a directory for information on how to secure the necessary resources to address their resilience needs.

6.4 Product Evaluation Survey Results

Nine participants accessed the evaluation survey QR code, and all received the guide, spreadsheet, and a follow-up survey link. The survey remained open for thirteen days, yielding seven responses, five of which were fully completed. The survey was mistakenly published with the incorrect questions initially, but seeing as the point of the survey was to gather concrete feedback and iterate the guide, rather than to provide statistical significance to the data, the survey was simply re-published with the corrected questions.

The survey feedback was generally positive, with many respondents commending the Guide as a comprehensive and informative introduction to resilient infrastructure that is valuable for both city and county management. The average score for the Guide's general organization was 9 out of 10, and the comments did not point out any changes to make on this front. The average usefulness score was 8.2 out of 10, ranging from scores 6-10. Respondents particularly appreciated how Chapter 2 covered a range of topics relevant to daily operations and noted that the sections on resilient bridges, fault trees, and defensible spaces in public buildings were useful. Chapter 3's Decision Matrix was seen as a promising tool for assessing project resilience, and the resource listings in Chapter 4 were well-received for both familiar and new funding sources. The Tables were also validated for their clarity and usefulness.

Some areas for improvement were identified. One respondent felt that certain graphics in Chapter 2, such as the roadway cross section and transit options, seemed better suited to larger urban settings rather than for smaller governments. In Chapter 3, reviewers suggested introducing the weighting process earlier in the chapter to better address the varied priorities of different local governments. Respondents also raised concerns about justifying the Matrix's overall value to decision-makers. Feedback for Chapter 4 emphasized the need to include funding sources commonly used by smaller governments, such as LMIG, SPLOST, and TSPLOST, and recommended incorporating numerical estimates in the strategy tables to enhance clarity.

6.5 Product Evaluation Discussion Findings

Based on feedback from the five responses, two participants were reached out to participate in discussions that gauged their opinions on the Guide and Decision Matrix and to create use cases for the matrix and demonstrate its usability.

1. *Fayette County*

A discussion with the Assistant Director of the Road Department was held in February 2025 via Zoom. This participant was chosen for the evaluation process due to their extremely thorough survey feedback. Their critiques of the Guide were to make it more relatable to smaller governments through the graphics and the blurbs. The Assistant Director said they even distributed the survey, Guide, and Matrix to another member of the Fayette County Road Department as a "training exercise" to get them acquainted with resilience in public works. They noted that this person thought the Guide was an excellent introduction to infrastructure resilience and learned a lot through its contents.

When initially using the Decision Matrix, the Assistant Director expressed their confusion with how to effectively use the tool. Without having benchmark/traditional strategies in each infrastructure table, there is nothing to compare each resilience strategy against to grasp the resilience concept. They also noted the specific goal of each strategy should be more clearly communicated so that the comparison process is more straightforward. Other feedback was that some of the strategy descriptions were not completely clear in what they did, such as the "Extended Shoulder Lane" in the Roadways Table. They recommended removing or editing specific strategies in the Roadways Table based on his expertise in the field. During the discussion, it became evident that the tool was unusable in its existing form for the Assistant Director's day-to-day use. However, the full review of the sequencing, formatting, and articulation of the tool was invaluable to refining and revising the guide for the following discussion meeting.

2. *Athens-Clarke County*

Another evaluation discussion was held with a Senior Transportation Planner with Athens-Clarke County in March of 2025 via Zoom. The original survey respondent was the Engineering Administrator with ACC, but they were unable to participate due to scheduling and availability issues. The participant highlighted that the guide had presented resilience and associated management strategies in an accessible manner for individuals without a public works background. They noted that the Guide had addressed challenges related to budget deficits and had provided clear, digestible strategies for communicating with elected officials. One recommendation was to incorporate real field photographs of deteriorating infrastructure in Chapter 2 to demonstrate the improvement, and hence the value of resilience, in infrastructure. Furthermore, they emphasized the importance of clearly presenting funding sources like LMIG, SPLOST, and federal grants (e.g., the PROTECT grant), which had proven critical for smaller governments.

During the Matrix evaluation, the participant, being a Transportation Planner, identified one benchmark strategy that Athens-Clarke County uses, "Mill-and-fill road resurfacing", and two other resilient strategies, "Using a rejuvenator for pavement preservation" and "Reinforcement with advanced polymer-modified asphalt", that their department may be interested in exploring. The targeted benefit of the chosen strategy options was to reduce pothole maintenance on their county's roads. Figures 6.17, 6.18, and 6.19 display the options they chose for each strategy and the resulting score.

Step 1. Select the infrastructure categories for each alternative to be assessed. The categories can be all the same (Ex: selecting all stormwater) or a variety (Ex: selecting stormwater for alternatives 1 & 2, roadways for alternative 3, and flood protection infrastructure for alternative 4). Up to 5 categories may be assessed at a time. If you wish to assess less than 5 categories, simply do not select a category for that cell. You may delete the contents of the cell to remove its settings.

The 8 categories to choose from are:

Stormwater	Roadways	Bridges	Public Buildings	Public Parks	DW Treatment & Distribution	WW Treatment & Collection	Coastal and Riverine Protection	

Select Category for Alternative 1	Roadways
Select Category for Alternative 2	Roadways
Select Category for Alternative 3	Roadways
Select Category for Alternative 4	
Select Category for Alternative 5	

Step 2. Select the resilience strategies you wish to analyze based on your category selection. These strategies can be explored more in depth by navigating to the respective infrastructure category tabs.

Select Resilience Strategy for Alternative 1	Traditional mill and fill road resurfacing
Select Resilience Strategy for Alternative 2	Using a rejuvenator for pavement preservation
Select Resilience Strategy for Alternative 3	Reinforcement with advanced polymer-modified asphalt
Select Resilience Strategy for Alternative 4	
Select Resilience Strategy for Alternative 5	

Figure 6.17. Steps 1 and 2: Infrastructure Sector and Individual Strategy Choices.

Step 3. For each strategy, determine the amount of time it will take to implement each project/strategy, including the design, planning, and construction phases from the dropdown in the "Time to Implement" Column.
Step 4. Then, determine the expected lifespan of the project post-construction in the context of the city/county you serve. Factors influencing this estimate include frequency of use, maintenance routine, climate conditions, etc.

The equation to calculate cost effectiveness is as follows:
(Project Savings x Expected Lifespan of Project) – (Project Cost x Time to Implement) = Cost Effectiveness

	Project Cost From Table	Corresponding Value to Project Cost	Project Savings From Table	Corresponding Value to Project Savings	Time to Implement Project	Corresponding Value to Project Implementation Timeline	Expected Lifespan of Project/Asset/Repair	Corresponding Value to Expected Lifespan	Cost Effectiveness Score
Alternative 1	$$$	3	$$	2	<1 year	1	10+ years	5	7
Alternative 2	$	1	$$	2	<1 year	1	3-10 years	3	5
Alternative 3	$$	2	$$	2	<1 year	1	3-10 years	3	4
Alternative 4	FALSE	0	FALSE	0		0		0	0
Alternative 5	FALSE	0	FALSE	0		0		0	0

Step 5. Based on local conditions, such as frequency of use, weather hazards (heat, snow, flooding, etc.), and local population, rank the resilience benefits received by the strategy in comparison with the intended problem that is aimed to be solved from the options in the drop-down menu.
Step 6. Rank the community impacts felt by the intended and unintended stakeholders based on local conditions. Community impacts include public health benefits, economic improvements, safety improvements, social equity, community cohesion, aesthetic improvements, traffic improvements, etc.

	Resilience Benefit	Corresponding Value	Community Impact	Corresponding Value
Alternative 1	Moderate Benefit/Impact	3	Fair Benefit/Impact	2
Alternative 2	Good Benefit/Impact	4	Moderate Benefit/Impact	3
Alternative 3	Good Benefit/Impact	4	Moderate Benefit/Impact	3
Alternative 4		#N/A		#N/A
Alternative 5		#N/A		#N/A

Figure 6.18. Steps 3, 4, 5, and 6: Cost Effectiveness Calculation, Resilience Benefit Scoring, and Community Impact Scoring.

Step 7. Finally, input the weight for the three categories of cost effectiveness, resilience benefits, and community impacts based on their importance or relevance in the project or in the overall government operations and mission.

		Traditional mill and fill road resurfacing		Using a rejuvenator for pavement preservation		Reinforcement with advanced polymer-modified asphalt		N/A		N/A	
	Weight	Value	Weighted Score	Value	Weighted Score	Value	Weighted Score	Value	Weighted Score	Value	Weighted Score
Cost Effectiveness	2	7	14	5	10	4	8	0	0	0	0
Resilience Benefit	1	3	3	4	4	4	4	#N/A	#N/A	#N/A	#N/A
Community Impact	1	2	2	3	3	3	3	#N/A	#N/A	#N/A	#N/A
		Total Score	19	Total Score	17	Total Score	15	Total Score	#N/A	Total Score	#N/A

Final Scores	Final Rankings		Strategy
19	1		Traditional mill and fill road resurfacing
17	2		Using a rejuvenator for pavement preservation
15	3		Reinforcement with advanced polymer-modified asphalt
N/A	#VALUE!		N/A
N/A	#VALUE!		N/A

Understanding the Score: The higher the score, the higher the indication of a resilience alternative suiting your community's specific needs, budget, timeline, and constraints.

Figure 6.19. Step 7: Final Weighting and Resulting Rankings of the Strategies.

While the traditional mill-and-fill resurfacing option scored the highest, they explained the value of stepping through this process as someone who is usually not in a decision-making role. They mentioned that the tool will be very helpful in facilitating future discussions amongst a diverse team with differing opinions and priorities that will reflect in the scoring of each strategy.

6.6 Resource Guide and Matrix Iteration

Based on feedback from survey respondents and discussions, revisions were made to improve the Guide, Tables, and Matrix. A new section was added to Chapter 1 to introduce the concept of BCR in order to prompt the audience's early consideration of cost-effectiveness. A key takeaway from the survey and discussions was to make the Guide and its images more relatable to small governments, so more rural-focused content with imagery from out in the field tailored to smaller governments was added to Chapter 2. Figure 6.20 shows imagery that was added to the Guide during its iteration to improve its relatability.

An example of resilient maintenance is trenchless repair methods use minimally invasive techniques that help lower project costs and minimize disruptions to roadways and community life. This approach not only extends the lifespan of assets but also ensures long-term durability and efficiency without the need for extensive excavation.

Figures 5, 6, 7, and 8 demonstrate the effectiveness of trenchless methods and how the minimally invasive techniques successfully rehabilitated a failing culvert system and addressed the deterioration without the extensive excavation required by traditional dig-and-replace methods.

Figure 5, 6. Before Trenchless Repairs [10].

Figure 7, 8. After Trenchless Repairs [10].

Figure 6.20. Addition of Resilient Strategy Images Geared Towards Small Communities.

Chapter 3 was restructured to lead with the weighting process, acknowledging the varying priorities of local governments. Chapter 4 was expanded to include SPLOST and TSPLOST funding opportunities, additional grant administration trainings, and resources covering all infrastructure sectors. Significant modifications were made to the Resilience Strategy Tables. A new column was introduced to allow categorization of strategies by new or existing asset, which provides more consistency with the Guide in using the term "asset" (see Figure 6.21).

		Benefits of Strategy								
Strategy	Involves New or Existing Assets?	Mitigates Flood Risk	Increases Operational Efficiency	Improves Emergency Preparedness	Extends SW Asset Lifespan	Level of Construction Required	O&M	Project Cost	Project Savings	Description of Resilience Benefits
GIS-based asset mapping and digitization of pipe infrastructure	Existing		X	X		Low	Low	$$	$$	Allows for better planning, tracking, and maintenance of overall system and its assets

Figure 6.21. New Column Addition to Categorize by New or Existing Asset.

New rows containing benchmark strategies, sourced from current Georgia and federal standards (e.g., GDOT, EPA, GA DNR) and established best practices, were added beneath the traditional resilience strategies, in accordance with recommendations from the evaluation discussions. Figure 6.22 shows an example of the benchmark strategies added to the Guide.

Benchmark Strategies	Open-cut trench excavation for pipe repairs	Existing					Medium	Medium	$$	$	No additional resilience benefits from traditional methods.
	Conventional hardscaped drainage channels (concrete/asphalt)	New					Low	Low	$	$	No additional resilience benefits from traditional methods.
	Emergency response via government staff to address blockages or flooding	Existing					Low	High	$	$	No additional resilience benefits from traditional methods.
	Reactive drainage system cleaning and inspection	Existing					Low	Medium	$	$	No additional resilience benefits from traditional methods.

Figure 6.22. Addition of Benchmark Strategies to Provide Direct Comparison to Resilient Strategies.

The table layout was reconfigured so that the "Benefits of Strategy" appears immediately to the right of the strategy description, thereby facilitating easier comparison of strategies with similar goals. Additionally, strategy titles were refined for clarity (e.g., "Extended Shoulder Lane" was revised to "Extended Shoulder Lane to protect main roadway against flooding"), and certain strategies that were deemed inapplicable to Georgia's current practices, such as pavement sensors, were removed. A new column was introduced to allow filtering by asset type, reinforcing consistency in terminology with the decision matrix in using the term "asset". The Decision Matrix was improved with an annotated table key, which aimed to reduce the need for users to cross-reference the guide, creating a more user-friendly experience. Collectively, these refinements significantly strengthened the guide's coherence and usability.

6.7 Resource Guide and Matrix Distribution

Upon approval of this thesis from the University of Georgia graduate program, the Guide and Matrix will be distributed to the Georgia Chapter of the APWA for local governments to use and integrate into their infrastructure management operations.

7.0 Conclusion

This research reiterates the fact that building resilience into local government infrastructure is not merely a technical challenge, but a grand challenge with funding constraints, political frictions, and a rapidly changing climate. Smaller and rural cities and counties tend to struggle more with these constraints when planning infrastructure projects than a larger city or county with more resources. There is a gap in translating broad resilience concepts and planning frameworks into actionable, cost-effective strategies, and many local governments lack the resources or data necessary to investigate resilience options and prioritize investments. The literature review found that there were no resources or guides available with the capability to address technical resilience at all community scales in Georgia.

To address this gap, the *Resilient Infrastructure Resource and Decision Guide for Local Georgia Governments* and the accompanying *Resilience Decision Matrix Excel Spreadsheet* were created based on the insights gained from research conducted through surveys, interviews, and an evaluation process. Both qualitative and quantitative analyses informed the selection of strategies, funding opportunities, infrastructure priorities, and organizational partnerships that were ultimately incorporated. Supplementing the literature review with an in-depth exploration of technical resilience strategies allowed the guide to offer a comprehensive suite of recommendations for infrastructure improvements. The Decision Matrix simplifies the investment prioritization process to cost, community, and resilience and ensures that even those with limited technical expertise can access well-researched, actionable strategies.

Future research could explore how the Decision Matrix is used over time by local governments. By following select cities and counties over the course of a year, researchers could track changes in infrastructure planning, investment decisions, and interdepartmental coordination as a result of using the Matrix for their decision-making processes. Another potential field of study is to further explore resilience applications for each of the eight infrastructure sectors and how to best incorporate those applications into capital improvement plans for Georgia local governments.

In conclusion, this thesis demonstrates that infrastructure resilience is not an abstract, unapproachable concept, but a term that describes infrastructure that is built to endure and adapt over time. Ultimately, the value of the Guide and Matrix lies in its ability to inform the resilience decision-making process and to serve as a resource for educating others beyond its intended audience.

8.0 REFERENCES

Accelerator for America. (2023, October 10). *ResilienCity Park Project Hoboken, NJ*. Local Infrastructure Hub. https://localinfrastructure.org/wp-content/uploads/2023/10/Hoboken-NJ-Resiliencity-Park-Project.pdf

Alvis, A., Schutte, D., Faust, B., & Sherer, M. (n.d.). *Two Harbors: Investments in Green Infrastructure Pay Off*. U.S. Climate Resilience Toolkit. https://toolkit.climate.gov/case-studies/two-harbors-investments-green-infrastructure-pay

The American Institute of Architects. (2017, February). *Issue Brief of AIA Government Relations Issue Position and Analysis: Investing in Our Nation's Infrastructure*. The American Institute of Architects. https://www.aia.org/advocacy/public-policies-position-statements

American Society of Civil Engineers. (2022). (rep.). *2021 Report Card for America's Infrastructure*. Retrieved from https://infrastructurereportcard.org/wp-content/uploads/2020/12/National_IRC_2021-report.pdf.

American Society of Civil Engineers. (2024). (rep.). *2024 Report Card for Georgia's Infrastructure*. Retrieved from https://infrastructurereportcard.org/wp-content/uploads/2016/10/2024-Report-Card-For-Georgias-Infrastructure.pdf.

American Society of Landscape Architects. (2012). *Stormwater Case 429 West Hall, Elmhurst College, Elmhurst, IL*. Stormwater Case Studies by State. https://www.asla.org/stormwatercasestudies.aspx

American Society of Landscape Architects. (2021). *Stormwater Case 041 Lick Run, Cincinnati, OH*. Stormwater Case Studies by State. https://www.asla.org/stormwatercasestudies.aspx

American Society of Landscape Architects. (n.d.). *Stormwater Case 255 Alabama Street CSO Abatement Pilot Project, Indianapolis, IN*. Stormwater Case Studies by State. https://www.asla.org/stormwatercasestudies.aspx

Arup, RPA, & Siemens. (2022). Toolkit for Resilient Cities.

Association of County Commissioners of Georgia. (2016). Special Purpose Local Option Sales Tax: A Guide for County Officials.

Bakkensen, L. A., Fox-Lent, C., Read, L. K., & Linkov, I. (2016). Validating resilience and vulnerability indices in the context of natural disasters. *Risk Analysis*, *37*(5), 982–1004. https://doi.org/10.1111/risa.12677

Benefit-cost analysis. FEMA.gov. (2024, September). https://www.fema.gov/grants/tools/benefit-cost-analysis

Bipartisan Infrastructure Law. U.S. Department of Energy's Grid Deployment Office. (n.d.). https://www.energy.gov/gdo/bipartisan-infrastructure-law

Bowers, B., & Gu, F. (2021). (rep.). *Asphalt Pavement: A Critically Important Aspect of Infrastructure Resiliency.* National Asphalt Pavement Association.

Branand, N. (2024). *Development Of An Asset Management Framework For Local Roadway Maintenance And Repair Within The State Of Georgia* (thesis).

Bresette, D., Davis, A., & Peterson, J. (2023, October 3). Policy Approaches for Building Resilience against Sea Level Rise in Coastal Communities. *The Climate Conversation Podcast*. other, Environmental and Energy Study Institute.

Building Resilience in Coastal Communities. (2020).

Building Resilient Infrastructure & Communities Program. Georgia Emergency Management and Homeland Security Agency. (n.d.). https://gema.georgia.gov/bric

Census Data. United States Census Bureau. (2021). https://data.census.gov/

Champlain Water District, South Burlington Vermont. (2023).

Chester, M. V., & Allenby, B. (2018). Toward adaptive infrastructure: Flexibility and agility in a non-stationarity age. *Sustainable and Resilient Infrastructure*, *4*(4), 173–191. https://doi.org/10.1080/23789689.2017.1416846

City of Alexandria, VA. (2021). *City of Alexandria Resilience Plan | September 2021*. https://media.alexandriava.gov/docs-archives/tes/stormwater/cityofalexandriaresilinceplanv2.pdf?_gl=1*q1x72p*_ga*MTMzNTY0ODI1NC4xNzMwMzA2MjIw*_ga_249CRKJTTH*MTczMDMwNjIxOS4xLjEuMTczMDMwNjM0NS4wLjAuMA.

Climate.gov. (2024). U.S. Climate Resilience Toolkit. https://toolkit.climate.gov/

Community development block grant program. HUD.gov / U.S. Department of Housing and Urban Development (HUD). (n.d.). https://www.hud.gov/program_offices/comm_planning/cdbg

Cutter, S. L., Ash, K. D., & Emrich, C. T. (2014). The geographies of community disaster resilience. *Global Environmental Change*, *29*, 65–77. https://doi.org/10.1016/j.gloenvcha.2014.08.005

DeJong, A., Littman, A., Fischbach, J., Hemmerling, S., Kane, P., Haertling, A., Black, V., Grismore, A., & Cowan, J. (2024). (rep.). *Exploration of Emerging Methods to Assess Equity in USACE Project Planning*. U.S. Army Corps of Engineers. Retrieved from https://thewaterinstitute.org/assets/docs/projects/Exploration-of-Emerging-Methods-to-Assess-Equity-in-USACE-Project-Planning.pdf.

Department of Energy & Environmental for the District of Columbia. (2021). Climate Ready DC: Resilient Design Guidelines.

Dickey, C. (2019). *Effective Approaches to the Development of Asset Management Programs for Small Scale Local Governments* (thesis).

Dzigbede, K. D., Gehl, S. B., & Willoughby, K. (2020). Disaster resiliency of U.S. Local Governments: Insights to strengthen local response and recovery from the covid-19 pandemic. *Public Administration Review*, *80*(4), 634–643. https://doi.org/10.1111/puar.13249

Echevarria, A., Zaghi, A. E., Christenson, R., & Accorsi, M. (2016). CFFT bridge columns for Multihazard Resilience. *Journal of Structural Engineering*, *142*(8). https://doi.org/10.1061/(asce)st.1943-541x.0001292

Elevated Rehabilitation Facility Functions Flawlessly Through Hurricane Sandy. U.S. Climate Resilience Toolkit. (n.d.-a). https://toolkit.climate.gov/case-studies/elevated-rehabilitation-facility-functions-flawlessly-through-hurricane-sandy

Entergy. (2010). (rep.). *Building a Resilient Energy Gulf Coast: Executive Report*. Retrieved from https://www.entergy.com/userfiles/content/our_community/environment/GulfCoastAdaptation/Building_a_Resilient_Gulf_Coast.pdf

Environmental Protection Agency. (2021). *Funding Resilient Infrastructure and Communities with the Clean Water State Revolving Fund.* EPA. https://www.epa.gov/cwsrf/funding-resilient-infrastructure-and-communities-clean-water-state-revolving-fund

Environmental Protection Agency. (2024). Creating Resilient Water Utilities (CWRU). https://www.epa.gov/crwu

FEMA. (2021, February). *Building bridges better: Keeping roads open with mitigation*. FEMA. https://www.fema.gov/case-study/building-bridges-better-keeping-roads-open-mitigation

FEMA. (2023). *The Economic Case for Coastal Resilience*. FEMA. https://www.fema.gov/sites/default/files/documents/fema_economic_case_coastal_resilience_guide_2023.pdf

Fisher, R., Norman, M., & Peerenboom, J. (2018). *Resilience History and Focus in the United States*. USDOE Office of Nuclear Energy. https://www.osti.gov/servlets/purl/1476740

Florida Department of Environmental Protection. (n.d.). *Project GreenShores*. Florida Department of Environmental Protection. https://floridadep.gov/rcp/aquatic-preserve/content/project-greenshores

Florida Power & Light Company. (2022, November). *Florida Power & Light Company Modified 2023-2032 Storm Protection Plan*. Florida Power & Light Company. https://www.floridapsc.com/library/filings/2022/02358-2022/02358-2022.pdf

Fox, J., Hall, N. F., & Rogers, K. (2020). *Benefit-Cost Analysis of the U.S. Climate Resilience Toolkit Based on Case Studies from the Southeast*, *7*.

Gambill, J., Russell, M., Spratt, K., Whitehead, J., Alfonso, M., Hopkinson, C. S., & Evans, J. M. (2017). (rep.). *St. Marys Project Flood Resiliency*. National Oceanic and Atmospheric Administration. Retrieved from https://gacoast.uga.edu/wp-content/uploads/2016/05/St_Marys_Flood_Resiliency_Project-1.pdf.

GDOT. (2024). *Local Maintenance & Improvement Grant (LMIG)*. GDOT. https://www.dot.ga.gov/GDOT/Pages/LMIG.aspx

Georgia Department of Community Affairs. (2014). BEST PRACTICES GUIDEBOOK: Community Disaster Resilience.

Georgia Department of Natural Resources. (2020). Enhancing Coastal Resilience with Green Infrastructure.

Giunta, M. (2017). Sustainability and resilience in the rehabilitation of road infrastructures after an extreme event: An integrated approach. *The Baltic Journal of Road and Bridge Engineering*, *12*(3), 154–160. https://doi.org/10.3846/bjrbe.2017.18

Goodwin, N. R., Harris, J. M., Nelson, J. A., Rajkarnikar, P. J., Roach, B., & Torras, M. (2023). *Microeconomics in context*. Routledge, Taylor & Francis Group.

Grand Isle: Louisiana's First Line of Defense from Coastal Flooding. (2024).

Hallegatte, S., Rozenberg, J., Rentschler, J., Nicolas, C., & Fox, C. (2019). (working paper). *Strengthening New Infrastructure Assets: A Cost-Benefit Analysis*. The World Bank. Retrieved from https://documents1.worldbank.org/curated/en/962751560793977276/pdf/Strengthening-New-Infrastructure-Assets-A-Cost-Benefit-Analysis.pdf.

Hanus, N. (2023, November). *Mitigation, Rapid Restoration Strategies, and Best Practices – with Case Studies*. *Resilience Training for States*. Retrieved from https://eta-publications.lbl.gov/sites/default/files/hanus_20231129_fin.pdf.

Hill, A., & Ayyub, B. (2019). Climate-Resilient Infrastructure: Engineering and Policy Perspectives. *Engineering for Disaster Resilience*, *49*(2). https://doi.org/10.1787/4fdf9eaf-en

Hinesville Stormwater Installation. (n.d.). https://iris.uga.edu/hinesville-stormwater-installation/

Infrastructure Investment in the United States. U.S. Department of the Treasury. (2024, February 23). https://home.treasury.gov/news/featured-stories/infrastructure-investment-in-the-united-states

Investing in America: President Biden's Bipartisan Infrastructure Law is Delivering in Georgia. (2024, March). *The White House*. Retrieved from https://www.whitehouse.gov/wp-content/uploads/2023/10/Georgia-Fact-Sheet.pdf#:~:text=The%20Biden-Harris%20Administration%20has%20hit%20the%20ground%20running,with%20over%20473%20specific%20projects%20identified%20for%20funding.

Investment in Infrastructure at Sea-Level Hospital Will Pay Off by Reducing Risk. U.S. Climate Resilience Toolkit. (n.d.-b). https://toolkit.climate.gov/case-studies/investment-infrastructure-sea-level-hospital-will-pay-reducing-risk

Jackson, C. R., Wenger, S. J., Bledsoe, B. P., Shepherd, J. M., Capps, K. A., Rosemond, A. D., Paul, M. J., Welch-Devine, M., Li, K., Stephens, T., & Rasmussen, T. C. (2023). Water supply, waste assimilation, and low-flow issues facing the southeast piedmont interstate-85 urban archipelago. *JAWRA Journal of the American Water Resources Association*, *59*(5), 1146–1161. https://doi.org/10.1111/1752-1688.13130

Johnson Creek Restoration, Portland, Oregon. Naturally Resilient Communities. (2017). https://nrcsolutions.org/johnson-creek-restoration-portland-oregon/

Lagasse, P. F. (2007). *Countermeasures to protect bridge piers from scour*. Transportation Research Board.

LaMorte, W. (2017). *Mann Whitney U Test (Wilcoxon Rank Sum Test)*. Nonparametric tests. https://sphweb.bumc.bu.edu/otlt/mph-modules/bs/bs704_nonparametric/bs704_nonparametric4.html

Levee Basics: Managing Levees. (n.d.).

Liu, W., Shan, M., Zhang, S., Zhao, X., & Zhai, Z. (2022). Resilience in infrastructure systems: A comprehensive review. *Buildings*, *12*(6), 759. https://doi.org/10.3390/buildings12060759

Marath, A., Swarna, S. T., & Mehta, Y. (2023). Resilient pavement materials to mitigate impact of climate change in New Jersey. *Journal of Testing and Evaluation*, *51*(4), 2186–2198. https://doi.org/10.1520/jte20220307

Marchese, D. Reynolds, E., Bates, M. E., Morgan, H., Clark, S. S., & Linkov, I. (2018). Resilience and sustainability: Similarities and differences in environmental management applications. *Science of The Total Environment*, *613–614*, 1275–1283. https://doi.org/10.1016/j.scitotenv.2017.09.086

Massachusetts Institute of Technology. (2011). *The Future of the Electric Grid*. MIT Energy Initiative. https://energy.mit.edu/wp-content/uploads/2011/12/MITEI-The-Future-of-the-Electric-Grid.pdf

Mikesell, J. L. (2011). *Fiscal administration: Analysis and applications for the Public Sector*. Wadsworth Cengage Learning.

Nashville Metro Water Services Stormwater Division. (2022).

National Asphalt Pavement Association. (2022, April). *Resilient Asphalt Roads: Modified Asphalt Mix Reduces Thermal Cracking*. Asphalt Pavement Alliance. https://www.driveasphalt.org/uploads/documents/NAPA_Case_Studay_Resilience_-_Adapt_-_Alaska.pdf

National League of Cities. (2023). Municipal Infrastructure Conditions.

National League of Cities. (2023, July 21). *State of the Cities 2023*. National League of Cities. https://www.nlc.org/resource/state-of-the-cities-2023/

National Park Service. (n.d.). *Appendix F Table 1, Trail Standards Summary*. National Park Service. https://www.nps.gov/romo/learn/management/upload/trail_standards_summary-detail_f.pdf

National Recreation and Park Association. (2017). *Resource Guide for Planning, Designing, and Implementing Green Infrastructure in Parks*. Natural Recreation and Park Association. https://www.nrpa.org/siteassets/gupc-resource-guide.pdf

Noel, R. (n.d.). Resiliency Lessons Learned from Hurricane Ida. *National Association of Home Builders*. other, NAHB.

Northern Powergrid. (2015, June). *Adapting to Climate Change*. Northern Powergrid. https://assets.publishing.service.gov.uk/media/5a803354ed915d74e33f90b5/clim-adrep-northern-powergrid-2015.pdf

Otter Creek Floodplain, Middlebury, Vermont. Naturally Resilient Communities. (2017). https://nrcsolutions.org/otter-creek-floodplain-middlebury-vt/

Patton, M. Q. (2002). *Qualitative Research & Evaluation Methods* (3rd ed.). Sage.

Poarch Band of Creek Indians' Utilities Authority. (2021).

Reed, B. J., & Swain, J. W. (1997). *Public Finance Administration*. Sage Publications.

Reid, R. L. (2022). Responding to code red. *Civil Engineering Magazine*, *92*(1), 36–45. https://doi.org/10.1061/ciegag.0001602

Sarhadi, A., Ausín, M. C., Wiper, M. P., Touma, D., & Diffenbaugh, N. S. (2018). Multidimensional risk in a nonstationary climate: Joint probability of increasingly severe warm and dry conditions. *Science Advances*, *4*(11). https://doi.org/10.1126/sciadv.aau3487

Sell, L. (2024, August 29). *Green City Clean Waters*. Philadelphia Water Department. https://water.phila.gov/green-city/

Shudtz, M., & Huang, Y. (2023, November). *Regulatory and policy support for nature-based solutions, ewn principles, and levee setbacks*. IRIS in Focus: A Legal, Regulatory, and

Policy Primer on Levee Setbacks. https://iris.uga.edu/iris-in-focus-a-legal-regulatory-and-policy-primer-on-levee-setbacks/

Simpson, R. (2017). 34th International Bridge Conference. In *Low-Cost Scour Preventing Fairings for Bridges*. National Harbor, MD. Retrieved from https://nebula.wsimg.com/6e561c97d7c91476f4617d3b44bc40f2?AccessKeyId=DE796BC2996E25316182&disposition=0&alloworigin=1.

Simpson, R., & Byun, G. (2019). 36th International Bridge Conference. In *Case Studies of Bridge Failure due to Scour and Prevention of Future Failures*. National Harbor, MD. Retrieved from https://nebula.wsimg.com/d5d4461258280d4bd254a3988b0a8c76?AccessKeyId=DE796BC2996E25316182&disposition=0&alloworigin=1.

Six Georgia Cities awarded Federal Infrastructure Grants. Georgia Municipal Association. (2024, July). https://www.gacities.com/News/GMA-Updates/Six-Georgia-Cities-Awarded-Federal-Infrastructure.aspx

South, J., Jones, R., Stansfield, J., & Bagnall, A.-M. (2018). *What quantitative and qualitative methods have been developed to measure health-related community resilience at a national and local level?* Health Evidence Network, WHO Regional Office for Europe.

Stanford, G., Ferreira, S., Landry, C., & Blachly, B. (2024). Valuing the ecosystem service benefits of Natural Infrastructure: A Quantitative Review of the literature. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.4927070

Tennakoon, M. (2023). *HARMONIZING CLIMATE ADAPTATION PLANNING FOR TRANSPORTATION SYSTEM RESILIENCE: DEVELOPMENT OF AN ADAPTATION GUIDEBOOK FOR THE STATE OF GEORGIA* (thesis). Retrieved from https://repository.gatech.edu/server/api/core/bitstreams/cc663e88-0067-4757-87e5-adf65424c23a/content.

Tiedmann, H. R., Spearing, L. A., Castellanos, S., Stephens, K. K., Sela, L., & Faust, K. M. (2023). Tracking the post-disaster evolution of water infrastructure resilience: A study of the 2021 Texas Winter Storm. *Sustainable Cities and Society*, *91*, 104417. https://doi.org/10.1016/j.scs.2023.104417

U.S. Department of Energy Grid Deployment Office. (n.d.). *GRID RESILIENCE AND INNOVATION PARTNERSHIPS PROGRAM*. Retrieved from https://www.energy.gov/sites/default/files/2023-10/DOE-GRIP-Georgia-Environmental-Finance-Authority.pdf.

U.S. Department of Energy. (n.d.). *Kaiser Permanente pioneers California's first Medical Center Microgrid*. Better Buildings Solution Center. https://betterbuildingssolutioncenter.energy.gov/implementation-models/kaiser-permanente-pioneers-californias-first-medical-center-microgrid/printpdf

U.S. Department of Energy Office of Energy Policy and Systems Analysis. (2016, September). Climate Change and the Electricity Sector: Guide for Climate Change Resilience Planning.

U.S. DOT Federal Highway Administration. (2018). *Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT) Program*. U.S. DOT Federal Highway Administration. https://www.fhwa.dot.gov/environment/sustainability/resilience/policy_and_guidance/protect_formula.pdf

U.S. DOT Federal Highway Administration. (2023, January 1). *Emergency relief program resilience case study – Hawai'i: Incorporating resilience through bridge replacement and rehabilitation*. Welcome to ROSA P. https://rosap.ntl.bts.gov/view/dot/72767

U.S. Environmental Protection Agency. (2015). (rep.). *Green Infrastructure for Stormwater Control: Gauging Its Effectiveness with Community Partners*. Retrieved from https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100NE3S.txt.

UGA Institute for Resilient Infrastructure Systems. (2023, December 15). Summary of the 2023 Georgia Resilience Roundtable. Atlanta, GA.

University of South Carolina. (2015a). *Georgia 2015 BRIC Map*. University of South Carolina Hazards Vulnerability & Resilience Institute. https://sc.edu/study/colleges_schools/artsandsciences/centers_and_institutes/hvri/data_and_resources/bric/

University of South Carolina. (2020b). *Georgia 2020 BRIC Map*. University of South Carolina Hazards Vulnerability & Resilience Institute. https://sc.edu/study/colleges_schools/artsandsciences/centers_and_institutes/hvri/data_and_resources/bric/

What is a benefit-cost analysis (BCA)?. U.S. Department of Transportation. (2024, January). https://www.transportation.gov/grants/dot-navigator/what-is-a-benefit-cost-analysis

Zhang, K., & Kevern, J. (2021). Review of porous asphalt pavements in cold regions: The State of Practice and Case Study Repository in design, construction, and maintenance. *Journal of Infrastructure Preservation and Resilience*, *2*(1). https://doi.org/10.1186/s43065-021-00017-2

Appendix A: Survey Questions

Introduction

The American Public Works Association (APWA), in collaboration with the University of Georgia (UGA) and the Carl Vinson Institute of Government, is conducting a survey to gather insights on the current state of infrastructure resilience among local governments in Georgia. This survey aims to understand the challenges, strategies, and resources being utilized by municipalities to enhance the resilience of their infrastructure against natural disasters, climate change, and other risks. The information gathered will be used to develop a comprehensive guide that will assist local agencies in improving infrastructure resilience.

By participating in this 10-15 minute survey, you will contribute to a statewide effort to strengthen the resilience of public infrastructure. For further questions, please contact the project's Graduate Research Assistant, Ella Terrell, at ella.terrell@uga.edu.

This project is supervised by Stephan Durham, Ph.D./P.E., Interim Dean of the UGA College of Engineering, and Walt McBride, EdS, MPA, Senior Public Service Associate.

General Information

Name

Position Title

Amount of Time Spent at Current Position

Contact Email

Name of City/Town/Municipality

Part 1

What is the population of the city/town/municipality you represent?

- ○ Rural: <2,500 people
- ○ Small City: 2,500 – 20,000 people
- ○ Mid-Sized: 20,000 – 75,000 people
- ○ Large City: >75,000 people

What is the approximate total annual government budget for your government? (millions of dollars)

[ ]

Approximately what percentage of your total annual government budget is allocated towards maintenance, design, and/or construction of your infrastructure (water and wastewater collection systems, water and wastewater plants, roads, bridges, electricity transmission and distribution, government buildings, public parks)?

	0	10	20	30	40	50	60	70	80	90	100	
0-100%												[ ]

Has your municipality applied to any federal funding opportunities relating to infrastructure resiliency (in water and wastewater collection systems, water and wastewater treatment plants, roads, bridges, electricity transmission and distribution, government buildings, and parks) within the past five years?

- ○ Yes
- ○ No
- ○ I don't know

If your municipality has applied for federal funding relating to infrastructure resiliency within the past five years, please list the funding program(s) and, if you applied to a program more than twice, please list how many times you applied that program.

[ ]

Please list the dollar amount awarded from each program.

[ ]

Part 2

Please rank the following infrastructure categories from highest priority (1) to lowest priority (7) in terms of needing rehabilitation, refurbishment, and/or expansion of the existing structures:

Water and wastewater collection systems

Water and wastewater plants (including drinking water distribution)

Roads

Bridges

Electricity transmission and distribution systems

Government buildings such as libraries, government offices, community centers, etc.

Public Parks

On a scale of 1 to 10, how informed do you feel your municipality is on how to incorporate resiliency into infrastructure design, construction, maintenance, and planning?

Not informed				Semi-Informed			Very well informed		
1	2	3	4	5	6	7	8	9	10

Please rank the following challenges your municipality faces with implementing resiliency measures in infrastructure projects, from most significant (1) to least significant (7).

Funding limitations

Lack of technical expertise

Regulatory hurdles

Political opposition

Public opposition

Not enough data/information to determine appropriate resiliency measures

Other

Does your municipality have a resiliency plan, policy, or set of guidelines for the design, maintenance, and/or construction of your infrastructure?

- Yes
- No

How often does your municipality update its infrastructure resiliency plan, policy, and/or guidelines?

- Annually

- Every 2-3 years
- Every 4-5 years
- Every 5+ years
- No Regular Updates

Please choose and rank the following issues facing your stormwater and sewer collection system infrastructure, from most pressing (1) to least pressing (13).

Note: If your municipality does not manage stormwater and/or sewer collection systems, please rank "Not applicable" as #1.

Combined Sewer Overflows

Unintentional Inflow/Infiltration due to Leaks in Collection Pipes

Street Flooding and Runoff Issues due to high impervious area

High Velocity Runoff

Insufficient stormwater storage capacity (lack of detention/retention ponds)

Poorly designed or outdated stormwater systems

Limited green infrastructure to manage stormwater

Tidal backflow into storm/sewer piping

Lack of real-time monitoring and control systems

Insufficient funding for upgrades and repair

Limited knowledge or documentation of the pipe network's location

Other: __________

Not Applicable

Please choose and rank the following issues facing your water and wastewater treatment plant infrastructure, from most pressing (1) to least pressing (9).

Note: If your municipality does not manage water and/or wastewater treatment plants, please rank "Not applicable" as #1.

Limited capacity to treat peak flows during wet weather

Aging infrastructure that might have functionality issues (low efficiency pump stations, bar screens that require laborious manual raking, etc)

Corroded or deteriorating drinking water distribution pipes

Outdated treatment technology

Limited access to skilled labor for maintenance and operation

Regulatory compliance issues with discharging to water body or distributing to customers

Infiltration and inflow problems

Other: ________

Not Applicable

Please choose and rank the following issues facing your roadway infrastructure, from most pressing (1) to least pressing (12).

Note: If your municipality does not manage any roads, please rank "Not applicable" as #1.

Sections of road are structurally unsound

Uneven roads

Roadway flooding

Potholes

Cracked pavement

Erosion of roadway edges

Insufficient lighting

Poor drainage

Traffic congestion

Sidewalk deterioration

Other: ________

Not applicable

Approximately what percentage of the bridges under your purview are in poor condition?

Note: If your municipality does not manage any bridges, please choose "Not applicable".

- ○ 0%
- ○ 1-10%
- ○ 11-20%
- ○ 20-40%
- ○ >40%
- ○ I do not know
- ○ Not applicable

Please choose and rank the following issues facing your electricity transmission and distribution infrastructure, from most pressing (1) to least pressing (9).

Note: If your municipality does not manage any electricity transmission and distribution infrastructure, please rank "Not applicable" as #1.

Downed lateral or feeder lines due to falling vegetation

Overheated lines

Line sagging due to high temperatures

Vandalism or theft

Damage from severe weather events (storms, ice, hurricanes)

Voltage fluctuations or power quality issues

Inadequate clearance from structures or other utilities

Other: ______

Not applicable

Please choose and rank the following issues facing your government building infrastructure, from most pressing (1) to least pressing (8).

Note: If your municipality does not manage any government building infrastructure, such as community centers, government offices, libraries, etc, please rank "Not applicable" as #1.

Leaky roofs or windows

Insufficient space for current needs

Flooding issues in buildings

Outdated electrical, plumbing, and/or HVAC systems

Security vulnerabilities

Structural deficiencies

Other ______

Not applicable

Please choose and rank the following issues facing your public park infrastructure, from most pressing (1) to least pressing (8).

Note: If your municipality does not manage any public park infrastructure, please rank "Not applicable" as #1.

Eroded footpaths

Flooding/drainage issues from wet weather or from proximity to river/stream

Security vulnerabilities

Insufficient lighting

Outdated playground equipment

Aging and/or poor condition of amenities such as restrooms, benches, and picnic tables

Other [ ]

Not applicable

Please rank the following issues facing your coastal waterway infrastructure, from most pressing (1) to least pressing (9).

Note: If your city/town/municipality is not on the coast or affected by coastal waterways, please rank "Not applicable" as #1.

Coastal erosion

Flooding during high tides or storm surges

Corrosion of metal structures

Deterioration of concrete structures

Loss of natural buffers (e.g., wetlands, dunes)

Saltwater intrusion into freshwater supplies

Tidal backflow into storm and/or sewer systems

Other: [ ]

Not applicable

If your city/town/municipality employs resiliency in the design, maintenance, and construction of your infrastructure, who is the best contact? Please provide their name, email address, and/or phone number.

[ ]

Please add any additional comments.

[ ]

Powered by Qualtrics

Appendix B: Interview Guide

1. How would you describe a resilient physical infrastructure asset to a friend?
2. What physical infrastructure assets and systems does your government manage?
3. Tell me about the maintenance and upkeep of the infrastructure systems your government manages.
4. Tell me about the process of developing your annual government budget and the allocation of funding directed towards your infrastructure systems.
5. In your survey response, you indicated you applied for external funding. Why did you select those particular opportunities?
6. In your survey response, you indicated you did not apply for external funding. Why not?
7. Of your physical infrastructure assets, tell me about the asset or system that you feel is the most resilient. How has your local government maintained that asset's strength over the years?
8. In your survey response, you scored your local government's understanding of resilience a * out of 10. How would you describe your government's level of commitment to incorporating resilience to your infrastructure planning?
9. If a neighboring city or county reached out to you for resources to use for resilient infrastructure planning, what would you recommend?
10. In your survey response, you ranked challenges of incorporating resilience into your infrastructure design and management. Could you share specific examples of how your government has experienced these challenges? Are there any additional challenges you've encountered that weren't listed?
11. Were you directly affected by Hurricane Helene? If not, have you experienced a catastrophic event that tested your infrastructure? How did your planning and preparation impact the outcome and the extent of damage to your infrastructure?

Zoom Information

Ella Terrell is inviting you to a scheduled Zoom meeting.

Topic: Ella Terrell's Personal Meeting Room

Join Zoom Meeting

https://zoom.us/j/2895349185

Meeting ID: 289 534 9185

Appendix C: Evaluation Survey Questions

Introduction

The American Public Works Association (APWA), in collaboration with the University of Georgia (UGA) and the Carl Vinson Institute of Government, have been working to develop a Resilient Infrastructure Resource and Decision Guide For Local Georgia Governments. This study aims to understand the merits, issues, and usability of the guide to be utilized by city and county governments to enhance the resilience of their infrastructure against natural disasters, climate change, and other risks. The information gathered will be used to improve the guide and iterate it to its final version.

By participating in this 10-15 minute survey, you will contribute to a statewide effort to strengthen the resilience of public infrastructure. Please use the guide and Excel spreadsheet attached in the email from the project's Graduate Research Assistant, Ella Terrell, elt70605@uga.edu, to complete the survey. For further questions, please contact Ella Terrell.

This project is supervised by Stephan Durham, Ph.D./P.E., Interim Dean of the UGA College of Engineering, and Walt McBride, EdS, MPA, Senior Public Service Associate.

General Information

Name

Position Title

Contact Email

Name of City/County

Part 1

On a scale of 1-10, how would you rank the organization of this guide, with 1 being unorganized, and 10 being extremely organized?

1	2	3	4	5	6	6	7	8	9	10

1-10

What are your suggestions to improve the organization of this guide? If you do not have suggestions, please put N/A.

On a scale of 1-10, how would you rank the usefulness of this guide, with 1 being not useful, and 10 being extremely useful?

1	2	3	4	5	6	6	7	8	9	10

1-10

What are your suggestions to improve the usefulness of this guide overall? If you do not have suggestions, please put N/A.

On a scale of 1-10, how would you rank the usefulness of Chapter 2: Understanding Resilience, with 1 being not useful, and 10 being extremely useful?

1	2	3	4	5	6	6	7	8	9	10

1-10

Chapter 2: Understanding Resilience

What information did you find helpful in this chapter of the guide that applies to your local government? What information would be more useful?

On a scale of 1-10, how would you rank the usefulness of Chapter 3: Implementing Resilience, with 1 being not useful, and 10 being extremely useful?

1	2	3	4	5	6	6	7	8	9	10

1-10

Chapter 3: Implementing Resilience

What information did you find helpful in this chapter of the guide that applies to your local government? What information would be more useful?

On a scale of 1-10, how would you rank the usefulness of Chapter 4: Guidance Resources, with 1 being not useful, and 10 being extremely useful?

	1	2	3	4	5	6	6	7	8	9	10
1-10											

Chapter 4: Guidance Resources

What information did you find helpful in this chapter of the guide that applies to your local government? What information would be more useful?

On a scale of 1-10, how would you rank the usefulness of Appendix A: Resilient Strategy Tables, with 1 being not useful, and 10 being extremely useful?

	1	2	3	4	5	6	6	7	8	9	10
1-10											

Appendix A: Resilient Strategy Tables

What information did you find helpful in this chapter of the guide that applies to your local government? What information would be more useful?

On a scale of 1-10, how would you rank the usefulness of Appendix C: Example Use of Decision Matrix Spreadsheet, with 1 being not useful, and 10 being extremely useful?

	1	2	3	4	5	6	6	7	8	9	10
1-10											

Part 2

Is the Decision Matrix Excel Spreadsheet something you would use in your government's operations?

- Yes
- No

If no, please explain why.

On a scale of 1-10, how useful is Decision Matrix Excel Spreadsheet to your government, with 1 being not useful, and 10 being extremely useful?

	1	2	3	4	5	6	6	7	8	9	10	
1-10												

On a scale of 1-10, how straightforward/clear is the Decision Matrix Excel Spreadsheet to use, with 1 being not straightforward/clear, and 10 being extremely straightforward/clear?

	1	2	3	4	5	6	6	7	8	9	10	
1-10												

Powered by Qualtrics

Appendix D: Evaluation Discussion Guide

Resource Guide (10 minutes)

1. What specific sections or concepts do you think should be expanded upon to make the guide more applicable to all government sizes?

2. How do you think the guide could better accommodate the needs of different departments within your government?

3. Could you suggest alternative visuals or examples that would make the content more relevant to your area?

Example Use of Decision Matrix Excel Spreadsheet (20 minutes)

Let's walk through the decision matrix together. Please review the infrastructure sector tabs and identify resilient strategies that your government is currently using or would consider implementing. We will then input them to the spreadsheet to assess their viability as solutions for your community.

1. What aspects of the spreadsheet stand out as particularly helpful or unclear?

2. Did you encounter any specific challenges while using it?

3. What features or modifications would make this spreadsheet more useful for your department?

4. What potential barriers do you see in getting your colleagues to adopt this matrix for decision-making?

Zoom Information

Ella Terrell is inviting you to a scheduled Zoom meeting.

Topic: Ella Terrell's Personal Meeting Room

Join Zoom Meeting

https://zoom.us/j/2895349185

Meeting ID: 289 534 9185

Appendix E: Resilience Decision Matrix Excel Spreadsheet

OneDrive Link to Spreadsheet: Resilience Decision Matrix Excel Spreadsheet

Appendix F: Resilient Infrastructure Resource and Decision Guide for Local Georgia Governments

RESILIENT INFRASTRUCTURE RESOURCE AND DECISION GUIDE FOR LOCAL GEORGIA GOVERNMENTS

May 2025

PREPARED BY:

Ella Terrell
Graduate Research Assistant
ella.terrell@uga.edu

College of Engineering
UNIVERSITY OF GEORGIA

Carl Vinson
Institute of Government
UNIVERSITY OF GEORGIA

Table of Contents

List of Tables and Figures

List of Tables and Figures (Cont.)

Acronyms and Definitions

Acronyms:

DCA: Department of Community Affairs

DOT: Department of Transportation

DW: Drinking Water

FHWA: Federal Highway Administration

GI: Green Infrastructure

GSI: Green Stormwater Infrastructure

NOAA: National Oceanic and Atmospheric Adminstration

PW: Public Works

USDA: United States Department of Agriculture

WW: Wastewater

Definitions:

Critical infrastructure: The physical assets and associated social systems that are so crucial to society that their failure would have extreme consequences to the economy, national security, and/or public safety, health, and welfare [1].

Resilience: The capacity to plan for, prepare for, mitigate, and adapt to evolving conditions caused by hazards, allowing for the swift recovery of physical, social, economic, and ecological systems [1].

Chapter 1: Introduction

1.1 Purpose

This guide is designed to support Georgia local governments in identifying and implementing resilient infrastructure practices by breaking down the concept of resilience into actionable strategies. It aims to bridge the gap between planning and implementation, helping cities and counties, regardless of population size, budget, or geography, overcome common challenges such as accessing technical expertise, securing funding, and navigating regulatory requirements. By defining and contextualizing resilience within various infrastructure sectors, this guide enables local governments to benchmark their progress and make informed decisions.

The primary objectives of this guide are to:

- Define resilience in the context of local infrastructure management
- Explore a range of strategies to enhance infrastructure resilience, considering varying levels of cost, construction, and implementation efforts
- Identify relevant grants, training opportunities, and organizations that can support resilience initiatives
- Provide decision-making tools to help local governments assess and select the most suitable resilience strategies for their needs

1.2 Significance of Resilience

Infrastructure resilience is a growing priority for local governments because it directly impacts economic development, public health, and budgets. Mayors across the U.S. have emphasized the need for “climate-ready infrastructure” to withstand disruptions and maintain essential services [2].

Recent events, including COVID-19 and weather-related disasters, have shown that adaptive management improves government efficiency and response. However, smaller local governments with budgets under $100 million tend to be less prepared for disasters than larger governments [3]. This necessitates proactive planning, financial resources, and mitigation strategies to strengthen resilience before disruptions occur.

1.3 Sustainability and Resilience

Sustainability and resilience are closely related, but not the same. Sustainability involves long-term resource management, and the benefits produced from those resources, as well as balancing environmental, social, and economic factors to keep infrastructure viable over time. Resilience, on the other hand, is a system’s ability to withstand, recover, and adapt from environmental, social, and economic disturbances.

An important difference between the two concepts is the timescale they operate under. Sustainability objectives operate on a longer time scale, so its benefits will likely not be felt immediately. On the other hand, resilience goals are measured on a shorter time scale and under more immediate circumstances, such as a natural disaster. Figure 1 displays a quadrant analysis of three spheres (energy production, water supply sources, and business practices) and the different resilient and sustainable practices that would fall within each category that balance resource productivity, a sustainability goal, and adaptive capacity, a resilience goal [4].

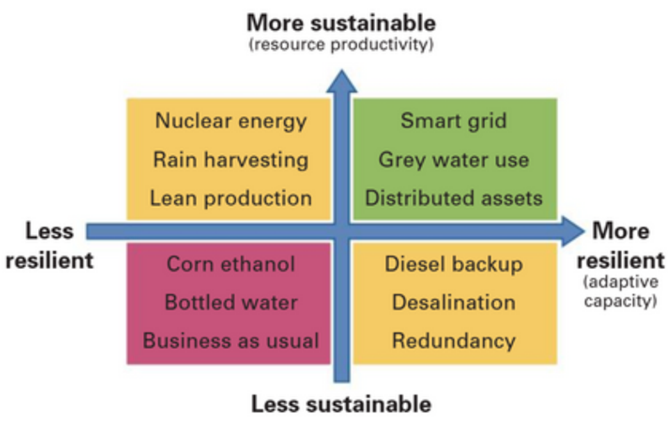


Figure 1. Quadrant analysis of resilient and sustainable practices [4].

1.4 Cost Savings of Resilience

Resilient infrastructure can hold significant inherent economic value by reducing the long-term costs associated with natural disasters, system failures, and climate impacts. Benefit-cost ratio (BCR) is a metric commonly used in infrastructure project evaluation, measured by the fraction of the economic value of outcomes from an infrastructure project, such as safety, travel time, health benefits, wildlife impacts, and effects on other infrastructure systems, over the economic value of building or maintaining a new or improved infrastructure asset over the course of the project [5]. A benefit-cost analysis (BCA), which produces a BCR score, is a common requirement in applications for hazard mitigation and infrastructure grant programs to demonstrate a project's cost effectiveness. For FEMA grant applications, a project is considered economical if the BCR is greater than or equal to 1.0 at a 3.1% interest rate [6]. Figure 2 displays calculated BCRs of resilience strategies in the U.S. Gulf Coast.

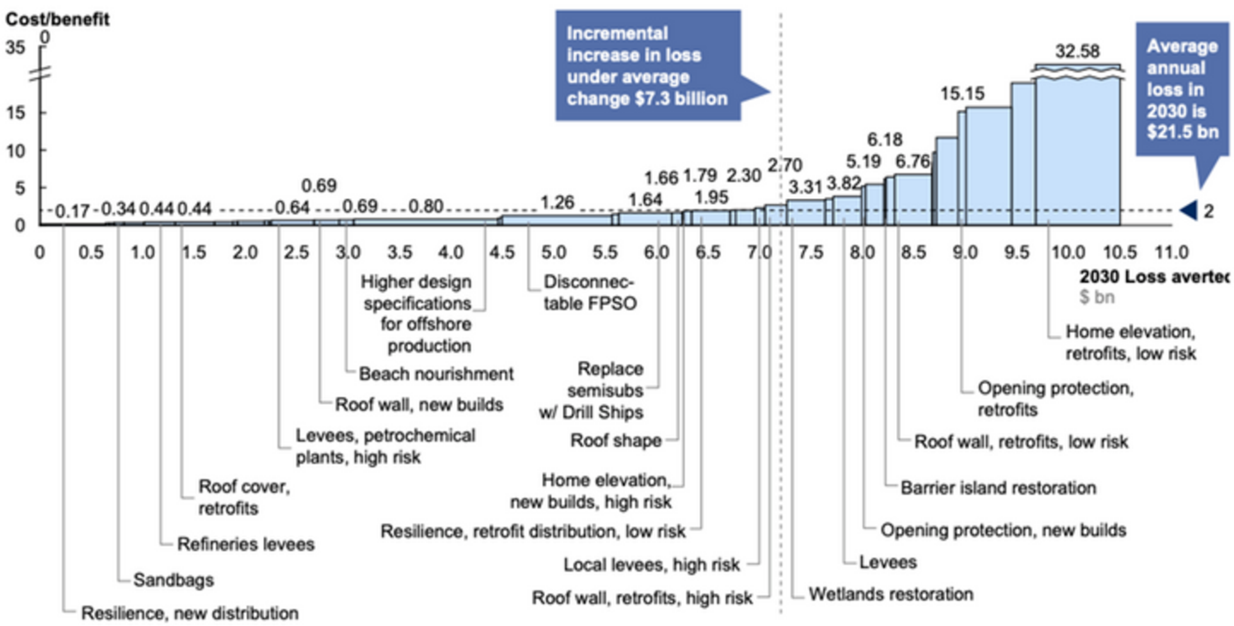


Figure 2. Economic benefit/cost ratio of resiliency measures in the U.S. Gulf Coast [7].

Chapter 2: Understanding Resilience

2.1 Resilient Infrastructure Assets

There are eight infrastructure sectors outlined in this guide:

1. Stormwater
2. Roadways
3. Bridges
4. Public Buildings
5. Public Parks
6. DW Treatment & Distribution
7. WW Treatment and Collection
8. Coastal and Riverine Protection

In Georgia, hazards, risks, and disasters faced by each infrastructure sector can vary, but commonly include flooding, hurricanes, extreme heat, and drought, as well as infrastructure aging. This chapter identifies physical assets in each infrastructure sector and provides examples of what resilience looks like with those assets. This chapter serves as an introduction to resilience across the sectors. Appendix A provides a deeper dive into technical strategies for implementation.

Stormwater Systems

A resilient stormwater system has the ability to withstand and recover quickly from hazards while managing runoff and minimizing flood risks. It should be adaptable to climate change and incorporate real-time data.

Stormwater systems are highly interconnected with the rest of a community's infrastructure assets, since precipitation affects all areas of a community. Hazards faced by stormwater infrastructure include, but are not limited to, *intense precipitation events, flash flooding, debris clogging, erosion and scour, sedimentation, sea level rise, and encroachment of other structures*. Building resilience in stormwater management requires a systems-thinking approach that extends beyond conveyance. Effective strategies that build resilience can also minimize stormwater impacts (flooding, ponding, rapid runoff) on other infrastructure, protect water quality, and preserve habitats and ecosystems.

Physical Assets to Improve Upon:

- Culverts
- Storm Drains
- Ditches
- Retention Ponds
- Pumps
- Pump Stations
- Detention Basins
- Surface water bodies
- Vegetation & Natural Infrastructure
- Conveyance pipes
- Retaining Walls
- Sediment traps
- Natural Floodplain
- Overflow structures
- Valves

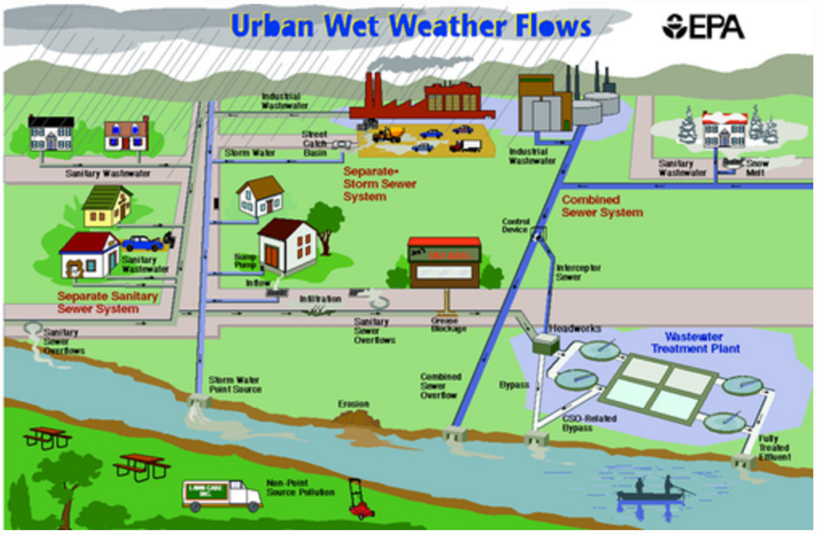


Figure 3. Separate storm/sanitary sewer and combined sewer flows diagram [8].

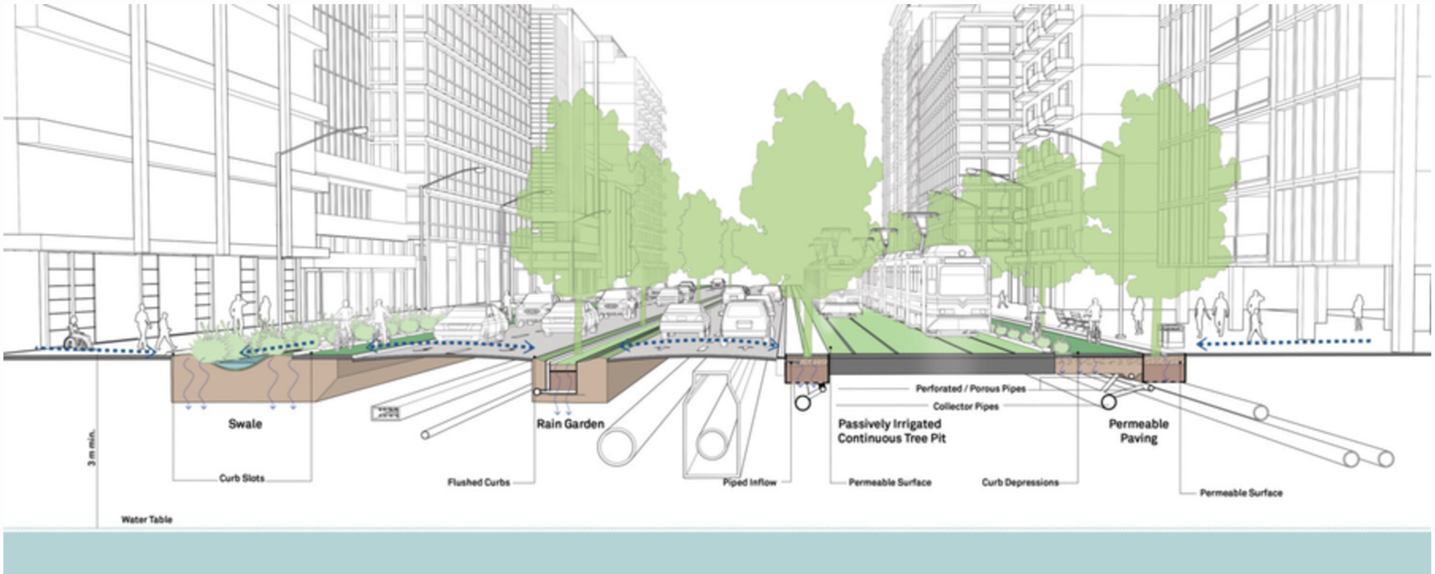


Figure 4. GI and stormwater management in urban areas [9].

Roadways and stormwater systems must be designed together with systems thinking, especially in urban areas, to manage stormwater effectively. GI enhances stormwater resilience by slowing and filtering runoff, reducing strain on drainage systems. Swales act like natural pipes, moving water through planted channels that trap pollutants. Rain gardens and bioretention systems filter roadway runoff, while permeable pavement allows water to infiltrate, reducing surface flooding. Street trees and passive irrigation further improve resilience by cooling streets, reducing runoff, and supporting vegetation.

An example of resilient stormwater maintenance is using trenchless repair methods as a minimally invasive technique to lower project costs and minimize disruptions to roadways and community life. This approach extends the lifespan of the stormwater asset and is an efficient method that does not require extensive excavation.

Figures 5, 6, 7, and 8 demonstrate the effectiveness of trenchless methods and how the minimally invasive techniques successfully rehabilitated a failing culvert system and addressed the deterioration without the disruptions required by traditional dig-and-replace methods.

Figure 5, 6. Culvert before trenchless repairs [10].

Figure 7, 8. Culvert after trenchless repairs [10].

Roadways

A resilient roadway system has the ability to withstand and recover from hazards by minimizing impacts and reducing the duration of disruptions. Roadway infrastructure is vulnerable to threat that include, but are not limited to, *flooding, erosion, wildfires, snow and ice, sea level rise, and overloading.* Achieving resilience can involve effective flood prevention, structure durability and stability, and enhanced structural and organizational recovery capabilities.

Physical Assets to Improve Upon:

- Asphalt material
- Surface Treatments
- Shoulders
- Traffic signals
- Sidewalks
- Lighting
- Embankments
- Landscaping
- Retaining Walls
- Guardrails

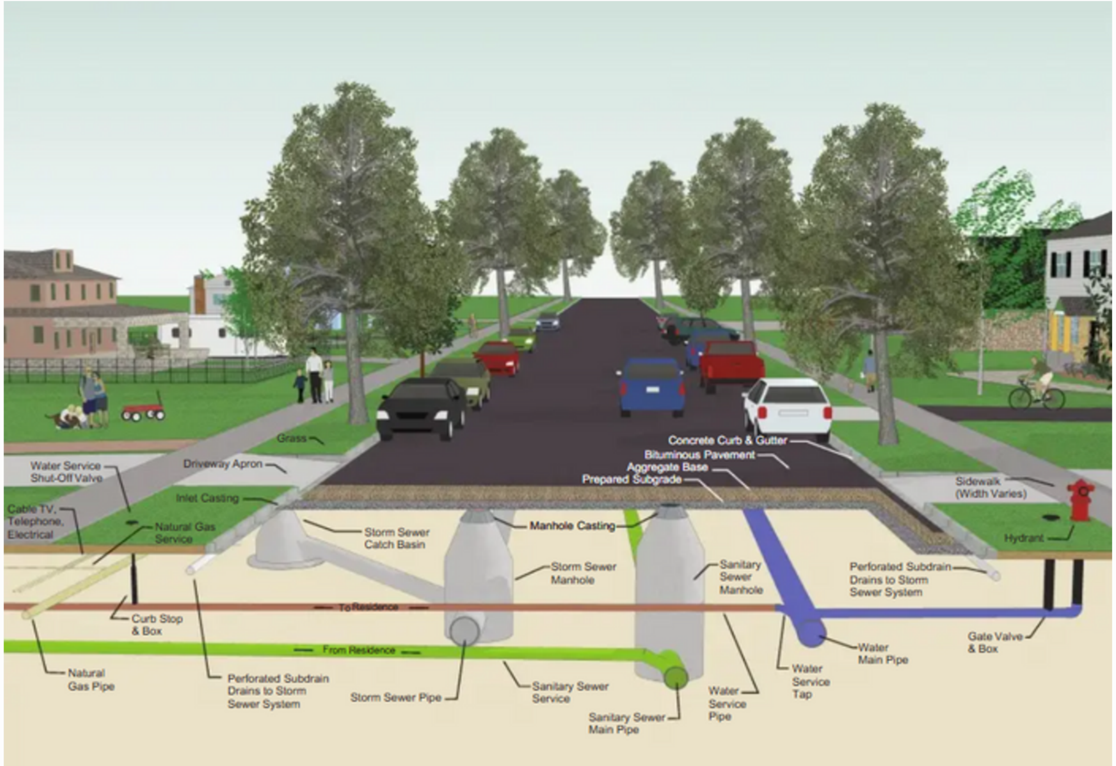


Figure 9. Cross Section of a Roadway [11].

Roadways must account for buried infrastructure such as water, sewer, and fiber-optic lines, ensuring that utility maintenance does not compromise structural integrity. By taking a systems-thinking approach, communities can design roads that balance longevity, adaptability, and ease of maintenance.

Figure 10 shows a typical cross-section of pavement produced by DOTs. Pavement infrastructure disruptions are caused by weather impacts, like precipitation, heat, cold, sea-level rise, wildfires, and sea-level rise, which have been studied thoroughly by the FHWA [18]. Stronger subgrades, improved drainage for roadways, and even permeable or flexible pavement materials can help roadway infrastructure recover from extreme heat, flooding, and heavy traffic, which ultimately reduces long-term costs and disruptions. Ensuring proper subgrade compaction and drainage prevents premature failure. Carefully selected base and subbase materials distribute loads to extend the pavement lifespan.

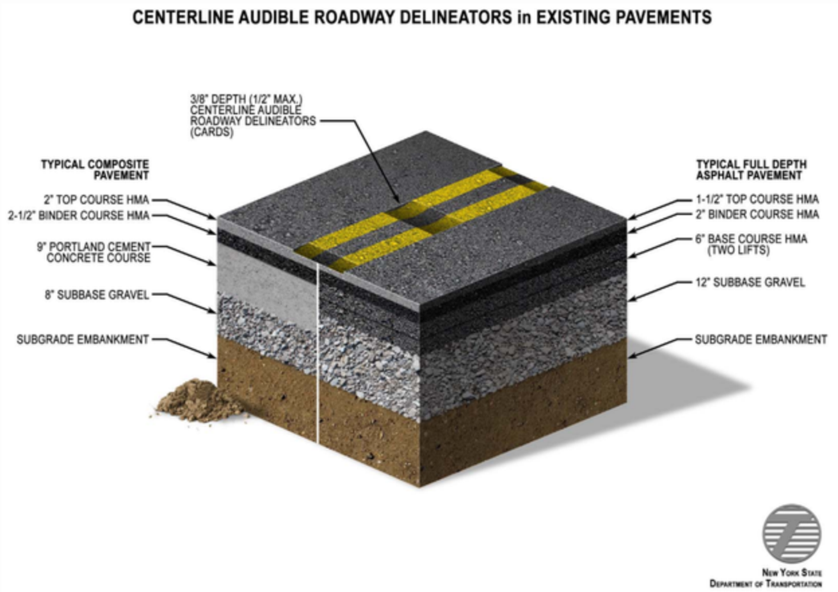


Figure 10. Cross-section of pavement in an urban environment [12].

Using asphalt rejuvenators for pavement preservation helps restore flexibility and durability to aging asphalt. Rejuvenators penetrate the asphalt to replenish lost binder and reduce cracking, all while offering a cost-effective, sustainable alternative to full-scale repairs. Figure 11 shows a community that uses rejuvenators yearly to extend the lifespan of its roadway by five to ten years.

Figure 11. Asphalt rejuvenation [13].

Bridges

A resilient bridge has the ability to withstand effects of emergencies/hazards and recover quickly while ensuring safe operation and access for users. A resilient project/practice for a bridge can aim to enhance its structural safety, longevity, environmental sustainability, and economic role as a corridor for commerce.

Physical Assets to Improve Upon:

- Deck
- Beams
- Piers or Columns
- Foundations
- Abutments
- Drainage Systems
- Median
- Joints
- Railings or Traffic Barriers
- Embankments
- Lighting

Bridges are critical transportation links that face a range of hazards that can threaten their functionality and lifespan, such as *flooding, scour, freeze-thaw cycles, and heavy traffic loads* that can degrade structural components, leading to costly repairs or even catastrophic failures. Climate change is increasing the frequency and severity of these hazards, making resilience a key focus in modern bridge design and maintenance. Figure 12 displays a fault tree of a substructure and superstructure of a steel girder bridge, which can be used to predict and plan for these failures.

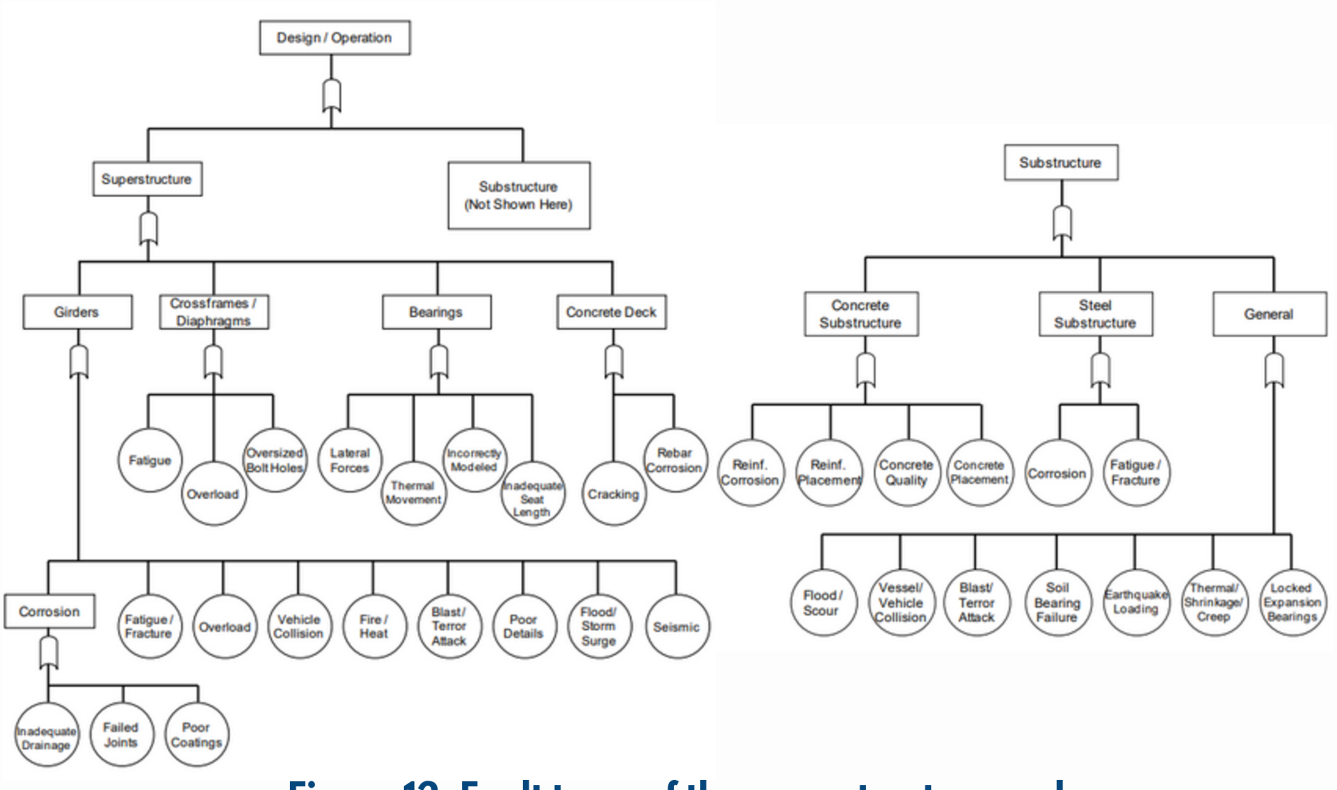


Figure 12. Fault trees of the superstructure and substructure steel girder bridge [14].

For bridges over water, scour, which is the removal of sediment from around bridge foundations due to fast-moving water, is a leading cause of failure. Increased precipitation and more intense storms exacerbate this issue. Strategies like deep foundations, riprap, and real-time scour monitoring can reduce risk and improve long-term stability. Additionally, elevating bridge decks or designing them with greater hydraulic capacity can prevent overtopping during extreme flood events.

Figure 13. Scour Prevention Measures in Southern California [15].

Aging bridges often suffer from material degradation and outdated design, posing significant structural challenges. However, full bridge replacements are usually cost-prohibitive. Instead, targeted repairs and rehabilitations offer a cost-effective alternative that extends a bridge's lifespan and minimizes community disruption.

Soil nailing is a method to stabilize slopes around structurally unstable bridges by inserting steel bars to form an integrated support system. Reticulated piles are another method of ground reinforcement with an interlocking network of rock foundations. In the case of Figure 14, together, they ensured a safer and more durable bridge in challenging soil conditions.

Figure 14. Failed abutment on historic bridge in the Northeast U.S. [16].

Public Buildings

A resilient building withstands disturbances and hazards including, but not limited to, *hurricanes and high winds, flooding, fire, extreme heat, sea level rise, snow and ice, and power outages*, while maintaining safety and functionality beyond minimum code requirements. A resilient public building should also adapt to regular use and aging.

Physical Assets to Improve Upon:

- Walls
- Roof
- Columns & Beams
- Ceiling
- Windows
- Doors

- Insulations
- Utilities & Mechanical Systems
- Accessibility Features
- Parking

- Landscaping and Stormwater management
- Security System
- Energy System and/or Power Supply

Public buildings serve a wide range of functions in a local community, emergency response centers, schools, government offices, and community shelters, each with unique needs and requirements to meet an acceptable level of functionality and safety. A resilient public building goes beyond meeting minimum codes; it is designed and/or retrofitted to withstand disasters.

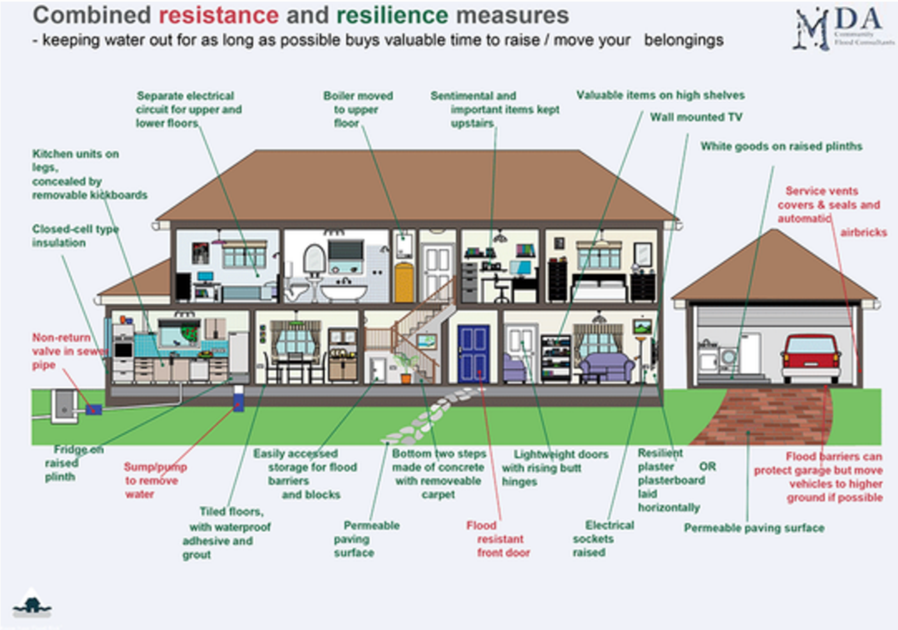


Figure 15. Combined resistance and resilience measures for flooding in homes [17].

As buildings age, their internal infrastructure slowly degrades. However, improving energy efficiency in a public building. does not always require a full HVAC overhaul. While upgrading heating and cooling systems can be expensive, lower-cost solutions like adding insulated panels, sealing air leaks, and upgrading windows can significantly reduce energy loss. Simple retrofits, such as improved insulation or reflective roofing materials, help regulate indoor temperatures, lowering energy costs while enhancing occupant comfort.

Figure 16. Prefabricated, insulated panels regulate heat and speed up the retrofit process [19].

The Okefenokee Swamp fires in South Georgia have demonstrated how quickly wildfires can escalate, threatening communities and infrastructure [16]. Given the state's mix of urban growth and forested landscapes, cost-effective retrofits are crucial for reducing wildfire risks. Maintaining defensible space, such as upgrading to metal or tile roofs, as seen in Figure 17, or clearing dry vegetation near buildings, can protect critical public facilities from disaster [15].

Figure 17. Metal or tile can protect roofs from ignition [20].

Public Parks

A resilient public park has the ability to withstand and adapt to hazards while maintaining safe, accessible, and operational recreational spaces. These hazards include, but are not limited to, *flooding, drought, fires, high winds, sea level rise, erosion, and overuse of the space*. Resilient design can incorporate features that enhance stormwater management, heat mitigation, ecological support, and natural resource conservation.

Physical Assets to Improve Upon:

- Soil and grading
- Stormwater systems
- Vegetation
- Roads
- Footpaths
- Surface water bodies and/or wetlands
- Lighting
- Amenities
- Signage
- Waste Management System
- Accessibility Features

While public parks are especially vulnerable to environmental stressors, integrating green infrastructure (see Figure 4) and adaptive strategies can transform them into valuable components of a community's resilience network. These spaces not only help manage stormwater and reduce the urban heat island effect, but also offer ecological and social benefits.

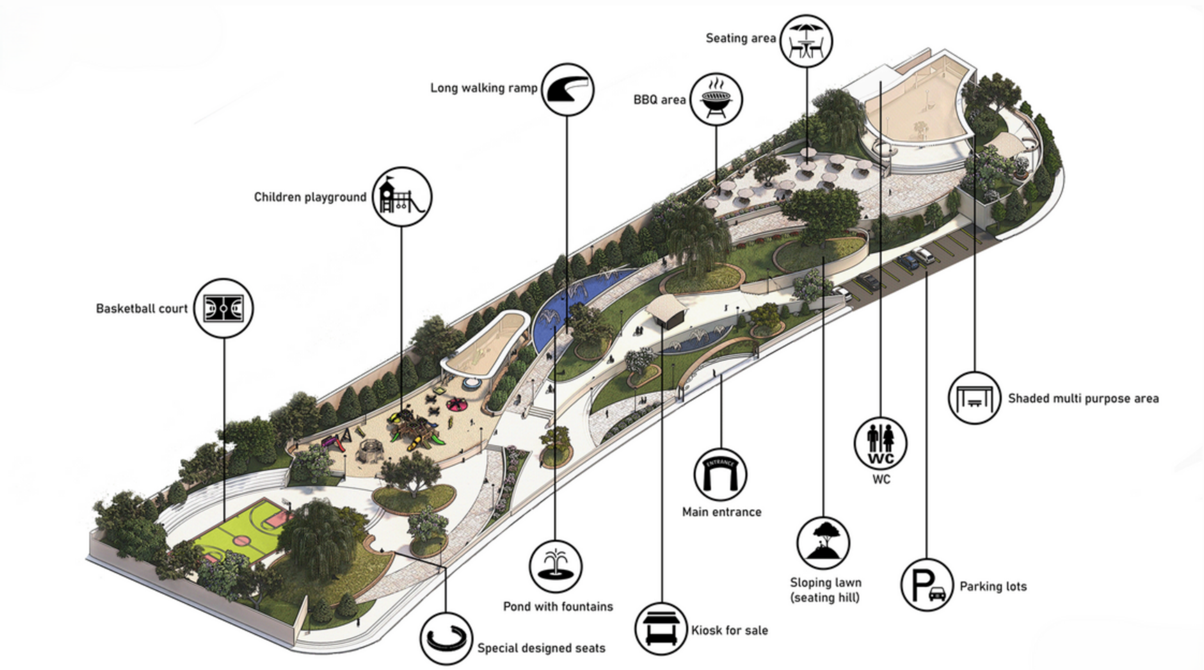


Figure 18. Public park map with labeled amenities [21].

Stormwater and flood control is a major issue in public parks. Check dams, built from straw, logs, or rocks, can serve as temporary erosion control measures and help to attenuate peak flows. These check dams work best when installed in series along gentle slopes high in the watershed, though they may be vulnerable during large storm events.

Figure 19. Small rock check dam [22].

Park assets, like playground equipment, can be made resilient against flood hazards. Elevating structures and sourcing equipment that uses flood-tolerant materials are ways to prevent park closures during flood risks. The playground equipment will have longer lifespans in these environments than traditional playground equipment.

Figure 20. Flood-resistant playground equipment in coastal South Carolina [23].

DW Treatment & Distribution

A resilient drinking water treatment plant and distribution system has the ability to withstand and recover quickly from disasters while maintaining safe, operational water services. These hazards include *aging infrastructure, flooding, drought, power outages, water supply contamination, cyber threats, and supply chain disruptions*. A resilient drinking water system would ensure continuous water quality, protect treatment processes, and preserve facility integrity, enabling quick recovery and reliable access to drinking water during emergencies.

Physical Assets to Improve Upon:

- Intake
- Treatment equipment
- Chemical storage
- Pipes
- Tanks
- Reservoirs
- Pumps
- Pump and Booster Stations
- Buildings
- Main and Backup Power Supply
- Monitoring Systems, Sensors, and Metering
- Service connections
- Valves

Drinking water is the most important infrastructure sector in a local community with respect to public health, so safeguarding its infrastructure is crucial to resilience and general operations. By integrating operational flexibility, supply chain preparedness, and proactive system management, water utilities can build resilience against the aforementioned hazards. Figure 14 displays some elements of a resilient water network, and more strategies can be found in Appendix A.

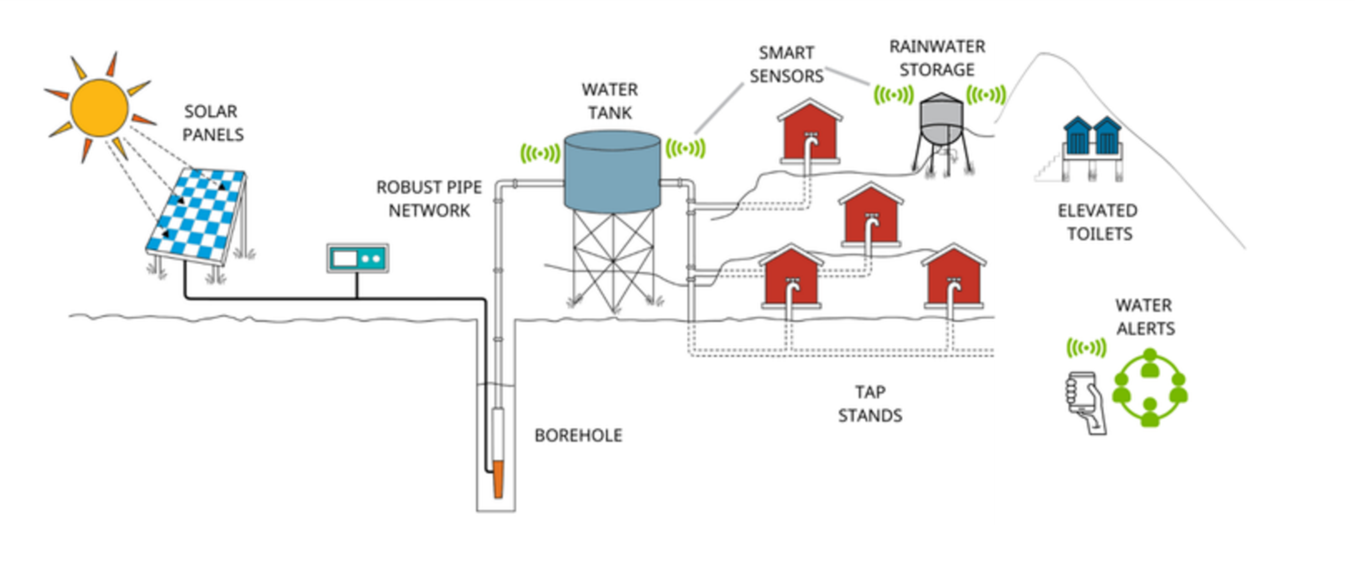


Figure 21. Elements of a Resilient Water Network [24].

Many small and rural water utilities continue to use paper maps or outdated digital versions, which lowers their ability to address common challenges efficiently and raises operational costs. By digitizing assets, utilities can lower operating costs, make more informed management decisions, and improve their emergency response capabilities.

Figure 22. Digitized DW Distribution Network in a Rural Community via ESRI [25].

WW Treatment & Collection

A resilient wastewater treatment plant and sanitary sewer system has the ability to withstand and recover quickly from hazards while ensuring continuous and safe operation of collection systems, treatment integrity, and facility protection. This infrastructure is vulnerable to hazards and disturbances that include, but are not limited to, *flooding, sea level rise, inflow and infiltration, equipment failure, power outages, and aging or undersized infrastructure*. A resilient wastewater system would be able to manage and expand components to meet future community needs, maintain environmental regulatory compliance, and provide uninterrupted service during and after hazard events.

Physical Assets to Improve Upon:

- Pipes
- Valves
- Pumps
- Storage tanks and basins
- Pump stations and Lift stations
- Treatment equipment
- Electrical & Utilities
- Service connections
- Backup power system
- Manholes
- Chemical storage
- Monitoring System, Sensors, and Metering

Figure 23 highlights the overlap in assets for DW and WW systems, along with shared resources supporting both. These shared assets like buildings, chemical storage, electrical controls, and power supply provide critical support for both systems, ensuring efficient and resilient water management. Resilience strategies for DW and WW can be found in Appendix A.

Figure 23. Assets shared by DW and WW [26].

Reliable power is critical for both drinking water and wastewater treatment plants to maintain operations during emergencies. Power redundancy strategies, such as installation of backup generators, dual power feeds, and on-site renewable energy, help ensure continued treatment and distribution during outages. Wastewater plants rely on redundancy to prevent overflows and untreated discharges, while drinking water facilities need consistent power to maintain pressure, filtration, and disinfection.

Figure 24. A mobile trailer for pump controls from South Monmouth Regional Sewerage Authority in Monmouth County, NJ [27].

GSI can help to mitigate Combined Sewer Overflows (CSOs) by reducing the volume and speed of stormwater entering the sewer system. Solutions like the ones seen in Figure 4 (permeable pavements, bioswales, rain gardens, etc.) allow water to infiltrate naturally and prevent system overload during heavy rainfall. By managing runoff at the source, GSI can protect aquatic ecosystems from untreated wastewater.

Coastal and Riverine Protection Systems

A resilient coastal or riverine protection system has the ability to withstand and recover quickly from hazards while protecting property and improving floodwater storage to protect other infrastructure and natural systems from flooding effects. A resilient flood protection system is able to mitigate storm damage and reduce the associated costs during hazards that include, but are not limited to, *sea level rise, storm surge, coastal and riverbank erosion, tidal flooding, and intense precipitation events.*

Physical Assets to Improve Upon:

- Seawalls
- Dunes
- Beach
- Breakwaters
- Tide gates
- Levee
- Embankments
- Wetlands
- Floodplain
- Floodgates
- Pumps
- Flood Control Ponds and Basins
- Culvert
- Natural Buffers
- Spillways
- Dikes
- Monitoring systems and Sensors

Major disasters, like Hurricane Helene, caused devastation in the southeast and across Georgia, underscoring the vulnerability of Georgia's coastal communities to extreme weather events. Coastal resilience focuses on strategies to mitigate the impacts of storm surge, flooding, and erosion while ensuring communities can bounce back quickly and build beyond, as shown in Figure 25.

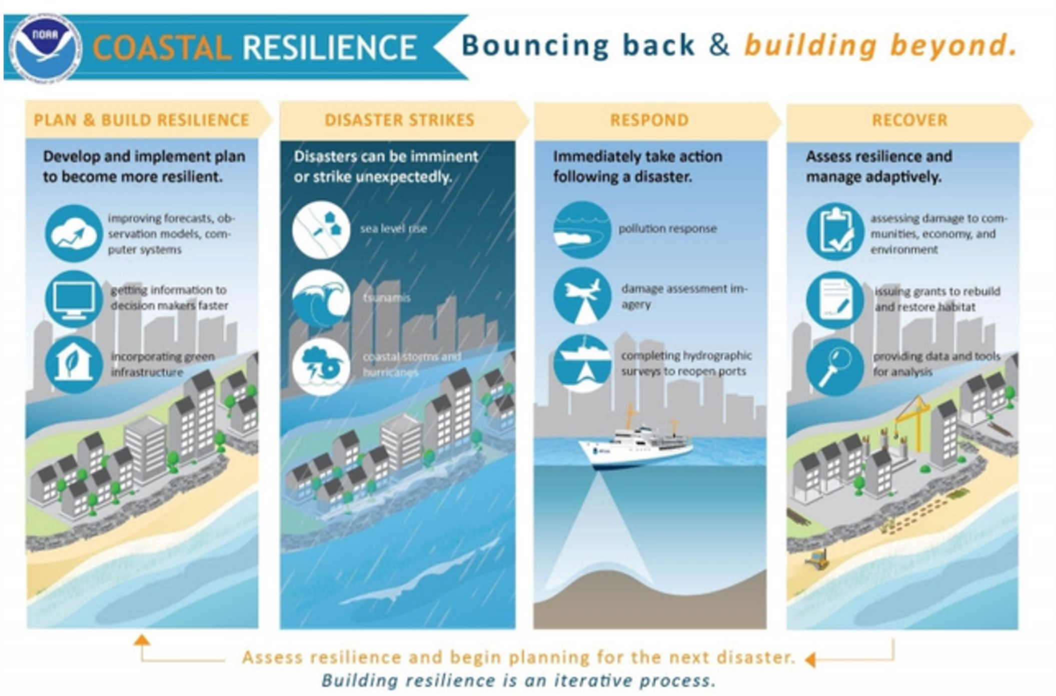


Figure 25. NOAA Coastal Resilience Graphic [28].

Riverine resilience focuses on restoring natural processes to help waterways adapt to climate change, reduce flood risk, and improve ecosystem health. Figure 26 highlights these markers of restoration, such as increasing channel sinuosity, reconnecting floodplains, restoring natural complexity, and reducing impervious surfaces. By allowing rivers to meander, creating space for floodwater storage, and incorporating green infrastructure, these approaches slow water flow, enhance watershed storage, and support wildlife habitats [29].

Figure 26. Slow the Flow for Climate Resilience Infographic [29].

2.2 Resilient Strategy Tables

The Resilient Strategy Tables, located in Appendix A, serve as a resource for identifying potential resilience starting points and for aligning strategies with budget constraints and infrastructure priorities. These tables can also help recognize common resilience themes that may be incorporated into engineering and public management practices. The strategies cover the eight infrastructure categories covered in Section 2.1.

A excerpt of the Roadways Table is shown below, categorizing strategies by whether it involves a new or existing asset, the level of construction required, operation and maintenance (O&M), project cost, and project savings. Additionally, resilience benefits are highlighted to show which challenges each strategy addresses. These strategies were selected based on infrastructure challenges identified through survey and interview research located in the thesis "*Enhancing Infrastructure Resilience: A Practical Framework For Georgia Local Government Implementation*", ensuring they directly target the gaps and needs of Georgia's local governments.

Strategy	Involves New or Existing Assets?	Reduces Pavement Cracking	Reduces Pothole Maintenance	Extends Asset Lifespan	Reduces Roadway Flooding	Level of Construction Required	O&M	Project Cost	Project Savings	Description of Resilience Benefits
Added geomats to shoulder for road stability	Existing			X	X	Medium	Low	$$	$$	Prevents pooling and stabilizes soil to improve drainage; distributes loads evenly
Extend shoulder lane on roadway for flood protection	New			X	X	High	Medium	$$$	$$	Improving stability; accommodates more traffic during emergencies; protects main lanes from flood effects

Figure 27. Excerpt of Roadway Resilience Strategy Table.

Rather than serving as a rigid blueprint, the tables should be viewed as a reference for integrating resilience into ongoing projects. Resilience is not limited to large-scale actions, and can be achieved through small adjustments in areas like maintenance, code enforcement, or smart monitoring.

Level of Construction Required

This category considers factors like levels of natural disturbance (grading, surface water flow, water quality, habitat conditions, deforestation, etc.), level of societal disturbances (traffic volume, noise disturbances, economic shifts), labor hours and intensity of labor, and specialized technology requirements. The low, medium, and high levels of construction are described below:

- **Low**: minimal labor and expertise, uses common technologies, and has little impact on the natural environment. Implementation is straightforward.

- **Medium**: Moderate level of labor that may require some specialized knowledge. Some natural disturbances. Remains feasible for most communities.

- **High**: Requires significant labor, advanced technologies, and specialized expertise. May involve major natural disturbances. Implementation is complex with many potential challenges.

Operation and Maintenance (O&M)

This category considers the long-term labor, resources, and expertise required to maintain a strategy over time. It includes factors such as routine upkeep, material durability, frequency of maintenance, and the need for specialized skills or technology. The low, medium, and high levels of operation and maintenance are described below:

- **Low:** Minimal labor and routine maintenance using readily available materials or technologies. Low-cost and simple to sustain.

- **Medium:** Moderate upkeep with some specialized skills or materials. Maintenance is more frequent but manageable.

- **High:** Significant labor, expertise, and costly materials required. Maintenance is frequent and resource-intensive.

Project Cost

This category considers the financial investment needed to implement a strategy, including material costs, labor, and contractor requirements. The low ($), medium ($$), and high ($$$) cost levels are described below:

- **$:** Little to no cost. Can be completed with internal resources and staff without contractor support.
- **$$:** Moderate cost and complexity. May require external funding and contractor assistance for implementation.
- **$$$:** High cost and complexity. Requires significant funding and one or more contractors to complete.

Project Savings

This category considers the potential cost savings over time from implementing a strategy. Savings may come from reduced maintenance, lower operational costs, extended infrastructure lifespan, or avoided damages and disruptions. The low ($), medium ($$), and high ($$$) cost savings levels are described below:

- **$:** Minimal cost savings. Any financial benefits are small or take a long time to materialize.
- **$$:** Moderate cost savings. Some reduction in long-term expenses, but upfront costs may still be significant.
- **$$$:** Significant cost savings. Leads to substantial long-term financial benefits, such as reduced maintenance, lower operational costs, or avoided major expenses.

Chapter 3: Implementing Resilience

The purpose of this chapter is to assist with navigating Appendix A: “Resilience Strategy Tables”. One of the biggest challenges in implementing resilience is that simply calling a project "resilient" is not enough to justify its value. Resilient infrastructure options often have higher upfront costs compared to conventional alternatives, but they provide long-term benefits by extending infrastructure lifespan and reducing future expenses. These benefits, such as economic development and improved community well-being, can be difficult to quantify.

The Decision Matrix is designed as an **exploration tool** to assign measurable values to these factors, giving decision-makers in local government a clearer understanding of resilience's financial and social impacts. It uses the Technical Strategy Tables and the Decision-Making Factors outlined in this chapter to guide decision-making.

Goals of the Decision Matrix:

- Provide a structured approach for evaluating resilience strategies based on cost, community impact, and long-term benefits.
- Offer a comparative tool to help decision-makers prioritize investments while considering real-world constraints.
- Encourage further research by serving as a reference point rather than a final determination, recognizing that every government has different needs and conditions.

This matrix is not meant to serve as a definitive answer, but rather as a tool to point decision-makers in the right direction. Since every government operates under different circumstances, the results should be used as a starting point for further technical research and evaluation.

3.1 Decision Matrix Factors

When evaluating resilient infrastructure strategies, decision makers must consider multiple factors to ensure the selected projects align with community needs, financial constraints, and long-term resilience planning. The decision matrix includes several primary evaluation criteria: time to implement the strategy, expected lifespan of the strategy, community impact, resilience impact, and weighting for each factor to reflect their relative importance. Each of these factors provides insight into a project's feasibility and potential benefits.

Weighting

Weighting assigns relative importance to each decision factor in this chapter, ensuring that the matrix aligns with specific project goals and priorities. While cost-effectiveness, community impact, and resilience impact each contribute to decision-making, different projects may require adjustments to reflect local priorities. The weighting process allows decision-makers to balance financial, social, and environmental factors to select the most effective resilience strategies for their community.

For example:

- If financial feasibility is a top concern, the cost-effectiveness factor may carry the highest weight.
- If social equity and public benefit are primary goals, the community impact factor may take precedence.
- If long-term sustainability is the focus, the resilience impact factor may receive the highest weighting.

Time to Implement

In the decision matrix, users will be asked to input the strategy's implementation timeline. The "time to implement" factor assesses the duration required to plan, approve, and execute the chosen strategy in accordance with their local processes and structure.

Key considerations include:

- Permitting & Approvals: Does the project require extensive regulatory review or environmental assessments?
- Funding & Procurement: Are funding sources readily available, or will it take time to secure grants/contracts?
- Construction & Deployment: Is implementation straightforward, or does it involve phased development over multiple years?

Expected Lifespan of Project

Users will also be asked to input the expected lifespan of the strategy, which will evaluate how long the strategy will remain effective before requiring major repairs, upgrades, or replacement.

Key considerations include:

- Material & Structural Durability: Will the project withstand wear, weather, and other stressors over time?
- Maintenance & Upkeep: Does the project require frequent repairs, or is it designed for long-term resilience with minimal intervention?
- Adaptability & Future-Proofing: Can the project accommodate future changes in climate, technology, or community needs?

Cost Effectiveness

The cost-effectiveness score assesses whether a project's financial benefits outweigh its costs, independent of resilience or co-benefits. This metric is calculated as:

(Project Savings x Expected Lifespan of Project) - (Project Cost x Time to Implement)

= Cost Effectiveness

A negative score (-8 to -1) indicates that the project cost exceeds its financial savings, making it a less viable investment from a purely economic standpoint. Conversely, a positive score (1 to 24) suggests that the financial savings surpass the project cost, demonstrating a favorable return on investment. This approach allows decision-makers to prioritize strategies that maximize financial efficiency while balancing other critical factors such as resilience and community benefits.

Community Impact

Community impact evaluates how a project affects residents, businesses, and local government operations. This factor considers elements such as public accessibility, social equity, economic benefits, and potential disruptions during implementation. A higher score indicates that the strategy provides broad, long-term benefits with minimal negative consequences, while a lower score suggests limited or even adverse community effects.

Key considerations include:

- Equity & Accessibility: Does the strategy benefit all residents, including underserved populations?

- Economic & Social Value: Will it create jobs, boost local businesses, or enhance quality of life?
- Disruptions & Acceptance: Does implementation require extensive closures, displacement, or public buy-in?

Resilience Impact

Resilience impact measures a project's ability to enhance long-term sustainability, adaptability, and preparedness against disturbances, both environmental and societal. This factor accounts for how well a strategy mitigates risks such as flooding, infrastructure degradation, or climate stressors. Higher scores reflect projects that significantly strengthen resilience and provide long-term benefits, whereas lower scores indicate minimal or short-term improvements.

Key considerations include:

- Risk Reduction: How effectively does the project mitigate hazards or prevent future costs?
- Longevity & Adaptability: Can the solution withstand evolving environmental and societal conditions?
- Co-benefits: Does the strategy enhance ecosystem services, improve public health, or support multi-use infrastructure?

3.2 Using the Decision Matrix

The decision matrix combines the understanding of technical, resilient strategies to improve local government infrastructure with the decision-making factors to allow users to explore, analyze, and quantify their options. In order to quantify resilience, corresponding values have been assigned to each factor based on user choice, as seen in Table 1.

Table 1. Corresponding Values for Decision Matrix Factors.

Factor	From Table	User Input	Corresponding Value
Project Cost	$ $$ $$$	-	1 2 3
Project Savings	$ $$ $$$	-	1 2 3
Time to Implement	-	<1 year 1-3 years 3+ years	1 3 5
Expected Lifespan of Project/Asset/Repair	-	0-3 years 3-10 years 10+ years	1 3 5
Resilience Benefit	-	Low Benefit Fair Benefit Moderate Benefit Good Benefit Excellent Benefit	1 2 3 4 5
Community Impact	-	Low Impact Fair Impact Moderate Impact Good Impact Excellent Impact	1 2 3 4 5

The final score calculation uses the cost effectiveness score (calculated), resilience benefits, community impact, and weights for each in accordance to the formula seen below:

$$(\text{Weight}_{cost} \times \text{Cost Effectiveness}) + (\text{Weight}_{resilience} \times \text{Resilience Benefits}) + (\text{Weight}_{community} \times \text{Community Impact})$$

$$= \text{Final Score}$$

The higher the score, the higher the indication of a resilience alternative suiting a community's specific needs, budget, timeline, and constraints. Appendix B contains the Excel spreadsheet with the Resilience Decision Matrix for Local Georgia Governments, and Appendix C contains an example that uses the matrix in order to weigh various resilience strategies for stormwater infrastructure.

Chapter 4: Resilience Resources

Funding is often the biggest obstacle to implementing resilient infrastructure projects. While many local governments recognize the need for resilience, limited budgets and competing priorities can make it difficult to take action. However, a variety of funding sources, grants, and technical assistance programs are available to support resilience efforts. This chapter provides an overview of key organizations, funding opportunities, and grant training resources that can help governments navigate the financial challenges of resilience planning. By connecting elected and city staff officials with these resources, the goal is to bridge the gap between identifying resilience needs and securing the means to address them.

4.1 Organization Profiles

There are many organizations geared towards assisting cities and counties with resilience project planning, with tools such as, but not limited to, technical expertise, funding, training, and emergency response support.

UNIVERSITY OF GEORGIA

Carl Vinson Institute of Government + Center for Continuing Education & Hotel

The Carl Vinson Institute and the Center for Continuing Education & Hotel offer continuing education support for Georgia's local governments, including a grant writing certificate, online grant writing courses, and a training course on formulating and administering a Capital Improvement Plan (CIP) [30].

Institute for Resilient Infrastructure Systems (IRIS)

IRIS collaborates with local governments to develop and implement solutions that address climate risks, aging infrastructure, and disaster resilience. The institute offers technical expertise, resources, and educational opportunities to support the development of sustainable, resilient infrastructure across Georgia and beyond [31].

RESOURCE FOR ASSISTANCE AND COMMUNITY TRAINING IN REGION 4 (REACT4)

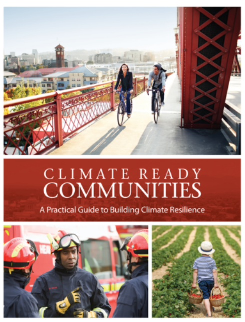
REACT4 is a Thriving Communities Technical Assistance Center — a federal initiative that assists local governments and non-profits working to address environmental issues. They provide training and technical support to help communities in EPA region 4 build up capacity and acquire funding [32].

GEORGIA MUNICIPAL ASSOCIATION (GMA)

The Georgia Municipal Association assists with strengthening Georgia's cities and their resilience by collaborating with elected officials and city staff. Their website contains recently published grants and awards with links, deadlines, and grantor information, which include resilience-related grants like the Community Wildfire Defense Grant [33].

GEORGIA ASSOCIATION OF REGIONAL COMMISSIONS (GARC)

The GARC supports resilience-building by assisting local governments with securing funding for infrastructure, hazard mitigation, and climate adaptation projects. Their GIS mapping services help with spatial planning for flood risk, transportation resilience, and environmental protection. Training resources are available to help build local capacity to manage and execute resilience projects [34].



CLIMATE READY COMMUNITIES & GEOS INSTITUTE

Climate Ready Communities helps small to medium-sized communities develop climate resilience plans using their step-by-step framework, the "Practical Guide to Building Climate Resilience." They also provide additional resources, including climate projections, workshop facilitation, report writing assistance, and training opportunities [35].

GA EMERGENCY MANAGEMENT AND HOMELAND SECURITY AGENCY (GEMA)

GEMA administers federally funded grant programs, including the Building Resilient Infrastructure & Communities Program, Pre-Disaster Mitigation Program, Flood Mitigation Assistance Program, and Hazard Mitigation Grant Program. GEMA also provides public assistance and infrastructure support to areas affected by state or federally declared emergencies, with eligibility determined through the Private Non-Profit Questionnaire for facilities seeking assistance [36].

GA DEPARTMENT OF COMMUNITY AFFAIRS (DCA)

DCA provides community and economic development financing, housing financing and technical assistance for community development throughout the state. The organization has produced guidance for community disaster resilience and administers funding associated with resilience and hazard mitigation planning [37].

4.2 Funding Profiles

Securing funding is a critical step in implementing resilient infrastructure projects. This section provides an overview of various funding programs and mechanisms available to support resilience initiatives, infrastructure improvements, and disaster preparedness. Each profile highlights the funding source, any eligibility requirements, and the specific opportunities for resilience that the program supports. These funding sources can help local governments and organizations invest in long-term, sustainable solutions that enhance community resilience and adaptability.

Community Facilities Direct Loan & Grant Program in GA

Provides direct loan or grant approvals to develop essential community facilities in rural areas, such as hospitals, clinics, town halls, courthouses, fire departments, libraries, and more. Cities and towns may not have more than 20,000 people to be eligible. Requires environmental review [38].

Funding Allocated by: USDA - Rural Development
Opportunity for Resilience: Public building infrastructure improvements, environmental impact.
Key words: Community facility, Essential facility, Rural
Link: https://www.rd.usda.gov/programs-services/community-facilities/community-facilities-direct-loan-grant-program-15

Promoting Resilient Operations for Transformative, Efficient, and Cost-saving Transportation Program (PROTECT)

Provides funding to ensure surface transportation resilience to natural hazards through support of support of planning activities, natural infrastructure, flood mitigation, community resilience and evacuation routes, and at-risk coastal infrastructure. Requires benefit-cost analysis [39].

Funding Allocated by: U.S. DOT / FHWA & GDOT
Opportunity for Resilience: Prioritizes nature-based solutions and emergency preparedness
Key words: Transportation resilience, Emergency preparedness
Link: https://www.fhwa.dot.gov/infrastructure-investment-and-jobs-act/protect_fact_sheet.cfm

---

Community Development Block Grant Disaster Recovery (CDBG-DR)

Provides funding to rebuild disaster-impacted areas (from Presidentially declared disasters) and provide crucial seed money to start the long-term recovery process, especially in low-income areas. HUD notifies states, cities, and counties of their eligibility to apply for funding, which is allocated based on unmet recovery needs. Must create a disaster recovery web page, action plan approval, environmental reviews, and grant agreement with HUD before funding can be used [40].

Funding Allocated by: U.S. HUD, Administered by GA DCA
Opportunity for Resilience: Infrastructure improvements, flood mitigation, community preparedness.
Key words: Disaster recovery, federal disaster, low-income areas
Link: https://www.hud.gov/program_offices/comm_planning/cdbg-dr

Community Development Block Grant Mitigation (CDBG-MIT)

Provides funding to high-impact activities to increase resilience to disasters and lessen their future impact on life and property. Mitigation efforts must align with other federal programs that address hazard mitigation. Selected based on projects that effectively address low- and moderate-income people [41].

Funding Allocated by: U.S. HUD, Administered by GA DCA
Opportunity for Resilience: Property protection, hazard mitigation planning, capacity building, public/private partnerships
Key words: Hazard mitigation, low-income areas
Link: https://www.hud.gov/program_offices/comm_planning/cdbg-dr/cdbg-mit

---

Special Purpose Local Option Sales Tax (SPLOST)

One percent county or qualified municipal government sales tax, voted on by a community, that is used to fund a capital outlay project or capital improvement plan (CIP). Examples of acceptable use of SPLOST funding include projects involving roads, streets, bridges, stormwater and drainage, and natural disaster damage. SPLOST and Transportation SPLOST (T-SPLOST) are widely used throughout Georgia for infrastructure improvements. Resilient strategies can easily be integrated into a CIP [42].

Funding Allocated by: Sales tax within county, municipality, or defined “special district”
Opportunity for Resilience: General public infrastructure improvements that incorporate technical resilient strategies.
Key words: Capital improvements, public facilities, community development, resilient transportation
Link: https://accg.org/library/legal/SPLOST%202016.pdf

Building Resilient Infrastructure and Communities (BRIC)

Provides funds to states, territories, tribal governments and communities for hazard mitigation planning and the implementation of mitigation projects before a disaster event occurs. Applicants must be in good standing with the National Flood Insurance Program and must have an active FEMA approved Hazard Mitigation Plan [43].

Funding Allocated by: GEMA
Opportunity for Resilience: Disaster risk reduction, hazard mitigation planning
Link: https://gema.georgia.gov/bric

Local Maintenance and Improvement Grant

Allocated based on total centerline road miles for a local road system and the total population of a city/county as a proportion of total state centerline miles and state population. Acceptable activities include preliminary engineering, roadway resurfacing, grading and drainage, storm drain replacement, dirt road maintenance, and intersection improvements. Cities/counties are responsible for 10% or 30% match depending on region. Preconstruction activities are the responsibility of the local government [44].

Funding Allocated by: GDOT
Opportunity for Resilience: Integration of resilience measures into routine roadway projects. Projects are able to provide co-benefits to stormwater infrastructure.
Key words: Preventative maintenance, roadway durability, resilient roadways.
Link: https://www.dot.ga.gov/GDOT/Pages/LMIG.aspx

Environmental Justice Thriving Communities Grantmaking (TCGM) Program

Provides funding and assistance to underserved communities to support the planning, assessment, and development of community-based projects and alleviate the burdens associated with traditional federal grants. No cost matching or sharing requirement [45].

Funding Allocated by: EPA and Cultivating Healthy Environments
Opportunity for Resilience: Reduces administrative and planning burdens for resilience-building community projects.
Key words: TCGM, Federal grant assistance, Technical assistance, Grant management, Underserved communities
Link: https://region4.thrivingenvironments.org/about/

4.3 Funding Administration Training

This section outlines various grant writing and infrastructure funding training and workshop opportunities that equip local governments with the skills needed to develop strong proposals, navigate funding requirements, and successfully obtain financial support for resilience initiatives. These resources provide essential guidance on proposal writing, grant management, and state and federal application processes.

Table 2. Funding Administration Training Information.

Author / Publisher	Title	Description
Writing for Green	REACT4 Cohort 1: Training Session Recordings [46]	A series of recordings of Writing for Green's grant writing course via Youtube.
U.S. DOT Technical Assistance Resources	DOT Navigator [47]	A databased to help communities understand the DOT grant application process and execute projects. Includes webinars, funding opportunities, technical assistance resources, and data and mapping tools.
GEMA	GEMA Hazard Mitigation Planning Webinar [48]	A webinar that introduces the various grants offered by GEMA.
EPA	EPA Grants Management Training Webinars [49]	Online training course designed to introduce EPA grant applicants and recipients to core elements of EPA's grant process, from application to closeout.
Local Infrastructure Hub & National League of Cities	Grant Application Bootcamp [50]	Geared towards small and mid-sized municipalities. Suite of trainings and supports to develop strong, competitive grant applications through free technical training and grant-writing Bootcamps.
Carl Vinson Institute of Government | GA Center for Continuing Education & Hotel	Capital Improvement Plan (CIP) Training [51]	Online, self-paced course for government employees. It will give an overview and importance of the CIP process, budget policy, prioritizing requests, funding options in the CIP. NASBA approved course
American Society of Adaptation Professional	Ready-to-Fund Resilience Toolkit [52]	Self-guided resource for local government staff and the supporting technical assistance providers to secure investment for climate resilience projects. Helps users overcome lack of funding, lack of resources, political will, or community will.
HUD Exchange	CDBG-DR Problem Solving Clinic [53]	Training recordings for CDBG-DR and CDBG-MIT grantees to improve funding administration and allocation. Includes (but is not limited to) webinars on utilizing funds for climate services, flood insurance, housing resilience, and emergency preparedness

Appendix

Appendix A: Resilient Strategy Tables

Stormwater

			Benefits of Strategy								
	Strategy	Involves New or Existing Assets?	Mitigates Flood Risk	Increases Operational Efficiency	Improves Emergency Preparedness	Extends Asset Lifespan	Level of Construction Required	O&M	Project Cost	Project Savings	Description of Resilience Benefis
Resilient Strategies	GIS-based asset mapping and digitization of pipe infrastructure	Existing		X	X		Low	Low	$$	$$	Allows for better planning, tracking, and maintenance of overall system and its assets
	Installing flow meters/sensors within stormwater network for flow monitoring	New	X	X	X		Medium	Low	$$	$$$	Provides real-time data for maintenance and system performance purposes
	Regularly scheduled storm drain cleaning and inspection	Existing	X	X		X	Low	Medium	$	$$	Ensures water flows freely and prevents localized flooding
	Smoke testing for leak and blockage detection	Existing	X	X			Low	Low	$	$$	Detects leaks causing inflow/infiltration and promotes system resilience during wet-weather
	Installing backup/redundant pump systems	New	X	X	X	X	High	Medium	$$$	$$$	Provides redundancy during extreme conditions and prevents system failure
	Vegetated swales for runoff attenuation and reduction	New	X	X		X	Medium	Medium	$$	$$$	Improves stormwater retention and absorption while reducing burden on conventional systems
	Trenchless lateral pipe repairs	Existing	X	X		X	Low	Low	$$	$$	Minimizes disruptions to stormwater system and natural environment during maintenance
	Property buyouts for floodplain reconnection	Existing	X			X	High	Low	$$$	$$$	Restores natural flow of water in floodplains and reduces damage to properties and infrastructure

Stormwater Strategies continue on following page

Stormwater, Cont.

			Benefits of Strategy								
	Strategy	Involves New or Existing Assets?	Mitigates Flood Risk	Increases Operational Efficiency	Improves Emergency Preparedness	Extends Asset Lifespan	Level of Construction Required	O&M	Project Cost	Project Savings	Description of Resilience Benefis
Benchmark Strategies	Open-cut trench excavation for pipe repairs	Existing					Medium	Medium	$$	$	No additional resilience benefits from traditional methods.
	Conventional hardscaped drainage channels (concrete/asphalt)	New					Low	Low	$	$	No additional resilience benefits from traditional methods.
	Emergency response via government staff to address blockages or flooding	Existing					Low	High	$	$	No additional resilience benefits from traditional methods.
	Reactive drainage system cleaning and inspection	Existing					Low	Medium	$	$	No additional resilience benefits from traditional methods.

Roadways

			Benefits of Strategy								
	Strategy	Involves New or Existing Assets?	Reduces Pavement Cracking	Reduces Pothole Maintenance	Extends Asset Lifespan	Reduces Roadway Flooding	Level of Construction Required	O&M	Project Cost	Project Savings	Description of Resilience Benefis
Resilient Strategies	Added geomats to shoulder for road stability	Existing			X	X	Medium	Low	$$	$$	Prevents pooling and stabilizes soil to improve drainage; distributes loads evenly
	Extend shoulder lane on roadway for flood protection	New			X	X	High	Medium	$$$	$$	Improving stability; accommodates more traffic during emergencies; protects main lanes from flood effects
	Using a rejuvenator for asphalt preservation	Existing	X	X	X		Low	Low	$	$$	Restores flexibility and durability to extend pavement lifespan
	Using a rejuvenator in recycled asphalt mixture	Existing	X	X	X		Medium	Low	$$	$$	Adds flexibility and durability, making recycled asphalt mixture comparable to virgin asphalt.
	Open-graded intercourse layer for improved roadway drainage	New	X	X	X	X	High	Medium	$$$	$$	Reduces runoff and flooding by allowing water to pass through pavement
	Reinforcement with advanced polymer-modified asphalt	Existing	X	X	X		Medium	Low	$$	$$	Increases resistance to wear, temperature changes, and weather conditions
	Geotextile fabric reinforcement for road stability	New	X	X	X	X	Medium	Low	$$	$$	Improves stability by reinforcing underlying soil layers
	Stormwater detention near flood-prone roadways	New			X	X	High	Medium	$$$	$$$	Manages excess water to reduce flooding effects on nearby roadways

Roadway Strategies continue on following page

Roadways, Cont.

	Strategy	Involves New or Existing Assets?	Benefits of Strategy: Reduces Pavement Cracking	Benefits of Strategy: Reduces Pothole Maintenance	Benefits of Strategy: Extends Asset Lifespan	Benefits of Strategy: Reduces Roadway Flooding	Level of Construction Required	O&M	Project Cost	Project Savings	Description of Resilience Benefis
Resilient Strategies	Bioretention cells for stormwater diversion and/or collection	New			X	X	Medium	Medium	$$	$$	Mitigates pooling, flooding, and water damage on roadway; dissipates roadway heat; provides habitat
Benchmark Strategies	Mill and fill road resurfacing	Existing					High	Medium	$$$	$$	No additional resilience benefits from traditional methods.
	Increase Roadway Elevation	Existing					High	Medium	$$$	$$	No additional resilience benefits from traditional methods.
	Standard pothole patching	Existing					Low	Medium	$	$	No additional resilience benefits from traditional methods.

Bridges

			Benefits of Strategy								
	Strategy	Involves New or Existing Assets?	Improves Water Flow Management	Increases Structural Stability	Reduces Erosion and Scour	Extends Asset Lifespan	Level of Construction Required	O&M	Project Cost	Project Savings	Description of Resilience Benefits
Resilient Strategies	Gabion mattresses for stream erosion prevention	Existing	X		X	X	Medium	Low	$$	$$$	Protects foundations from scour and erosion while enforcing embankments; dissipates energy in high-flow events
	Reticulated piles for ground reinforcement	Existing		X		X	High	Low	$$	$$$	Improves load-bearing capacity and stabilizes soil to prevent settlement and structural failure
	Soil nails for slope stabilization	Existing		X	X	X	Medium	Low	$$	$$	Reinforces slopes to prevent landslides and erosion near load-bearing bridge structures
	Column reinforcement with glass FRP wrap	Existing	X			X	Medium	Low	$$	$$$	Reinfroces existing columns by increasing resistance to corrosion and cracking
	Nearby Low Water Crossings for overtopping prevention	New	X	X	X	X	High	Medium	$$$	$$$	Allowing controlled water passage to prevent overtopping; diverting excess runoff
	Ultra-high performance concrete overlay on deck	Existing		X		X	Medium	Medium	$$	$$	Protective layer reduces cracking and infiltration; increasing freeze-thaw cycle resistance
	Stainless steel retrofits on piers for vortex prevention	Existing	X	X	X	X	Medium	Low	$$	$$	Mitigates vortex effects that cause vibration, material degradation and structural instability
Benchmark Strategies	Concrete or stone armoring on abutments or piers	Existing					Medium	Medium	$$	$	No additional resilience benefits from traditional methods.

Bridge Strategies continue on following page

Bridges, Cont.

			Benefits of Strategy								
	Strategy	Involves New or Existing Assets?	Improves Water Flow Management	Increases Structural Stability	Reduces Erosion and Scour	Extends Asset Lifespan	Level of Construction Required	O&M	Project Cost	Project Savings	Description of Resilience Benefis
Benchmark Strategies	Articulated concrete block revetment systems	Existing					Medium	Low	$$	$$	No additional resilience benefits from traditional methods.
	Asphalt overlay with membrane on deck	Existing					Medium	Medium	$	$	No additional resilience benefits from traditional methods.

Public Buildings

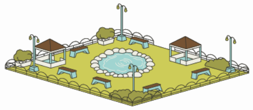
			Benefits of Strategy								
	Strategy	Involves New or Existing Assets?	Reduces Leaks and Infiltration	Maximizes Existing Built Space	Improves Heating/Cooling Efficiencies	Extends Asset Lifespan	Level of Construction Required	O&M	Project Cost	Project Savings	Description of Resilience Benefis
Resilient Strategies	Vegetated swales in parking lot for runoff reduction	New			X	X	Low	Low	$	$$$	Ensures new building construction meet the latest safety, energy efficiency, and environmental standards
	Including rainscreens in siding construction for moisture control	Existing	X		X	X	Medium	Low	$$	$$	Improves building performance by reducing moisture intrusion and increasing thermal efficiency
	Prefabricated, insulated panels installed over existing building façade	Existing	X		X	X	Low	Low	$	$$	Identifies energy inefficiencies and low-cost improvements to reduce expenditures and environmental impact
	Apply high-reflectivity coatings on roofs	Existing			X	X	Low	Low	$	$$	Improves building cooling efficiency and reduces urban heat island effect
	Extend roof eaves above windows and doors to reduce leaking	New	X		X	X	Medium	Low	$$	$$	Improves energy efficiency and sustainability by mimicking natural processes, reduces carbon footprint of overall building life cycle
	Repurposing or reconfiguring existing, underutilized space	Existing		X		X	Low	Low	$	$$	Reduces the need for building expansion/construction by maximizing on existing space
	Roof Slope re-design with added rain capture device	Existing	X			X	Medium	Medium	$$$	$$	Improves roof drainage and re-captures rainwater for detention or potential reuse
Benchmark Strategies	Replace HVAC & Energy Systems as they fail	New					Low	High	$$	$	No additional resilience benefits from traditional methods.

Public Building Strategies continue on following page

Public Buildings, Cont.

			Benefits of Strategy								
	Strategy	Involves New or Existing Assets?	Reduces Leaks and Infiltration	Maximizes Existing Built Space	Improves Heating/Cooling Efficiencies	Extends Asset Lifespan	Level of Construction Required	O&M	Project Cost	Project Savings	Description of Resilience Benefis
Benchmark Strategies	Install basic eaves for moderate weather protection	Existing					Medium	Medium	$$	$	No additional resilience benefits from traditional methods.
	Routine drainage system inspection	Existing					Low	Low	$	$	No additional resilience benefits from traditional methods.

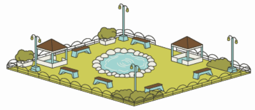
Public Parks



			Benefits of Strategy								
	Strategy	Involves New or Existing Assets?	Improves Stormwater Management	Extends Asset Lifespan	Improves Lighting	Increases Ecological Benefits	Level of Construction Required	O&M	Project Cost	Project Savings	Description of Resilience Benefis
Resilient Strategies	Minor grading/re-grading of areas and trails with poor drainage	Existing	X	X			Low	Low	$	$	Reduces standing water; improves drainage and accessibility to park users
	Check dams for erosion control and peak flow attenuation	New	X	X		X	Low	Low	$	$	Attenuates peak flows; prevents erosion; increases groundwater infiltration; creates small habitats
	Changes to vegetation mulching, and soil management practices	Existing	X	X		X	Low	Low	$$	$$	Manages drainage issues; enhances soil health that promotes plant growth
	Deploy sandbags or modular flood barriers in poorly drained or flood-prone areas	Existing	X	X			Low	Medium	$	$$	Provides temporary flood protection; minimizes infrastructure damage; preserves park usability during heavy rainfall
	Asphalt replacement with permeable gravel and/or pavers	New	X	X			High	Medium	$$$	$$$	Reduces surface runoff; improves groundwater recharge; increases resilience against storm events
	Rainwater capture and non-potable reuse system	New	X	X			Medium	Medium	$$	$$	Maximizes water efficiency within the park; reduces reliance on public water supply
	Underground stormwater storage cistern	New	X	X			High	High	$$$	$$$	Maximizes park usability; preserves and protects park infrastructure from flooding

Public Park Strategies continue on following page

Public Parks, Cont.



			Benefits of Strategy								
	Strategy	Involves New or Existing Assets?	Improves Stormwater Management	Extends Asset Lifespan	Improves Lighting	Increases Ecological Benefits	Level of Construction Required	O&M	Project Cost	Project Savings	Description of Resilience Benefis
Resilient Strategies	Solar-powered pathway lighting	New			X		Low	Medium	$	$	Ensures lighting during power outages; reduces energy costs; improves park safety and accessibility
Benchmark Strategies	Install traditional storm drains in park areas	New					Medium	Medium	$$	$	No additional resilience benefits from traditional methods.
	Using incandescent or CFL bulbs	Existing					Low	Low	$	$	No additional resilience benefits from traditional methods.
	Construct above-ground detention ponds for stormwater detention	New					High	Medium	$$$	$$	No additional resilience benefits from traditional methods.

Drinking Water Treatment and Distribution

			Benefits of Strategy								
	Strategy	Involves New or Existing Assets?	Improves Operational Efficiency	Improves Water Quality	Improves Emergency Preparedness	Extends Asset Lifespan	Level of Construction Required	O&M	Project Cost	Project Savings	Description of Resilience Benefits
Resilient Strategies	Installing backup power systems at treatment plant	New			X		Medium	Low	$$	$$$	Ensures continuity of service during emergencies and power disruptions
	GIS-based asset mapping and digitization of distribution network infrastructure	Existing	X		X		Low	Low	$$	$$	Allows for better planning, tracking, and maintenance of overall system and its parts
	Maintaining sufficient backup chemical inventories	Existing			X		Low	Low	$	$$	Ensures continuity of service during supply chain disruptions
	Weatherizing residential water connections	Existing	X		X	X	Low	Low	$	$	Prevents freeze-thaw damage; reduces water loss; protects infrastructure
	Conduct smoke testing for leak and defect detection	Existing	X			X	Low	Low	$	$$	Reduces water loss; preserves system distribution capacity
	Pressure sensors and automated valves for line pressure and water loss maintenance	New	X	X	X	X	Medium	Low	$$	$$	Identify performance inefficiencies; minimizes water loss
	Trenchless lateral repairs for water mains	Existing	X	X		X	Medium	Low	$$	$$	Extends lifespan of water mains and surrounding infrastructure; minimizes construction disturbance
	Construction of smaller, decentralized treatment facilities	New	X	X	X	X	High	High	$$$	$$$	Reduces reliance on single treatment facility; Increases system redundancy

Drinking Water Treatment and Distribution Strategies continue on following page

Drinking Water Treatment and Distribution, Cont.

			Benefits of Strategy								
	Strategy	Involves New or Existing Assets?	Improves Operational Efficiency	Improves Water Quality	Improves Emergency Preparedness	Extends Asset Lifespan	Level of Construction Required	O&M	Project Cost	Project Savings	Description of Resilience Benefis
Benchmark Strategies	Open-cut trench excavation for pipe repairs	Existing					Medium	Medium	$$	$	No additional resilience benefits from traditional methods.
	Using emergency water trucking for water source during outages	Existing					Low	Low	$	$	No additional resilience benefits from traditional methods.
	Basic/infrequent valve exercising schedule	Existing					Low	Low	$	$	No additional resilience benefits from traditional methods.

Wastewater Treatment and Collection

			Benefits of Strategy								
	Strategy	Involves New or Existing Assets?	Reduces Flooding or CSO Effects	Reduces I/I	Improves Emergency Preparedness	Extends Asset Lifespan	Level of Construction Required	O&M	Project Cost	Project Savings	Description of Resilience Benefis
Resilient Strategies	Emergency Backup and Bypass Pumping Systems	New	X		X	X	High	Low	$$$	$$	Provides redundancy during extreme conditions and prevents system failure
	Bioretention Basins and Vegetated Bioswales for CSO Control	New	X	X		X	Medium	Medium	$$	$$	Reduces effects of CSO by reducing the risk of high stormwater flows combining with sewer systems
	Trenchless Sewer Pipe Rehabilitation	Existing	X	X		X	Medium	Low	$$	$$$	Preserves existing infrastructure; reduces surface disruption; minimizes community impact.
	Constructed Wetlands for Overflow Management	New	X	X	X		High	Low	$$$	$$	Provides natural treatment for overflow events; mitigates flood risks while enhancing biodiversity
	Smoke Testing for Leak and Defect Detection	Existing		X		X	Low	Low	$	$$	Helps identify leaks and reduce infiltration; preserves sewer capacity
	Installing Emergency Standby Generators at Treatment Plant	New			X	X	Low	Low	$	$$	Ensures functionality during power outages and continuity of service
	Constructing Smaller, Decentralized WW Treatment Systems	New	X	X	X	X	High	High	$$$	$$$	Reduces dependency on centralized systems during extreme weather; provides more local surface water replenishment

Wastewater Treatment and Collection Strategies continue on following page

Wastewater Treatment and Collection, Cont.

			Benefits of Strategy								
	Strategy	Involves New or Existing Assets?	Reduces Flooding or CSO Effects	Reduces I/I	Improves Emergency Preparedness	Extends Asset Lifespan	Level of Construction Required	O&M	Project Cost	Project Savings	Description of Resilience Benefis
Resilient Strategies	Implementing Large-Scale Greywater Reuse System	New	X		X		High	Medium	$$$	$$$	Reduces wastewater volume by reusing water for irrigation or non-potable needs
Benchmark Strategies	Open-cut trench excavation for pipe repairs	Existing					Medium	Medium	$$	$	No additional resilience benefits from traditional methods.
	Using emergency water trucking for water source during outages	Existing					Low	Low	$	$	No additional resilience benefits from traditional methods.
	Basic/infrequent valve exercising schedule	Existing					Low	Low	$	$	No additional resilience benefits from traditional methods.

Coastal and Riverine Protection

			Benefits of Strategy								
	Strategy	Involves New or Existing Assets?	Protects Critical Infrastructure	Reduces Flood Risk	Enhances Water Flow Management	Provides Environmental Benefits	Level of Construction Required	O&M	Project Cost	Project Savings	Description of Resilience Benefis
Resilient Strategies	Bank vegetation and seeding for soil and riverbank stabilization	Existing		X	X	X	Low	Low	$	$$	Provides lowland habitat; stabilizes soil and bank structures; provides aesthetic benefits
	Living Shoreline construction on coastal edge	New Asset	X	X	X	X	Medium	Low	$$	$$$	Stabilizes shorelines; reduces erosion; provides wildlife habitat
	Installing duckbill check valve at the end of pipe outfall	Existing	X	X	X		Low	Medium	$	$$	Autonomous technology; effective at reducing tidal flooding and compound flooding severity
	Seawall Retrofit with Recurve Wall	Existing	X	X			Medium	Medium	$$$	$$	Reducing wave overtopping; preventing obstruction of ocean view; reduces construction disturbance and environmental impacts
	Tieback Anchors for Seawall or Bulkhead Reinforcement	Existing	X	X			Medium	Medium	$$	$$$	Stabilizes seawalls and bulkheads to prevent failure and increase structural longevity.
	Riparian Buffers for Floodplain Restoration	New	X	X	X	X	Medium	Low	$$$	$$	Improves water quality and wildlife habitat; slows and stores flood waters
	Temporary Flood Barriers	Existing	X	X			Low	Low	$	$	Provides rapid deployment flood protection during emergencies.
	Addition of in-stream structure to alter flows away from eroding banks	Existing	X	X	X		High	Medium	$$$	$$	Protect streambanks from high, eroding flows on the toe of the bank

Coastal and Riverine Protection Strategies continue on following page

Coastal and Riverine Protection, Cont.

			Benefits of Strategy								
	Strategy	Involves New or Existing Assets?	Protects Critical Infrastructure	Reduces Flood Risk	Enhances Water Flow Management	Provides Environmental Benefits	Level of Construction Required	O&M	Project Cost	Project Savings	Description of Resilience Benefis
Benchmark Strategies	Coastal gated storm surge barriers	New					High	Medium	$$$	$$$	No additional resilience benefits from traditional methods.
	Groin structures to intercept parallel-moving water and sand	New					Medium	High	$$$	$$	No additional resilience benefits from traditional methods.
	Earthen levee	New					Medium	High	$$	$$	No additional resilience benefits from traditional methods.
	Rock seawall for storm surge flood prevention	New					High	Medium	$$$	$$	No additional resilience benefits from traditional methods.

Appendix B: Resilience Decision Matrix Spreadsheet

OneDrive Link to Excel File:

https://outlookuga-
my.sharepoint.com/:f:/g/personal/elt70605_uga_edu/Em8VXR
VzeaVKvyjcErJe1R0B2kVI4Xs2MfUjb36K6wo9mg?e=HLfGPj

Appendix C: Example Use of Decision Matrix

Introduction:

Sheila is a Public Works Director in a city in northwest Georgia with a population of 18,000. She is interested in weighing her options with stormwater strategies to make her stormwater management system more resilient in the face of more frequent, intense weather events. Additionally, a nearby river is experiencing an increasing frequency of high water and flood events. She wants to reduce runoff volume and flood occurrence. She is interested in increasing operational efficiencies in the stormwater system while also providing ecosystem protection.

Process:

Step 1: Choose Categories and Number of Alternatives

After taking stock of the infrastructure categories in the spreadsheet, Sheila decides she wants to compare three alternatives, all within the stormwater category.

The 8 categories to choose from are:

Stormwater	Roadways	Public Buildings	Public Parks	DW Treatment & Distribution	WW Treatment & Collection	Flood Protection Infrastructure	No Selection

Select Category for Alternative 1	Stormwater
Select Category for Alternative 2	Stormwater
Select Category for Alternative 3	Stormwater
Select Category for Alternative 4	No Selection
Select Category for Alternative 5	No Selection

Step 2: Selecting Specific Resilience Strategies

Sheila selects the following three strategies, one "traditional" and two "resilient", to dig further in to:

1. Conventional hardscaped drainage channels (concrete asphalt) – Traditional strategy to use to convey stormwater runoff into storm drain system
2. Property buyout for floodplain reconnection – Buying out private property near the river to increase floodplain area
3. Vegetated swales for runoff attenuation and reduction – Constructing bioswales adjacent to major roadway to reduce runoff volume and flow rate to river

Select Resilience Strategy for Alternative 1	Conventional hardscaped drainage channels (concrete/asphalt)
Select Resilience Strategy for Alternative 2	Property buyouts for floodplain reconnection
Select Resilience Strategy for Alternative 3	Vegetated swales for runoff attenuation and reduction
Select Resilience Strategy for Alternative 4	
Select Resilience Strategy for Alternative 5	

Step 3. Estimating Implementation Timeline

Sheila's options are: <1 year, 1-3 years, or 3+ years.

1. Conventional hardscaped drainage channels (concrete asphalt): 1-3 years – Requires site-specific design and permitting
2. Property buyout for floodplain reconnection: 3+ years – Requires funding, property acquisition, and community coordination
3. Vegetated swales for runoff attenuation and reduction: 1-3 years – Requires site-specific design and permitting

Step 4. Estimating Project Lifespan

Sheila's options are: 0-3 years, 3-10 years, or 10+ years.

1. Conventional hardscaped drainage channels (concrete asphalt): 10+ years – Permanent solution that requires frequent maintenance
2. Property buyout for floodplain reconnection: 10+ years – Permanent flood risk reduction once completed
3. Vegetated swales for runoff attenuation and reduction: 10+ years – Sustainable and self-maintaining with proper upkeep

Now, a cost effectiveness score is calculated with the data input and the data from the tables.

(Project Savings x Expected Lifespan of Project) - (Project Cost x Time to Implement)
= Cost Effectiveness

	Project Cost From Table	Corresponding Value to Project Cost	Project Savings From Table	Corresponding Value to Project Savings	Time to Implement Project	Corresponding Value to Project Implementation Timeline	Expected Lifespan of Project/Asset/Repair	Corresponding Value to Expected Lifespan	Cost Effectiveness Score
Alternative 1	$$	2	$	1	1-3 years	3	10+ years	5	-1
Alternative 2	$$$	3	$$$	3	3+ years	5	10+ years	5	0
Alternative 3	$$	2	$$$	3	1-3 years	3	10+ years	5	9
Alternative 4	FALSE	0	FALSE	0		0		0	0
Alternative 5	FALSE	0	FALSE	0		0		0	0

Step 5. Assessing Resilience Benefits

Sheila evaluates each strategy's ability to mitigate stormwater related-risks and how she values the resilience benefits listed in the Excel table.

- Conventional hardscaped drainage channels (concrete asphalt): 1/5 – Conveys runoff quickly to storm sewers without any added resilience benefits
- Property buyout for floodplain reconnection: 5/5 – Restores natural flow of water in floodplains and reduces damage to properties and infrastructure
- Vegetated swales for runoff attenuation and reduction: 4/5 – Improves stormwater retention and absorption while reducing burden on conventional systems

Step 6. Assessing Community Impacts

Sheila evaluates each strategy's impact on residents, businesses, and quality of life.

1. Conventional hardscaped drainage channels (concrete asphalt): 2/5 – Construction will be disruptive but will achieve standard conveyance goals.
2. Property buyout for floodplain reconnection: 4/5 – Protects vulnerable residents but requires relocation, which can be disruptive
3. Vegetated swales for runoff attenuation and reduction: 5/5 – Enhances public spaces, improves aesthetics, and provides co-benefits like heat reduction and water quality improvement

	Resilience Benefit	Corresponding Value	Community Impact	Corresponding Value
Alternative 1	Low Benefit/Impact	1	Fair Benefit/Impact	2
Alternative 2	Excellent Benefit/Impact	5	Good Benefit/Impact	4
Alternative 3	Good Benefit/Impact	4	Excellent Benefit/Impact	5
Alternative 4		#N/A		#N/A
Alternative 5		#N/A		#N/A

Step 7. Assigning Weights to Decision Factors

Sheila wants to prioritize solutions with high long-term payoffs while ensuring that community well-being is central to decision-making. She determines the relative importance of evaluation criteria:

- Cost effectiveness: 3 – Must ensure long-term return on investment
- Resilience benefits: 1 – Important, but balanced against cost and feasibility
- Community impact: 2 – Prioritizes benefits for residents and businesses

	Weight
Cost Effectiveness	3
Resilience Benefit	1
Community Impact	2

Step 8. Score Review

Conventional hardscaped drainage channels (concrete/asphalt)		Property buyouts for floodplain reconnection		Vegetated swales for runoff attenuation and reduction	
Value	Weighted Score	Value	Weighted Score	Value	Weighted Score
-1	-3	0	0	9	27
1	1	5	5	4	4
2	4	4	8	5	10
Total Score	2	Total Score	13	Total Score	41

Final Scores	Final Rankings	Strategy
2	3	Conventional hardscaped drainage channels (concrete/asphalt)
13	2	Property buyouts for floodplain reconnection
41	1	Vegetated swales for runoff attenuation and reduction

Sheila will use the results of this matrix as an indicator that pursuing vegetated swales may be a good option for her city's stormwater system, flooding issues, and overall public benefit.

Step 9. Re-evaluation of Score

During a town council meeting, Sheila presents the proposed stormwater strategies for consideration. Feedback from council members, staff, and the public prompts her to revisit the decision matrix and reassess her original scoring and weightings. In response to this input, Sheila adjusts several values to more accurately reflect community priorities, practical implementation challenges, and long-term resilience goals.

<u>Resilience Benefits:</u>

- Vegetated swales were revised from 4 (Good) to 3 (Moderate) after acknowledging the small scale of the site and that it would have only a moderate effect on city-wide runoff reduction.

<u>Community Impact:</u>

- Vegetated swales were revised from 5 to 3 due to anticipated maintenance challenges and limited visibility of benefits to all residents.
- Property buyouts were revised from 4 to 3, acknowledging potential disruption to residents during relocation, a topic of concern that was voiced commonly at the meeting.

	Resilience Benefit	Corresponding Value	Community Impact	Corresponding Value
Alternative 1	Low Benefit/Impact	1	Low Benefit/Impact	1
Alternative 2	Excellent Benefit/Impact	5	Moderate Benefit/Impact	3
Alternative 3	Moderate Benefit/Impact	3	Moderate Benefit/Impact	3
Alternative 4		#N/A		#N/A
Alternative 5		#N/A		#N/A

Weighting Adjustments:

- The weight of cost effectiveness was reduced from 3 to 2. Although cost remains a concern, Sheila wanted the qualitative impacts to be considered more equitably and did not wish for low-performing but low-cost options, like the hardscaped channels, to be undermined as much in the final rankings.

	Weight
Cost Effectiveness	2
Resilience Benefit	1
Community Impact	2

The updated results are as follows:

Conventional hardscaped drainage channels (concrete/asphalt)		Property buyouts for floodplain reconnection		Vegetated swales for runoff attenuation and reduction	
Value	Weighted Score	Value	Weighted Score	Value	Weighted Score
-1	-2	0	0	9	18
1	1	5	5	3	3
1	2	3	6	3	6
Total Score	1	Total Score	11	Total Score	27

Final Scores	Final Rankings	Strategy
1	3	Conventional hardscaped drainage channels (concrete/asphalt)
11	2	Property buyouts for floodplain reconnection
27	1	Vegetated swales for runoff attenuation and reduction

Final Takeaways:

- All scores decreased due to the lower weighting of cost effectiveness. Vegetated swales was the strategy most impacted by this change (-14) but still remained the top option amongst the three.

- **Removing the cost effectiveness score** from the equation would shift the rankings:
  - 1st - Property buyouts for floodplain reconnection (11 pts)
  - 2nd - Vegetated swales (9 pts)
  - 3rd - Hardscaped channels (3 pts)
- Buyouts would become the top option without cost as a factor, showing their strength with non-financial factors like long-term adaptation and environmental benefits.

Sheila's updates reflect improved alignment with local values and real-world feasibility after public and city official input.

References

1. https://www.asce.org/advocacy/policy-statements/ps518---unified-definitions-for-critical-infrastructure-resilience/

2. https://www.nlc.org/resource/state-of-the-cities-2023/

3. https://doi.org/10.1111/puar.13249

4. https://issuu.com/thesolutionsjournaldigital/docs/fea_fiksel

5. https://www.transportation.gov/grants/dot-navigator/what-is-a-benefit-cost-analysis

6. https://www.fema.gov/grants/tools/benefit-cost-analysis

7.https://www.entergy.com/userfiles/content/our_community/environment/GulfCoastAdaptation/Building_a_Resilient_Gulf_Coast.pdf

8. https://www.epa.gov/water-research/storm-water-management-model-swmm

9. https://globaldesigningcities.org/publication/global-street-design-guide/utilities-and-infrastructure/green-infrastructure-stormwater-management/

10. https://trenchlesstechnology.com/nassco-report-how-trenchless-technology-saved-a-failing-culvert-system/

11. https://www.scribd.com/document/367664888/Street-Cross-Section

12. https://www.dot.ny.gov/programs/rumblestrips/centerrumblestrips

13. https://www.newsandsentinel.com/news/community-news/2023/06/parkersburg-to-begin-asphalt-rejuvenation-treatments/

14. https://www.pwri.go.jp/eng/ujnr/tc/g/pdf/28/28-8-3_Myint.pdf

15. https://www.asce.org/publications-and-news/civil-engineering-source/civil-engineering-magazine/issues/magazine-issue/article/2022/07/bridge-scour-protections-bolster-flood-prevention-efforts-in-southern-california

16. https://www.geostabilization.com/project-gallery/historic-bridge-abutment-repair/

17. https://doi.org/10.1093/acrefore/9780199389407.013.111

18. https://www.fhwa.dot.gov/environment/sustainability/resilience/

19. https://knowledge.uli.org/-/media/files/research-reports/2022/resilient-retrofits-climate-upgrades-for-existing-buildings.pdf?rev=36e6e8d45f0e452a868fa3855431f0e0&hash=45C38A1E9B8BA9D74A2B7632E066D16E

20. https://gatrees.org/reflections-on-the-big-fire-of-2007/

21. https://www.behance.net/gallery/119598555/Public-park

22. https://afterwildfirenm.org/post-fire-treatments/report_print_section

23. https://wpde.com/news/local/conway-riverfront-park-opens-after-hurricane-florence-damage-repairs

24. https://www.wateraid.org/us/stories/blueprint-for-a-climate-resilient-water-project

25. https://www.esri.com/en-us/landing-page/industry/water/2019/getting-started-digital-transformation-whitepaper

26. https://www.epa.gov/sites/default/files/2015-08/documents/flood_resilience_guide.pdf

27. https://www.epa.gov/sites/default/files/2016-03/documents/160212-powerresilienceguide508.pdf

28. https://blog.response.restoration.noaa.gov/after-storm-supporting-disaster-recovery

29. https://www.fs.usda.gov/nrs/pubs/jrnl/2024/nrs_2024_nislow_001.pdf

30. https://cviog.uga.edu/training/online-training.html

31. https://iris.uga.edu/

32. https://www.react4ej.org/

33. https://www.gacities.com/Resources/Grants-and-Award-Opportunities.aspx

34. https://garc.ga.gov/

35. https://geosinstitute.org/initiatives/climate-ready-communities/

36. https://gema.georgia.gov/assistance/preparedness-grants-and-programs

37. https://dca.georgia.gov/financing-tools/infrastructure

38. https://www.rd.usda.gov/programs-services/community-facilities/community-facilities-direct-loan-grant-program-15

39. https://www.fhwa.dot.gov/infrastructure-investment-and-jobs-act/protect_fact_sheet.cfm

40. https://www.hud.gov/program_offices/comm_planning/cdbg-dr

41. https://www.hud.gov/program_offices/comm_planning/cdbg-dr/cdbg-mit

42. https://accg.org/library/legal/SPLOST%202016.pdf

43. https://gema.georgia.gov/bric

44. https://www.dot.ga.gov/GDOT/Pages/LMIG.aspx

45. https://region4.thrivingenvironments.org/about/

46. https://www.youtube.com/playlist?list=PL4xFHIEwo_dkiDGnU_K2soYPw3_cqU1e2

47. https://www.transportation.gov/dot-navigator

48. https://www.youtube.com/watch?v=9UX8ND4U6-A

49. https://www.epa.gov/grants/epa-grants-management-training-applicants-and-recipients

50. https://localinfrastructure.org/application-bootcamp/

51. https://www.georgiacenter.uga.edu/courses/governmental-training

52. https://adaptationprofessionals.org/ready-to-fund-resilience-toolkit/

53. https://www.youtube.com/watch?v=YTwNlGl7tZY&list=PLS7Yr7j8XXlZVPUHzyGkxDrDPitIllR8P