Floodplain Management and Transportation System Resiliency Study and Action Plan

Boulder County, Colorado
Boulder County Transportation Department

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Executive Summary

2013 Boulder County Floods, Jamestown, CO. FEMA

Executive Summary

The Boulder County Transportation Department works to improve the resilience of our community through management of flood risk and infrastructure improvements.

The Boulder County Transportation Department Floodplain Management and Transportation System Resiliency Study and Action Plan (Study) identifies potential actions that the Boulder County Transportation Department could implement to improve the resiliency of its transportation system and flood-prone areas. Using both qualitative and quantitative analysis, the potential actions were evaluated to determine which would have the greatest impact on attaining the Boulder County Transportation Department's resiliency goals and objectives (Section 1.2).

This study was funded with a grant from Housing and Urban Development's Community Development Block Grant-Disaster Recovery program through the State of Colorado's Department of Local Affairs.

Vulnerability Assessment

The Study identified potential future flood vulnerabilities due to climate change based on multiple downscaled Global Climate Model runs using historical rainfall in Boulder County. This model was incorporated into City Simulator software to assess impacts from flood events (see Chapter 2 for further description of the City Simulator vulnerability assessment). Key findings of the vulnerability assessment include:

- One rain event similar in size to Boulder County's 2013 flood occurred over the next 32 years (2019 to 2050) according to the City Simulator analysis.
- 993 of 1,759 (56.4 percent) buildings in unincorporated Boulder County in the special flood hazard area (SFHA) flooded at least once between 2019 and 2050 in the simulation.
- Approximately $259.70 million in total damage (building and contents) occurred to 1,282 buildings under the simulation. $104.28 million of this damage was to residential buildings (1,018 buildings in total).
- Flooding outside of the mapped 100-year and 500-year floodplains contributes significantly to projected future building damage and should be incorporated into flood risk management approaches.

Approximately $1 billion in productivity is lost over 32 years due to flooding according to vulnerability simulations.

Approximately $206 million in transportation infrastructure (at current replacement value) is at risk, according to Study simulations.

Analysis

The Study identified nearly 200 potential actions that the Boulder County Transportation Department could take to improve the resilience of the transportation system and to reduce flood risk. Through a qualitative analysis, the actions were evaluated on their level of effort to implement, likelihood of securing support, and cost, as well as how well each would help Boulder County to reach its resilience goals and objectives. Based on this analysis, 22 top actions were further developed and placed into one of four categories (see Chapter 4 for descriptions of the top actions):

1. Improve Building Stock Resiliency
2. Institutionalize Resiliency
3. Public Infrastructure Risk Reduction
4. Increase Community Preparedness

A quantitative benefit-cost analysis was completed using City Simulator for four of the top recommended actions: (1) improve resiliency of transportation infrastructure, (2) incentivize property owner flood protection projects, (3) apply a home buyout program, and (4) regulate residential and commercial construction in areas at risk for flooding.

Findings from the benefit-cost analysis include:

- Improving transportation infrastructure could reduce disrupted trips related to flooding and/or flood damage by 39 percent.
- Participation of Boulder County homeowners is key to future resilience. Incentivizing flood protection projects by Boulder County property owners could yield an increase in substantially protected homes of 50 percent over the next 32 years.

- By steadily buying the most at-risk homes and allowing the stream to recapture the floodplain in those areas, up to $9 million of flood damage can be avoided over the next 32 years.

Through the City Simulator analysis, the transportation infrastructure that is most at risk of being impacted by flooding was further evaluated to determine the highest-priority projects for improvement based on the anticipated number of commuters whose trips would be disrupted. The top ten results of this analysis are outlined in Executive Summary Table 1.

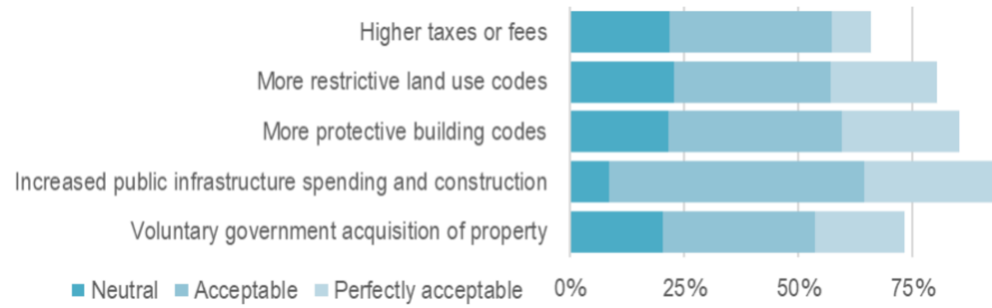
Executive Summary Table 1. Infrastructure Improvement Needs

Type		Road	Average Annual Trips Disrupted
1	Bridge	Highway 7/Arapahoe Rd at Dry Creek 3	148,039
2	Bridge	Kenosha Rd at Boulder Creek	114,112
3	Bridge	US 287 at Dry Creek 2	113,100
4	Bridge	S. Sunset St at St. Vrain Creek	101,534
5	Bridge	N. 95th St at Boulder Creek	92,140
6	Bridge	U.S. 287 at Boulder Creek	66,051
7	Road	Diagonal Highway at Left Hand Creek	58,222
8	Road	S. Hover Rd/95th St at Left Hand Creek	57,716
9	Bridge	Hwy 119/Boulder Canyon at Four Mile Creek	55,289
10	Bridge	Niwot Rd at Dry Creek 2	48,792

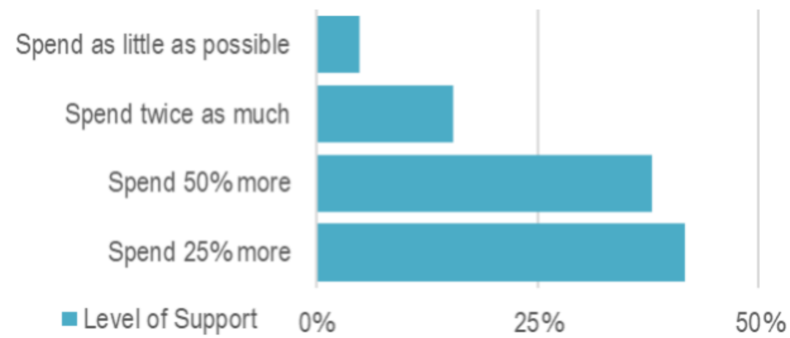
The following assets were excluded from the analysis:120th Street at Coal Creek (Lafayette), East County Line Road at Dry Creek 2, East County Line Road at Boulder Creek, and East County Line Road at Coal Creek (Erie).

Survey Results

The study included an online survey to determine community resilience priorities and acceptable levels of risk. More than 400 people responded to the survey from areas throughout the county. The survey respondents indicated a general support for government actions that would increase resilience of the transportation system and flood prone areas. For example, the following responses were provided for the question, "which are acceptable trade-offs for having greater resiliency when considering potential catastrophic disasters?"



Many survey respondents also supported increased infrastructure spending to increase resiliency. The following results came from respondents when asked, "what level of spending on road and bridges would one support to better prepare for the next major event?"



Recommendations and Implementation Plan

The Study recommends that Boulder County pursue implementation of the 22 top actions outlined Executive Summary Table 2.

In Section 5.1, top actions have been categorized based on implementation variables, financial cost, staff time and effort, public support, and level of urgency. The section also notes documents or plans that need to be updated and potential funding sources. This categorization helps the Boulder County Transportation Department determine when and how top actions can be implemented based on resource availability and county priorities.

Executive Summary Table 2. Recommended Resiliency Actions

Top Action by Category and Study Section Number	Implementation Timeframe
Improve Building Stock Resiliency	
3.1.1 Fortify regulatory floodplain building rules	Immediate Term
3.1.2 New and substantially improved critical facilities to be floodproofed	Immediate Term
Institutionalize Resilience	
3.2.2 Complete watershed management planning necessary under National Flood Insurance Program Community Rating System Activity 452.b to obtain Class 2 certification	Immediate Term
3.2.7 Flood risk tracking tool and climate vulnerability assessments	Immediate Term
3.2.5 Sediment/debris removal occurs when/where needed	Mid Term
3.2.6 Establish metrics for achieving community resilience	Mid Term
3.2.3 Develop and adopt plans, policies, and routes for emergency access and egress in a flood	Long Term
3.2.4 Develop a post-wildfire flood risk reduction program	Long Term
3.2.1 Develop procedures, capabilities, and Multi-Hazard Mitigation Plan recommendations to maximize infrastructure resilience funding from FEMA	Continuous
3.2.8 Increase awareness of resiliency matters among county staff and elected officials	Continuous
Public Infrastructure Risk Reduction	
3.3.1 Improve critical high-risk roads, bridges, and culverts	Immediate Term
3.3.3 Implement project prioritization processes that include resiliency	Immediate Term
3.3.4 Develop scour risk-based prioritization of bridge improvements	Mid Term
3.3.5 Update infrastructure design standards and maintenance regimes to account for climate change	Mid Term
3.3.6 Update design standard to favor bridges over multiple cell pipe culverts in critical locations	Mid Term
Increase Community Preparedness	
3.4.1 Create high-risk building buyout program	Mid Term
3.4.3 Incentives for voluntarily raising freeboard	Immediate Term
3.4.4 Incentives for other voluntary flood protection measures	Immediate Term
3.4.2 Low- and moderate-income resiliency needs assessment: transportation systems	Mid Term
3.4.7 Increase transit service in response to economic or natural disasters	As-needed
3.4.5 Resiliency-focused engagement with the community	Continuous
3.4.6 Provide meaningful bilingual resiliency materials, engagement, and event-recovery support	Continuous

Contents

1 Introduction

Colorado storm, Flickr. Photo: Pat Gaines

1 Introduction

Since the devastating floods of September 2013, the Boulder County Transportation Department has invested time and resources to achieve long-term flood recovery for public infrastructure and private property through its road and bridge improvements, capital planning processes, and floodplain management programs. These efforts have created lessons-learned and generated ideas for future improvements. In addition, many of the research, studies, and plans by federal, local, and state partners are applicable to the county's current activities and potential future efforts to improve resiliency throughout Boulder County.

These efforts support Boulder County's strategic priority for resiliency. The goal is that "Boulder County prevents and mitigates negative impacts to Boulder County's community, economy, and environment due to climate change and other shocks and stresses." This goal is supported by three objectives that, together, underpin this Study:

- Integrate resilience into policy, plans, regulations, decision-making, processes, and budgets across all departments.
- Respond effectively and reduce long-term impact of disasters and shock events, including but not limited to floods and wildfires.
- Increase community resilience by building capacity, increasing connectedness, and fostering cooperation.

1.1 Study Purpose

The Boulder County Transportation and Floodplain Program is working to make our community more resilient to flooding, wildfire, economic downturns, and other shocks and stresses. Boulder County works to make this happen by identifying, evaluating, and implementing actions to reduce risk to community facilities, such as structures inside and outside of the floodplain and to the multimodal transportation system, which includes buses, bicyclists, and pedestrians. As part of this effort, this Boulder County Transportation Department Floodplain Management and Transportation System Resiliency Study and Action Plan (Study) helps make Boulder County more resilient by identifying, evaluating, synthesizing, and providing an implementation plan for actions that minimize risk and reduce damage. Furthermore, the Study seeks to reduce risks and stresses in an equitable fashion and protect low-income populations. The Study process emphasized three tracks, including floodplain management, infrastructure design, and transportation planning.

In short, the Study identifies actions the Transportation Department can take to make Boulder County communities more resilient now and in the future. In service to this outcome, this project answers the following questions, as noted throughout the Study.

1. What does it mean for the county's transportation network to be resilient?
2. What are the community's acceptable levels of risk and uncertainty in planning for that desired flood-related resiliency?
3. What are the potential actions and steps that Boulder County could take to improve resiliency?
4. What have previous plans and studies said about specific measures that could improve the resiliency of our transportation infrastructure and lessen flood risk?
5. What level of public investment would be required for a range of results?
6. What are the potential actions that Boulder County and its partners could take to improve resiliency, particularly within existing Boulder County programs?
7. What actions are most cost-effective to achieve desired levels of resiliency?
8. What actions are supported by the public to achieve desired resiliency levels?

Key Concepts

For the purposes of the Study, "**resilience**" is the capability to anticipate risk, limit impact, and respond to events by adapting and learning in the face of disruptive shocks and stresses. The concepts expressed in this Study's goals and objectives embody Boulder County resilience.

"**Shocks**" are acute events that have the potential to cause major loss of life and damage to assets and negatively impact a community's ability to function and provide basic services, particularly for low-income or other vulnerable populations.

"**Stresses**" are chronic conditions that render a community less able to function and provide basic services, particularly for low-income or other vulnerable populations.

"**Risk**" is the exposure to the chance of injury or loss.

1.2 Goals and Objectives

For the purposes of this Study, the Boulder County Transportation Department defines "resiliency" through the collective tenets expressed in the goal and objective statements. These statements also serve as the foundation for all project analysis and recommendations. Recommendations are, therefore, reflections of what it means for the county to be resilient. This is measured by the degree to which recommendations further the principles expressed in Study goal and objective statements inside and outside of the county's delineated floodplain and throughout its transportation network.

Due to the importance of goal and objective statements in defining resiliency and determining the outcome of this study, great care was taken to establish statements that truly represent Boulder County values and experience. Accordingly, the process used to develop the statements built upon the aspirational goals developed through the previously conducted plans noted below. The previous work was supplemented with additional input provided by the Study's Steering Committee as well as input obtained through the two public meetings and the project website. Previous studies that were consulted for the development of Study goals are:

- Putting on a Resilience Lens: BOCO Strong Resilience Assessment for Boulder County (2016)
- BOCO Strong: Resiliency for All (2017)
- Floods in Boulder County: A Study in Resilience (2014)
- The Impact of Climate Change: Projected Adaptation Costs for Boulder County, Colorado (2018)
- Creating Room for the River (2018)
- Resilient Design Performance Standards for Infrastructure and Dependent Facilities (2016)
- Boulder County Resiliency Coordination Plan (2018)
- Colorado Resiliency Framework (2015)

What are goals and objectives?

Goals are descriptive, open-ended, and often broad statements of desired future conditions that convey a purpose.

Objectives are concise statements of what needs to be achieved to reach the aspirations expressed in a goal statement. Objectives can include what and how much something will be achieved, when and where it will be achieved, and who is responsible.

The goals and objectives used to guide the Study are:

Goal 1. Institutionalize Resiliency: Strengthen Boulder County Transportation Department and local governments' culture and prioritization of transportation system and flood risk resiliency.

Objective A. Coordination occurs internally among and between departments, and externally between agencies, organizations, and the public.

Objective B. Risk is determined and evaluated regularly for short-term and long-term conditions.

Objective C. Risk-mitigating solutions and innovations are evaluated, prioritized, funded, and implemented regularly.

Objective D. Resiliency is continuously integrated into Transportation Department policy, regulations, decision-making, processes, and budgets.

Objective E. Resiliency is considered along with other factors when prioritizing infrastructure upgrades and replacement.

Objective F. People are educated about resiliency and have plans to respond to shocks.

Goal 2. Withstand Shocks: Transportation systems and flood risk management reduce long-term impact of shock events.

Objective A. A broad range of risks and vulnerabilities are identified and addressed so that infrastructure and services are made to withstand shocks and/or designed to fail in predictable ways which minimize impacts to people as well as natural and manmade features.

Objective B. Actions to prepare transportation systems and manage flood risk are socially equitable and ensure that vulnerable populations are appropriately served.

Objective C. Current commitments to make resiliency improvements are carried forward and implemented.

Goal 3. Respond to Shocks: **Transportation systems and flood risk management respond effectively to shock events.**

Objective A. Essential activities are preserved following shock events.

Objective B. Recovery from shocks is performed methodically, prioritizing efforts to minimize interruptions.

Objective C. Transportation systems are redundant and adequate for multimodal community mobility and emergency access and egress following shocks.

Objective D. Floodplain management strategies are adequate to respond to and mitigate shocks and reduce harm.

Objective E. Shock recovery enables Boulder County communities to improve capability of affected transportation infrastructure and systems to better withstand future shocks and stresses.

Objective F. Transportation systems and flood risk management responses to shocks are socially equitable and ensure that impacts to vulnerable populations are minimized and that appropriate mobility and access to services, jobs, commerce, and community are preserved.

Goal 4. Address Stresses: Improve transportation system and flood risk management responsiveness to stresses.

Objective A. On-going and potential transportation system stresses and flood risks are identified and monitored.

Objective B. Solutions to flood risk stress on the transportation system are developed.

Objective C. Reduction of flood risk and transportation system stresses benefits the public equitably and protects vulnerable populations.

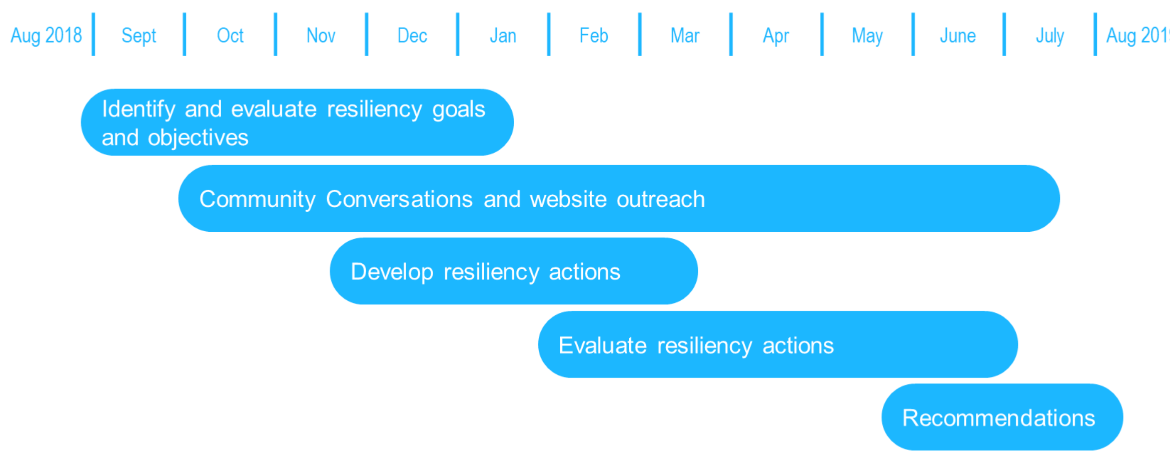
Objective D. Actions to address transportation systems and manage flood risk stresses emphasize assets that are critical, are connected to other systems, and are significant to peoples' lives.

1.3 Study Process

The Study was conducted in a sequence which mirrors Figure 1. Public input was as an ongoing activity. Input was gathered through the project's website via surveys and comments. In-person meetings with Boulder County communities also generated public input, as described in Section 1.3.1. Public and Steering Committee input was instrumental in developing Study goals and objectives. Throughout the Study process, a multidisciplinary Steering Committee was used to share holistic perspectives, provide fresh ideas, advise on key decisions, and provide discipline-specific solutions. Committee members participated through in-person meetings. Steering Committee membership was comprised of Boulder County departments and other stakeholders, such as the City of Boulder, the City of Longmont, Foothills United Way, Larimer County, State of Colorado, and the Mile High Flood District (MHFD). Four Steering Committee meetings were convened throughout the course of the Study.

As described in Section 1.3.2, the Study leverages the vast amount of work that has already been completed throughout the county in documenting resiliency-related needs and offering solutions. Building from the needs and solutions previously documented, potential resiliency actions were developed to address needs and provide additional solutions not previously discussed in earlier efforts (detailed further in Section 1.3.2). Evaluation of the nearly 200 potential resiliency actions was performed to gauge how well actions produced resiliency benefits and how costly they might be to implement (detailed further in Section 1.3.3, and further in Chapter 3). Top-performing actions with reasonable levels of cost were elevated for consideration by the public and Steering Committee, as well as additional evaluation as possible candidates for implementation.

Figure 1. Study Process



1.3.1 Public Input

Public participation and input were necessary for answering two Study questions: (1) what are the community's acceptable levels of risk and uncertainty in planning for desired flood related resiliency? and (2) what actions are supported by the public to achieve desired resiliency levels? The Study's engagement program was designed to answer these questions as well as collect impressions, thoughts, and values needed for setting evaluation weights, identifying resiliency needs and actions, fine-tuning Study goals, and establishing baseline conditions.

To accomplish these ends, the Study deployed online tools and conducted three “community conversations,” which were in-person open-house style meetings with Boulder County residents. The first two community conversations and the online survey focused on developing a better understanding of Boulder County communities’ acceptable levels of risk and uncertainty. The outcome of the survey and two community conversations provided input for developing benefit, cost, and scenario evaluations described in Chapters 3 and 4. A detailed summary of survey results is provided in Appendix 1. In-person community conversations and the Study’s online presence also provided opportunities for the public to share ideas and suggestions. For example, the inclusion of low-water crossings in the Study is the direct result of a request from a public comment. The idea was added as a potential resiliency action, evaluated, and ultimately included as a top action to update infrastructure design standards and maintenance regimes to account for climate change.

Survey results and community conversations helped the Study team better understand community tolerances for various risk-mitigating actions and discuss their tradeoffs. The third community conversation and online comment tool captured input on which proposed resiliency actions were supported by the public. Staff and materials presented pros/cons and benefits/costs of taking several hypothetical courses of actions, or scenarios.

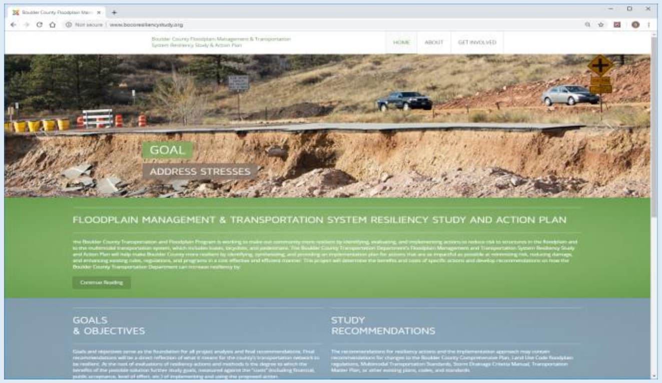
The positive impact of public and Steering Committee input is referenced throughout the following chapters. In summary, however, benefits of public input on the Study include:

- Broadly agreed upon Study goal and objective statements
- Level of public investment desired to improve resiliency
- Actions that are supported by the public to achieve resiliency
- Feedback on possible resiliency actions
- Calibrating Study goal-based analytical weights used to evaluate possible resiliency actions
- Verified level of public awareness of emergency planning resources
- Acceptable tradeoffs of having improved resiliency

While these tangible input-driven outcomes directly influenced the Study, other public input findings provided valuable context for the Study. For example, survey respondents were asked *“Are you aware of any resources available to help develop household emergency plans?”* Of the total responses received, 174 respondents said “yes,” 144 said “no,” and 76 said “no, but want to receive information about resources via email.” Knowing that 44 percent of responders are aware of resources available to them to help develop household emergency plans proved to be important context for the creation of resiliency actions that focus on increasing awareness of emergency plans.

Online Participation

In addition to in-person “community conversations,” countywide participation was achieved through the Study’s website. For example, a survey used to calibrate benefits, costs, and ranking of resiliency actions received 413 responses from locations across the county.



Similarly, an awareness of the flood insurance baseline was provided (see Figure 2) through questions like "do you have flood insurance for your home? (Note that most homeowner insurance policies do not cover flooding. Specific flood insurance is often required for coverage)." Of the total responses received, 14 percent said "yes," 67 percent said "no, I do not live in a designated floodplain" and 6 percent said "no, and I live in a designated floodplain." It is notable that, of those who responded "No," only 1 percent were unaware of flood insurance. Twelve percent of respondents selected "Other, please specify," and included comments ranging from "Not sure if I live in a floodplain," "I do not live in a designated floodplain, but my home was damaged by floods," and "I live on an upper floor."

Additional context about the public's first-hand experience with natural disasters was provided by engagement with the public. As summarized in Figure 3, 51 percent of survey respondents said they had been impacted by recent natural disasters such as the 2013 flood or recent wildfire events. Conversely, 45 percent were not impacted, and 5 percent were not living in their current residence when it was impacted by a natural disaster. Of those who had been impacted by recent natural disasters (Figure 4), 65 percent were impacted by flooding, 20 percent by wildfires, and 23 percent by other factors, some of which also are associated with flooding (e.g., rain damage, mud damage, natural disasters) and/or wildfire (e.g., evacuation, loss of utilities, loss of access to/from work).

1.3.2 Building on Previous Efforts

Since the floods of September 2013, Boulder County has created numerous studies, data, plans, regulatory policies and standards that address resiliency-related risk, stress, and shocks in some way. Twenty-four of these resources (see 0), including those used to help develop Study goals and objectives, were examined through a structured literature review process to capture and build upon documented recommendations and lessons-learned that met the goals and objectives of this Study. The literature review process was used to leverage the time and effort spent by Boulder County and other jurisdictions in determining the needs of individual communities by documenting known needs, solutions, and actions for use in the Study. Results from the literature review were used as the foundation for developing resiliency actions that would later be evaluated for the degree to which they advance resiliency goals and for their relative costs.

The literature review resulted in 376 findings representing previously recommended resiliency projects, procedures, requirements, or policies. In some cases, findings also represented goals, recommendations, needs, principles, or observations that were not fully developed ideas for actions but were starting points for further research and effort to develop new ideas for resiliency actions. Each of the literature review findings was traced back to its source document and Study goal and objective to which it relates the most (Figure 5).

Figure 2. Public Survey Result: Do you have flood insurance for your home?

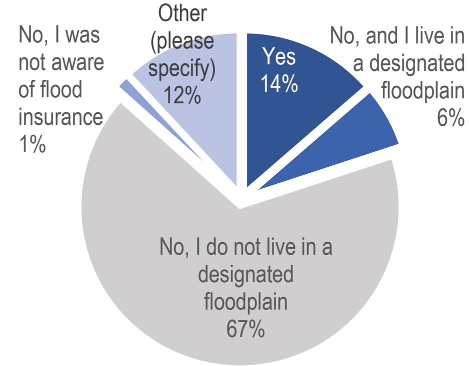


Figure 3. Public Survey Result: Have you been impacted by recent natural disasters?

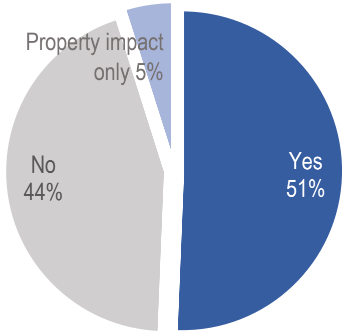


Figure 4. Public Survey Result: How were you impacted (by natural disasters)?

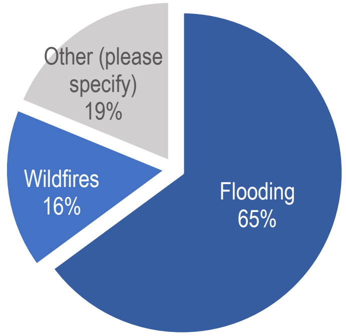
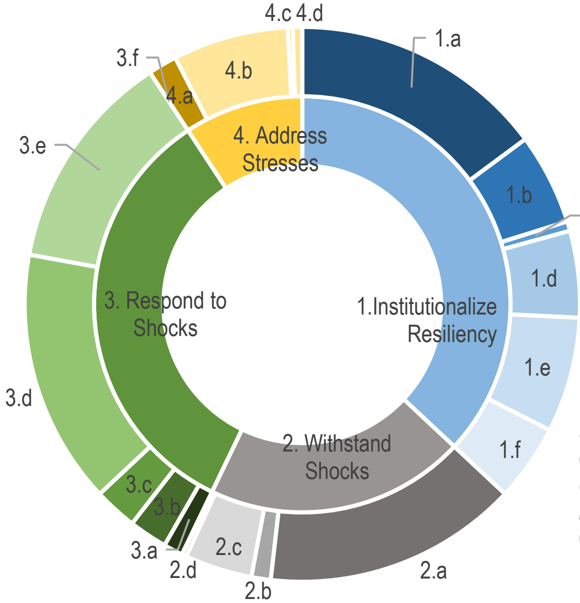


Figure 5. Literature Review Findings by Goal and Objective



Note: Text descriptions of objectives 1.a through 4.d correspond to those documented in Section 1.2—Goals and Objectives.

1.3.3 Developing Potential Resiliency Actions

The 376 findings from the literature review processes were combined with additional research of state-of-the-practice resiliency actions that are being successfully deployed across the country as well as public and Steering Committee input. The combined body of knowledge was used to generate nearly 200 potential actions that Boulder County could take to improve resiliency. Actions include projects, intergovernmental and organizational agreements, regulations, funding ideas, policies, plans, design and operational standards, and organizational process improvements. The full list and description of potential resiliency actions is available Appendix 5.

Initial Evaluation of Potential Resiliency Actions

From the full list of potential resiliency actions (0), a structured qualitative evaluation process was used to highlight actions that are most likely to provide high resiliency benefit, while also being practical, implementable, and not cost prohibitive. A decision support model and application was used by the project team to evaluate the large number of potential resiliency actions and rank them according to how impactful they would be at achieving benefit-focused Study goals and objectives (stated in Section 1.2, e.g., institutionalizing resiliency, withstanding shocks, responding to shocks, and addressing stresses) while also balancing measures of cost, including financial, level of effort, and level of public support. This practice enabled the project team to test potential resiliency actions for how effectively they could meet specific goals and objectives or a broad range of goals and objectives. Model weights used in the final evaluation reflected public input received through community conversations and an online survey regarding the relative weight of the goal areas (summarized in Figure 6), which showed relatively equal value placed on all four goal areas. Scoring was based on consistent qualitative measures, as documented in Appendix 6. The findings of this evaluation are summarized in Figure 7, which shows effectiveness at meeting Study goals as bar heights.

From this evaluation, top-tier actions were identified (detailed in Chapter 3) and received additional consideration (as discussed in Chapter 4). These top actions are those that are effective in achieving resiliency objectives and are also reasonable to implement in terms of cost.

Figure 6. Public Survey: Goal Weighting

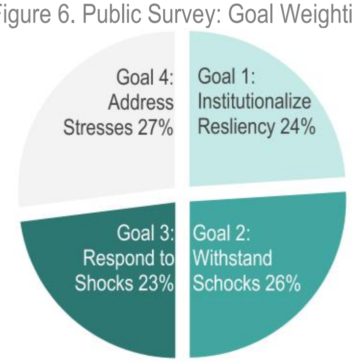
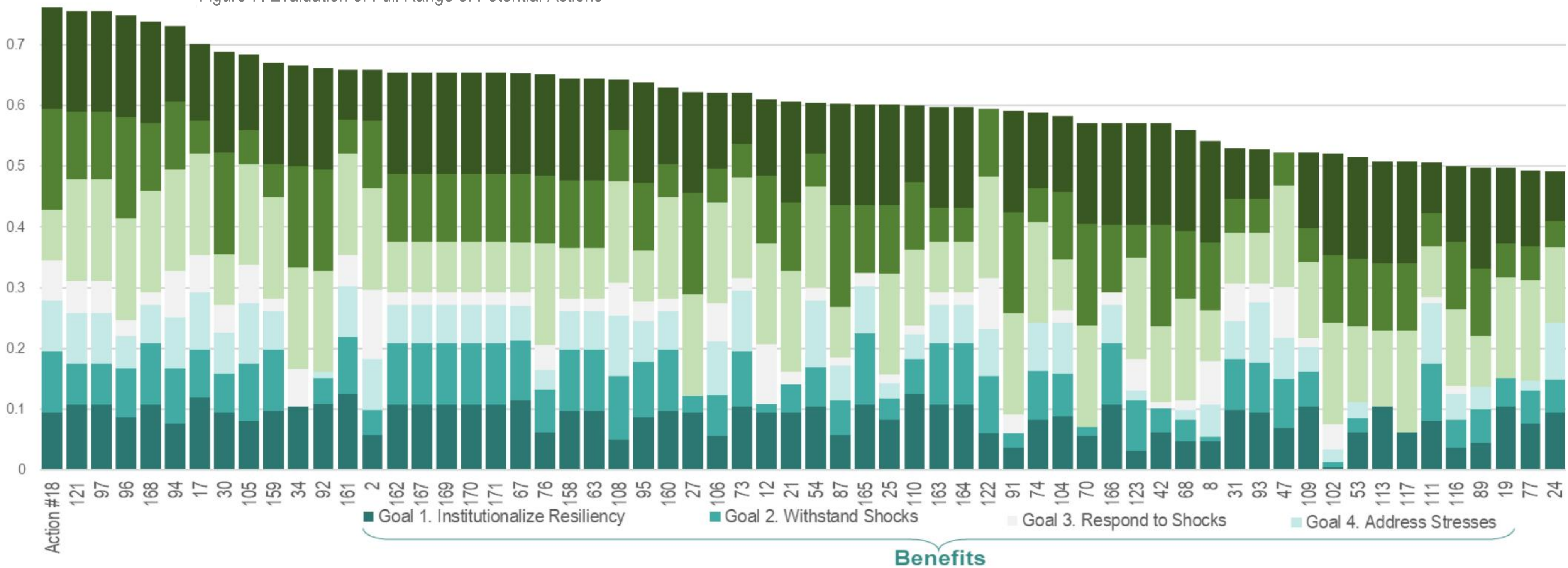
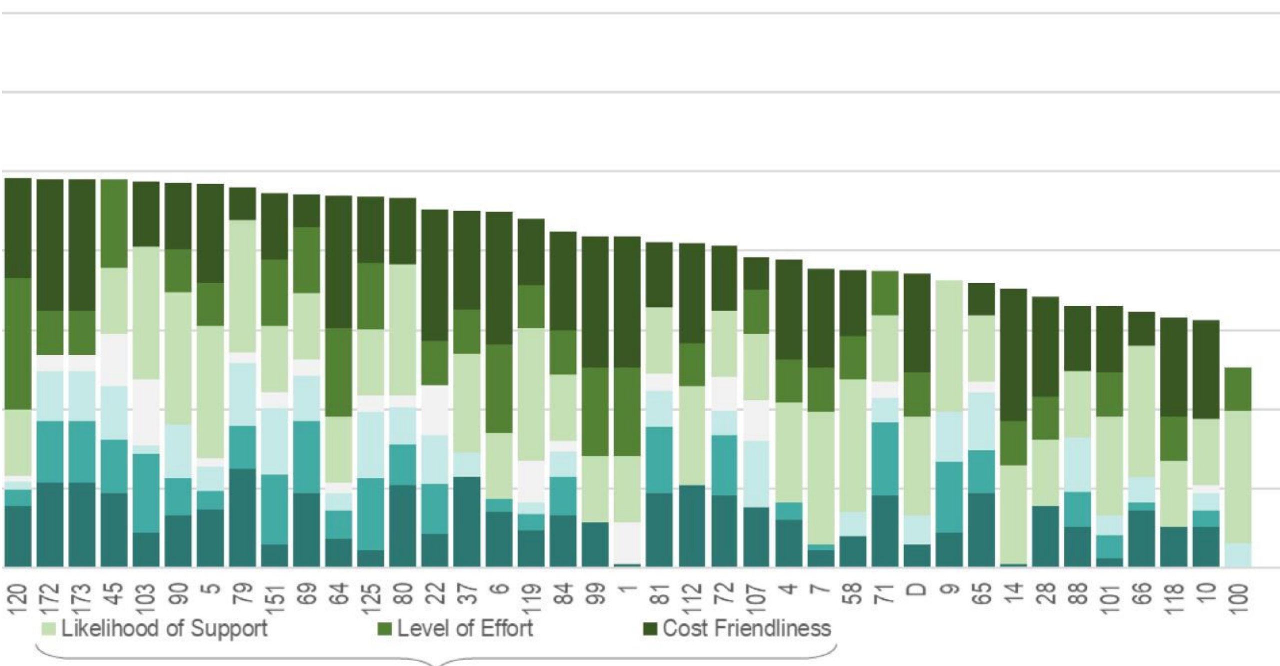


Figure 7. Evaluation of Full Range of Potential Actions



Potential Resiliency Actions (sorted by score)

18 Resiliency elements are in local-level plans
121 Policy for new subdivisions have two evacuation routes
97 Program redundancy into roadways when planning
96 Elevate new roadways above flood levels
168 Require dry land access for new development
94 Leverage FEMA hazard mitigation into infrastructure
17 Plans and policies for emergency access and egress
30 Infrastructure planning anticipates future land use
105 Develop evacuation program and agreements
159 Higher freeboard incentives
34 Emergency recovery planning
92 Resilient Design Performance Standards compliance
161 Incentives for voluntary flood protection
2 Develop a post-disaster recovery/redevelopment plan
162 Extend freeboard requirements
167 Prohibit hazardous materials in floodplain
169 Require elevated parking areas
170 Require floodplain setbacks
171 Require floodplain buffer zones
67 Limit/prohibit floodplain development
76 Promote flood insurance
158 Freeboard waivers, discounts, or rebates
63 Develop and promote higher freeboard incentives
108 Vulnerable population resiliency needs assessment
95 Update design standards to favor bridges over culverts
160 Higher freeboard incentives
27 Incorporate resiliency into project prioritization
106 Develop emergency diversion routes
73 Enhance flood control/drainage maintenance system
12 Have and maintain an Emergency Operations Plan
21 Responsiveness to undocumented people during disasters
54 Develop sediment removal management system
87 Modify substantial damage/improvement rules
165 Prohibit services for at-risk populations in floodplains
25 Have climate change elements in local plans
110 Apply best practices and resilient design standards
163 Prohibit critical facilities in floodplains
164 Higher building standards for critical facilities in floodplains
122 Increase transit service during recessions
91 Set policy to comply with the time-to-recovery targets



Cost (lower score, greater cost)

74 Flood mitigation investment programs
104 Adopt formal project selection system
70 Increase stakeholder engagement for MHMP update
166 Higher regulatory standards for floodplains
123 Transit evacuation/recovery agreements/partnerships
42 Target neighborhood-level public outreach
68 Promote "Do It Yourself" flood mitigation
8 Implement County's Multi-Hazard Mitigation Plan
31 Include debris considerations into engineering standards
93 Develop scour risk-based bridge prioritization/replacement
47 Develop post-wildfire flood risk reduction procedures
109 Develop climate preparedness/adaptation checklist
102 Agreements with USFS for evacuation routes
53 Adopt knowledge management and transfer process
113 Enable staff to interact with climate scientist/research
117 Educate policy-makers/public on resiliency costs
111 Climate vulnerability assessment for transportation
116 Update all climate-sensitive infrastructure standards
89 Obtain private land agreements for sediment control
19 Provide bilingual resiliency materials and engagement
77 Deliver a cohesive flood risk education
24 Design standards consider climate change
120 Encourage green alley improvements
172 Countywide freeboard requirements
173 On-site stormwater retention requirements
45 Include emergency response in maintenance program
103 Develop an Emergency Service and Evacuation Plan
90 Develop a debris operational plan
5 Develop natural hazard risk communications strategy
79 Flood risk tracking and mitigation tool
151 61st Street at Four Mile Canyon Creek
69 Erosion Hazard Mapping.
64 Promote nature-based design for new development
125 Address flooding at Boulder Creek and 95th Str
80 Flood risk communication and mapping
22 Reconcile building codes/land use across jurisdictions
37 Establish metrics for achieving community resilience
6 Develop Transportation Department programming priorities
119 Establish evacuation meeting spots
84 Regularly update building/floodplain intersect data
99 Augment resilience funding options
1 Establish stand-by contractors for recovery
81 Define and identify High Hazard Zones (HHZs)
112 Establish a Resiliency/Climate Change Program
72 "Quick Buy" program.
107 Install VMS signs on major routes for evacuations
4 Develop a strategic public communications plan
7 Educate workplaces about site-specific risks
58 Develop a resiliency how-to planning guide
71 Local floodplain buyout program
9 Implement creek/watershed masterplan recommended projects
65 Future conditions floodplain mapping
14 Score Boulder County's resiliency maturity
28 Implement a priority-based budgeting program
88 Develop and implement a climate change adaptation plan
101 Modify Public Work Manual for resilience
66 Procedure for updating floodplain maps events
118 Climate responsive infrastructure training
10 Develop a Green Infrastructure Guide
100 Urban heat island mitigation

A full list of actions listed in numerical order is available in Appendix 5

2 Vulnerability Assessment

2013 Boulder County Floods. Photo: U.S. Army National Guard

2 Vulnerability Assessment

Boulder County faces multiple impacts from flood in the future; to fully estimate vulnerability, the Study explores damage to buildings and transportation infrastructure, and its disruption to Boulder County daily routines over the next 32 years.

The objective of the vulnerability assessment is to estimate the level of damage and disruption that may be caused given expected impacts of climate change in the future.

To quantify disruption and damage, this study applied the Atkins City Simulator tool to Boulder County over a 32-year period (2019 to 2050) based on long-term assumptions of land development, economic development, population growth, and travel. The simulation uses current hydrologic and hydraulic models to estimate the response of individual buildings and transportation infrastructure (culverts, bridges, low road segments) to a series of storm events over that same 32-year timeframe.

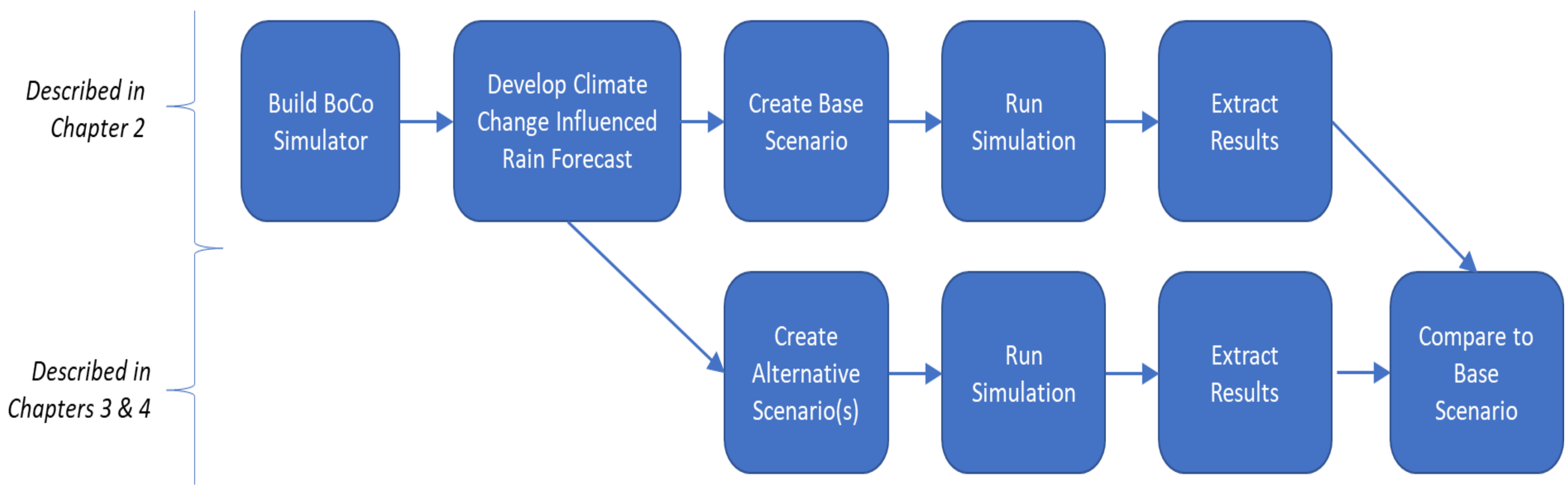
The simulation estimates disruption for each disaster on individual buildings, roads, employment and populations and aggregates the disruptions in the form of metrics of interrupted work and flooded homes and commercial buildings across the community.

The vulnerability study uses a “base” scenario that includes no resiliency actions other than those related to buildings that are already in place in unincorporated Boulder County. Resiliency actions already in place that were included in the “base” scenario include:

› Banning new building in the regulatory floodway.

› Requiring new and substantially improved homes in the County Floodplain Overlay District to be elevated to 2 feet of freeboard and remove basements at the time of renovation.

Figure 8. Study Process Diagram



2.1 Scenario Modeling Process

Figure 8 summarizes the process of running the vulnerability assessment. The steps include:

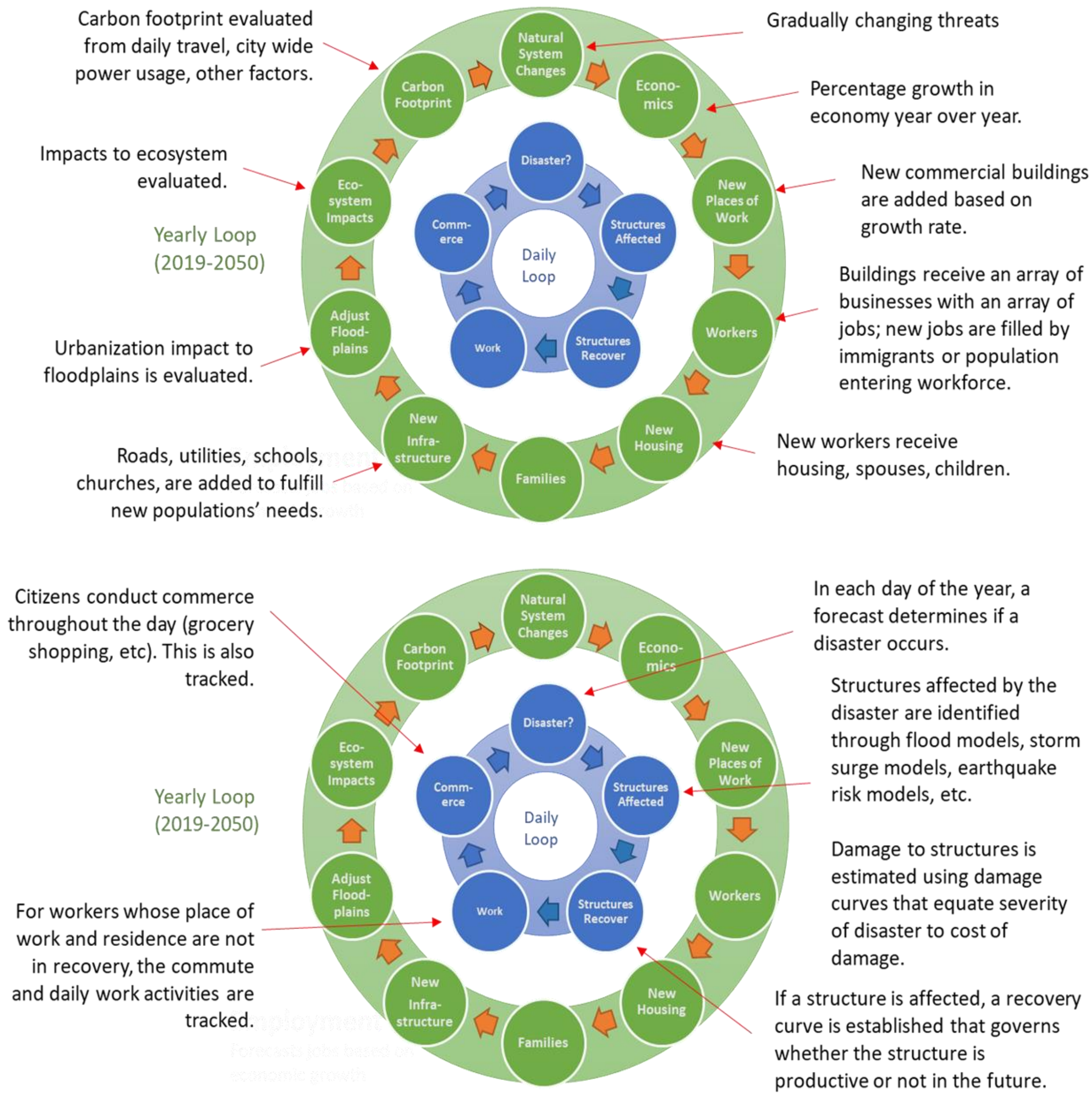
1. **Building the Boulder County City Simulation Model**. This entails collecting geographic information system (GIS) data on buildings, parcels, roads, County Floodplain Overlay District, topography, and hydraulic model result data for the entire county. The details of the data collection and model-building process are presented in Appendix 3 of this report. The end result is a virtual Boulder County, which can be used to simulate future growth and future disasters.
2. **Developing a climate-change influenced rainfall forecast**. This process involves blending the latest projections of rainfall from global climate models with local historical rainfall data to create a "driver" forecast of daily rainfall to run the simulation. The process is described in Section 2.2.
3. **Creating a model base scenario that reflects current policies and actions**. The intent of the base scenario is to forecast how well the community will stand up to projected changing climate given its concurrent urbanization and population growth. The base scenario results provide much of the information presented in this chapter because it reveals the vulnerability—and strengths—of the community.
4. **Conducting the simulation using the base scenario**. The simulation runs in a nested loop. See Figure 10 for details. The outer loop runs once yearly and simulates urbanization as follows:

- The past five-year economic growth rate of the community determines how many new commercial buildings will be added in the coming year.
- The buildings are added by placing them in the most likely locations for development, determined by proximity to the urban core, major roads, etc.
- A virtual working population, called "agents," then is added to each building.
- The agents are each allocated to either existing empty housing or, if no empty houses are available, new residential buildings are placed across the community for them using the same likelihood of development process as the commercial buildings.
- Each working agent is allocated a commute path. This is the shortest path along the community road network from the agent's home to the workplace.
- The agents then are joined by virtual family members; other working agents as spouses, non-working spouses, and children.
- If configured to do so, the simulation then adds to the infrastructure—roads, utilities, etc.—to accommodate the new growth in population.
- Finally, measurements are taken of impacts to the ecosystem, carbon footprint, etc.

In the daily loop, the simulation starts with a driver forecast each day. In this assessment, the driver was rainfall (see Section 2.2 for more detail on the development of the rainfall forecast). The simulation steps are:

- Check if a storm has occurred.
- If it has, then find the structures (buildings, culverts, bridges, frequently flooded road segments) that are impacted. Estimate the damage done to the impacted structures in terms of direct damage and the damage to their contents. Estimate the recovery time of the impacted structures using rain-to-flood curves (buildings) and rain-to-overtopping curves (transportation assets) that have been derived for each structure from existing hydraulic and hydrologic models.

Figure 9. 100-Year “Rain-Plain” Pluvial Flood Model



Disable the impacted structures for their projected recovery time; transportation infrastructure will be impassable and flooded buildings will be unusable.

› Simulate commuting for all working agents. Where their homes or workplaces are flooded, record their working day as disrupted and reduce their total productivity over the simulation time line by 8 hours of work and the salary they'd earn doing it. Where their commute path is flooded, evaluate if they can still get to work through another route. If they can, reduce the number of hours they work that day and record the reduction in productivity.

5. **Synthesizing the results** by extracting from the virtual Boulder County metrics of productivity, population, number of damaged buildings, direct damage, contents damage, and many more, which are presented in this chapter and are used to evaluate the impact of resiliency actions described in Chapter 4.

2.1.1 Estimating Flood Impacts to Buildings

A key element of the simulation process is estimating the flood response of structures to rain events. The approach taken within this assessment leverages the design storm-driven models that are traditionally completed for FEMA flood insurance studies. In these studies, rainfall of uniform depth is assumed to fall across a watershed of interest for a certain duration—for example, 3 inches of rain in 24 hours. A hydrologic model is used to estimate the resulting peak flow rates at points along the river that drains the watershed. A hydraulic model then is used to estimate the water surface elevation along the river when the river is at peak flow. A GIS process then is used to estimate the floodplain that will result from water surface at the estimated elevation along the river. From the floodplain, a "depth raster" is produced, which gives the depth of flooding for each design storm at every point in the community. In FEMA flood studies, the storms used are the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year storms, which are the storms that happen with 50 percent, 20 percent, 10 percent, 4 percent, 2 percent, 1 percent, and 0.2 percent probability in any given year, respectively.

In the City Simulator model used in Boulder County, the depth of flooding at buildings across the community is estimated by assuming that when a rain storm occurs, a flood of equal probability occurs as well. Through this assumption, the depth of flooding at a building can be estimated using the corresponding depth raster for the storm of interest. For example, the simulation assumes that a 100-year rain storm (5.54 inches) will produce a 100-year flood in rivers across the county and the corresponding 100-year depth raster will give the depth of flooding for each building that intersects it.

Implicit within this assumption is that antecedent soil moisture conditions are at saturation when large storms hit, and, therefore, the incoming rain will translate entirely into river runoff. This assumption is conservative in the sense that some buffer is likely to be present in the soil column, which would absorb some of the flood impacts. However, events like the 2013 event—where the soil was heavily saturated from a 3-inch (10-year to 25-year) rain event the day before the large 9.1-inch rain occurred—show that the assumption may be warranted.

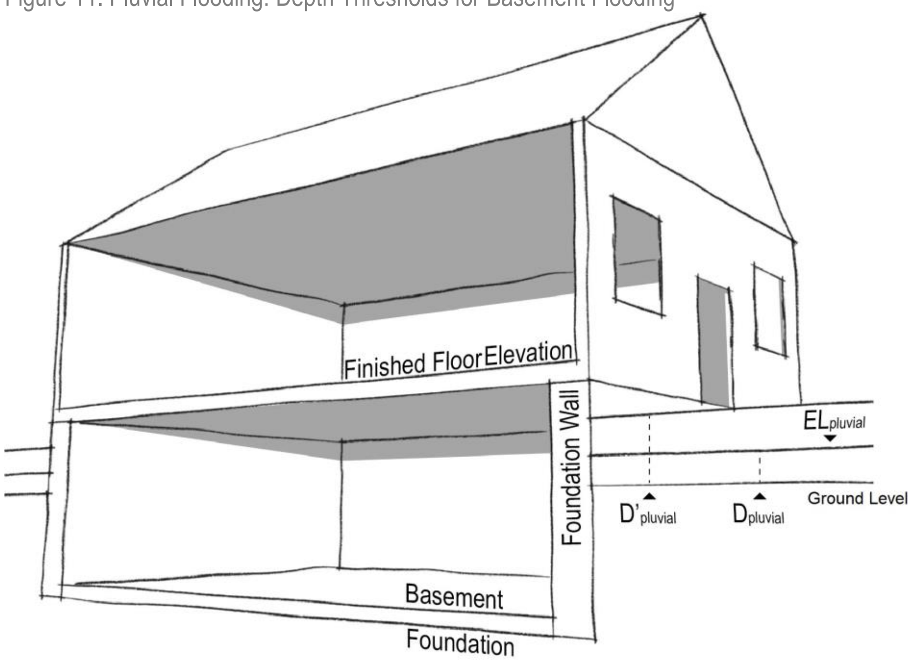
By using this assumption, a "rain-to-flood" response curve can be created for each building in the county by finding the depth of flooding for a range of storms estimated by a hydrologic and hydraulic model. In this assessment, rain-to-flood curves were created for buildings in both the incorporated and unincorporated county by using the results of a variety of hydraulic models run by the various jurisdictions across the county. For unincorporated Boulder County, depths were extracted from the HEC-RAS models from the 2017/2018 draft mapping from Colorado Hazard Mapping Program (CHAMP) study. They give the depth of flooding above ground level across the landscape for the various return period riverine floods (2-year, 5-year, 10-year, 25-year, 50-year, 100-year, 500-year). Several models were used for the incorporated parts of the county and ranged from HEC-RAS to MIKE-

FLOOD. For each, the models' depth raster results were used to extract the rain-to-flood curves.

As the simulation executes, the rain depth of each storm then is translated into a depth of flooding using the rain-to-flood curve. The curve is both interpolated between the return periods provided by the hydraulic models and extrapolated beyond them. This allows for modeling storms of any size—an important factor, given that future storms may extend outside the maximum 500-year return period modeled by traditional flood studies.

The simulation converts flooding depth to direct physical damage and contents damage estimates by way of the FEMA HAZUS model's flooding depth-to-damage curves. These curves have been developed over many years—primarily by the U.S. Army Corps of Engineers—and steadily made more accurate by including real insurance claims in their calibration. The family of curves accounts for building type (residential vs. commercial), number of stories, and whether the building has a basement. These attributes for each building were pulled from the county's building footprint GIS database and the county tax assessor parcel database.

Figure 11. Pluvial Flooding: Depth Thresholds for Basement Flooding



Part of the calibration process for the base scenario model was creating a 100-year event scenario with a simple 2-year time line. The total dollar damage levels experienced in this scenario were compared to the recent FEMA Losses Avoided Study (LAS) and they were found to be within 5 percent of each other. See Appendix 3 for more detail on the calibration process.

This calibration also was used to verify the estimated first floor elevation (FFE) for each building. FFE is an important attribute in the modeling process, as it directly and substantially impacts the flooding level estimates from the rain-to-flood curve, and by extension the dollar damage estimates. Given no county-wide dataset of FFE was available, a procedure was used that followed the LAS process, assigning FFE based on building type.

The close agreement between the LAS process's 100-year storm damage total and the 100-year event scenario's damage total found in the calibration process implies the FFE estimates are reasonably accurate on average. See Appendix 3 for more detail.

Rainfall-driven flooding can potentially impact Boulder much more significantly than flooding from riverine sources.

2.1.2 Flooding Outside the Floodplain

Rain-driven, or pluvial, flooding can be substantially more damaging than riverine flooding, which is the type of flooding that is the focus of FEMA flood models.

Within this assessment, a pluvial flood model was used to estimate damage to buildings from pluvial flooding both within the SFHA and 0.2 percent annual chance fringe and outside these flood zones.

This addition to the model included incorporating a “rain-plain,” which is a set of county-wide flood depth forecasts for the 10-, 100-, and 1,000-year rain events. See Figure 13 which depicts the 100-year rain-plains for Boulder County.

Like the process for modeling riverine flood, a rain-to-flood curve was developed for each building in the county using the rain-plains. When storms occur in the forecast, these curves were used to estimate rain-driven flooding at each building. Where the rain-driven flood depth was higher than the riverine flood depth, the rain-driven depth was used as the estimated flood depth for damage estimation purposes.

Incorporating a Depth Threshold for Pluvial Flooding Impact on Basements

As illustrated in Figure 13, the pluvial flood model predicts flooding across the landscape. Most of this flooding is one inch to two inches of depth. Within this assessment, this type of flooding was assumed to cause little damage, even with properties that have basements.

As Figure 12 shows, a threshold was introduced that specifies the level of pluvial flooding needed to impact buildings with basements. Based on a county-wide assessment—see Figure 14—a threshold of six inches was selected. This implies that even if pluvial flooding occurs around a building with a basement, it needs to reach six inches in depth before any damage is sustained in the building.

Pluvial Flooding: Setting the Depth Threshold for Basement Flooding

- Pluvial flooding represents accumulation of water because infiltration/runoff is not sufficiently fast to drain the surface.
- Pluvial flooding is unlike riverine flooding, which inundates the landscape and takes significantly longer to drain.
- Significant rainfall flooding depths ($D_{pluvial}$) are needed to fill a basement ($EL_{pluvial}$).
- Set a threshold, $D'_{pluvial}$
  - If $D_{pluvial}$ is less than $D'_{pluvial}$, there is no basement flooding
  - If $D_{pluvial}$ is equal to or greater than $D'_{pluvial}$, there is basement flooding up to $EL_{pluvial}$
- $D'_{pluvial}$ was set to 6 inches (rationale for which is documented in Appendix 3)

Figure 12. D’pluvial Sensitivity Analysis for Basement Flooding Threshold

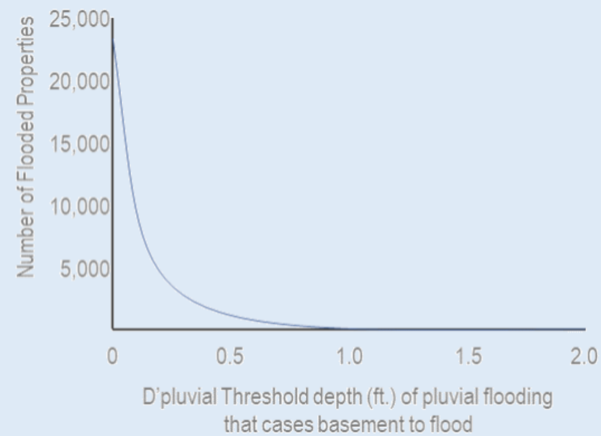
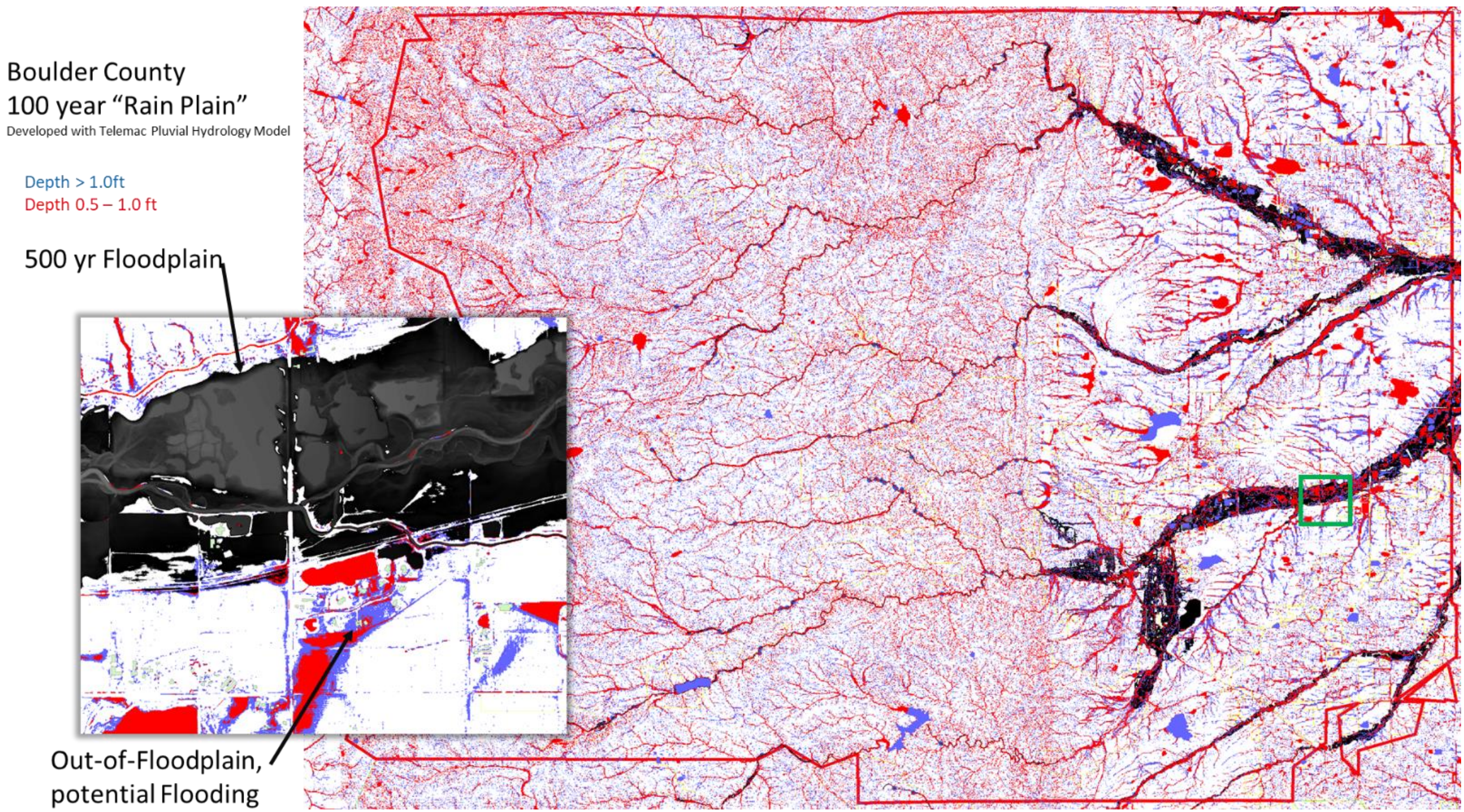


Figure 13. Boulder County “Rain-Plain”



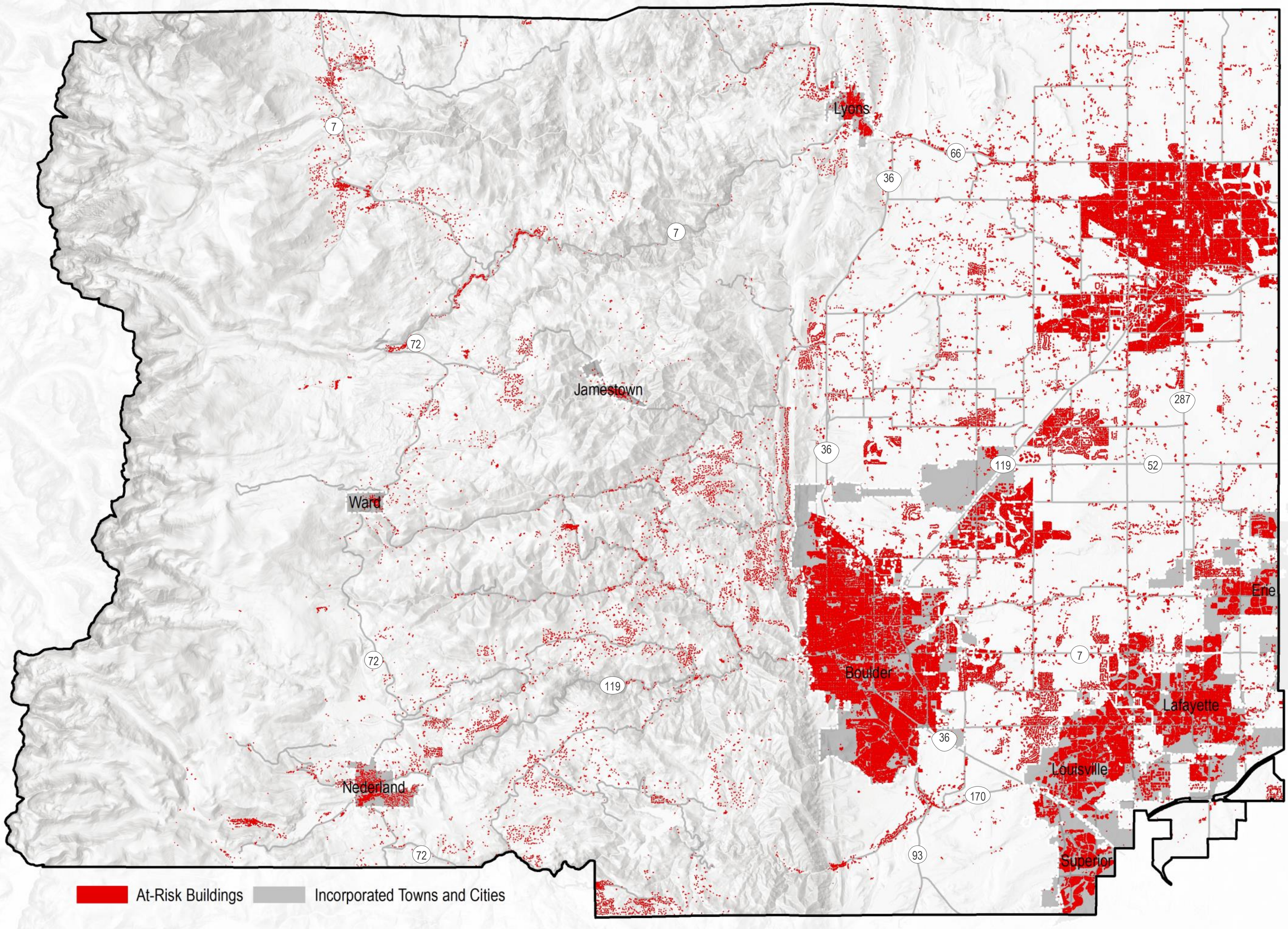


Figure 14: Structures with Potential Impact from Pluvial Flooding.

2.1.3 Base Scenario as a Bench Mark

The vulnerability assessment produces a “bench mark” on which alternative resiliency actions can be measured. Benefits provided by a resiliency action are quantified by comparing the values of metrics of economic robustness, damage to property, and disruption to normal community operation. As such, the results presented in Chapter 4 will be compared to the base scenario results presented in this chapter.

2.1.4 Key Metrics

To understand the degree to which each alternative resiliency action benefits the community, a set of key metrics was established and estimated in each of the scenarios simulated. These key metrics were designed to measure the amount of damage the community was suffering, as well as the disruption it felt during disaster events. The metrics are:

- **Building Recovery Days**: This is the total number of days that all buildings in the community are disabled on an annual average basis.
- **Disrupted Trips**: This is the total number of commutes that are disrupted due to home, workplace, or commute paths being flooded. The model’s travel module simulates commutes for each working individual in the community each day. It can, therefore, keep track of when a person’s home, workplace, or commute path are flooded and record the commute as being disrupted. See the travel simulation section of this report (Section 2.5) for more detail.
- **Lost Production**: This is the total salary not earned by community members due to disasters disrupting their ability to get to work.
- **Flood Damage**: This is the total amount of damage caused by floods across the community and annual average basis. It included direct damage to structures as well as contents damage.

Key metrics for the base run are described in the remaining sections of this chapter.

2.1.5 “Average Annual” Reporting

Most metrics reported in this Study are calculated as average annual figures. This means that they are the average of the metric per year over a long time frame. In the case of metrics like flood damage, this means the damage for the events has been summed up over the 2019 to 2050 time frame and then divided by the 32-year duration of the simulation to give an annual average number. Normalizing the metrics to annual averages allows for comparison between metrics in this Study and other studies. Unless otherwise noted, assume all metrics reported are “annual average.”

2.1.6 Vulnerability Assessment Elements

The remainder of this chapter explains:

- How future climate was incorporated into the base scenario
- The level of damage to buildings forecasted
- The forecasted damage resulting from pluvial (rain-driven) flood outside the floodplain; rain-driven flooding can be substantially more damaging than riverine flooding, which is the type of flooding that is the focus of FEMA flood models; this addition to the model included incorporating a “rain-plain,” which is a set of county-wide flood depth forecasts for the 10-year, 100-year, and 1,000-year rain events, and using these model results to forecast flooding at individual buildings across the county
- The impacts to the transportation system and the public that travels it during a flood
- The impacts to low- to moderate-income populations in the community
- Conclusions about the base scenario and guidance they provide for selecting resiliency actions for modeling in Chapter 4

2.2 Future Climate

Rainfall forecasts that include potential climate change influence show that in 40 percent of possible future scenarios, a storm the size of the 2013 event or larger is likely.

On September 12th and 13th 2013, a rain storm almost twice as large as any seen in recorded history fell on Boulder County, flooding homes and places of work, washing away whole sections of road, and disrupting the community for years (historic precipitation levels are shown in Figure 15).

This event put the residents of Boulder County on high alert for what future climate may bring. The base model run in this study uses a daily rainfall forecast to drive the day-to-day simulation of Boulder flooding. To ensure the influences of climate change are part of the simulation, the rainfall forecast was developed using an approach that integrates future climate projections from dozens of global climate model (GCM) runs with historical rainfall in Boulder County.

GCMs are coupled models of the earth's atmospheric, oceanic, and terrestrial systems. Their outputs are projections of rainfall and temperature that are considered our best estimates of future climate.

The GCM results used in this study were extracted from the coupled model inter-comparison project (CMIP5) online database. This database aggregates climate projections from more than 20 GCMs run by research centers around the world. The centers all run their models according to scenarios created by the UN intergovernmental panel on climate change (UN IPCC).

The scenarios are keyed to how global governments will control greenhouse gas (GHG) emissions in the future. The scenarios are named RCP2.5, RCP 4.5, RCP 6.0, and RCP 8.5. RCP – or representative concentration pathways - scenarios reflect the resulting GHG concentration that may occur depending on the level of GHG emission control in the future. RCP 2.6, for example means that in the year 2100, the radiative forcing (difference between incoming solar radiation absorbed by the earth and the energy radiated back into space) in year is 2100 is 2.6 W/m^2. The higher this number is, the more energy is retained in the earth's atmosphere.

In this study, the RCP8.5 scenario was used to create all rainfall forecasts, as it represents the worst-case scenario in terms of climate variability.

Using the RCP8.5 forecasts from 63 GCM model runs, Monte Carlo Simulation was used within this study to generate 630 plausible realizations of future climate. Each of these realizations was then given a Severity Index, which is a measure of the cumulative rainfall amount over the 32-year timeframe of the forecast. The 630 realizations were then ranked by severity and the 0th, 5th, 25th, 50th, 75th, 95th, and 100th percentile realizations were extracted as the ensemble of forecasts used to run the base scenario. See Appendix 3 for how climate forecasts were made.

Figure 15. Boulder County Daily Precipitation

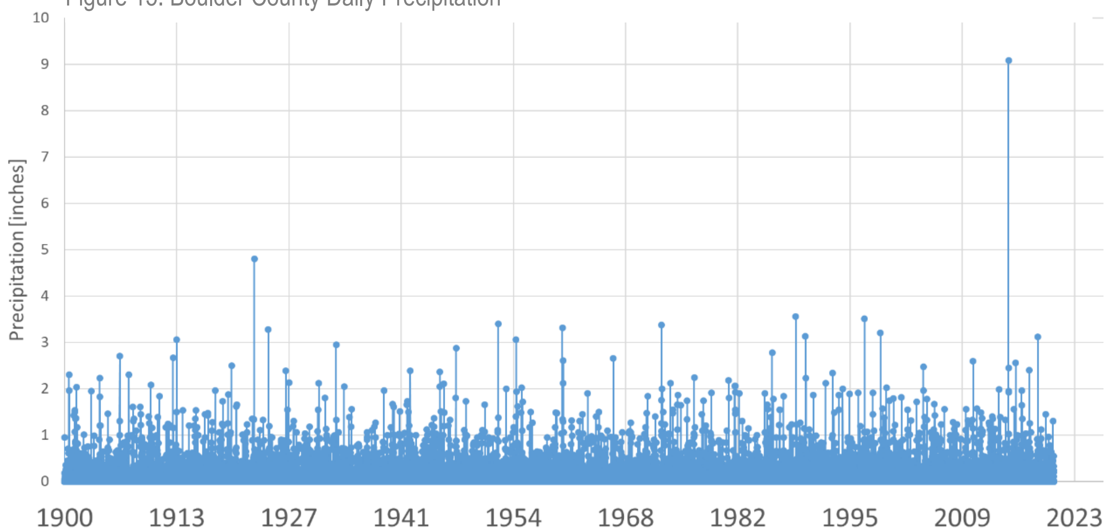


Figure 17. Ensemble of daily rain forecasts used in the vulnerability study

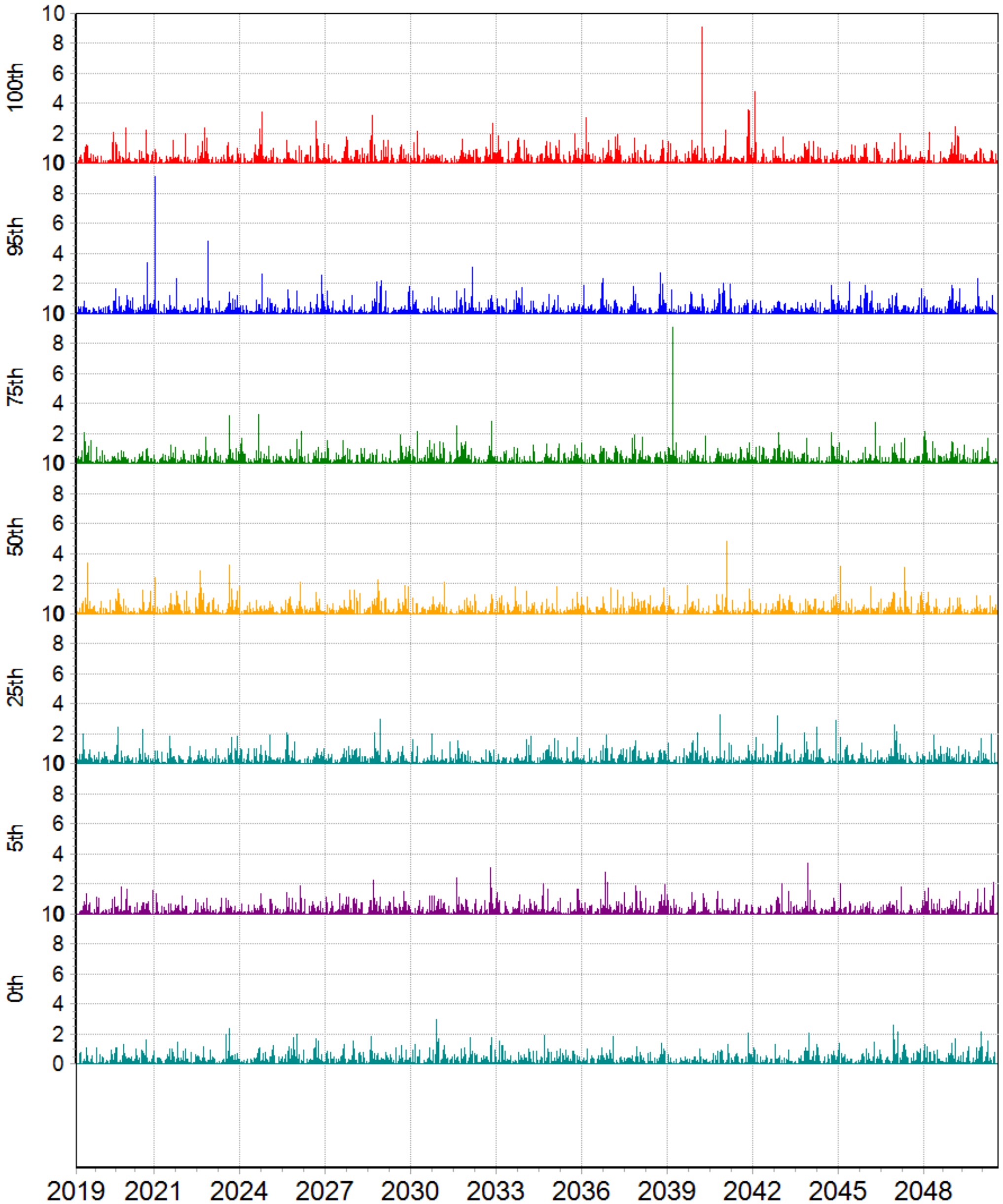


Figure 15 shows the array of forecasts of daily rainfall. Note that in the 0th percentile forecast, the maximum rain events are approximately 3", while the 100th percentile forecasts are as high, or in some cases higher than the 2013 event's 9.1 inch 24-hour rain total. Moreover, in the 100th percentile event, there are multiple storms in the 4 to 5 inch range in addition to a large 9 to 10 inch storm, a series of events that would certainly challenge the county.

The forecasting process showed that for 40 percent of the realizations, an event similar in size or larger than the 2013 event was present. This can be seen in the 75th, 95th, and 100th percentile forecasts.

For the base scenario, the Study assumed that each of these realizations are equally plausible, accordingly, simulations were run for each. The result was a distribution of estimates for each of the key metrics in the study. Figure 5 shows the distributions of 7 of the key metrics.

Using Figure 17, the study team selected the 75th percentile forecast as the key forecast to use when testing all the alternative actions described in Chapter 4. Considerations in choosing this forecast specified that the forecast should:

- Include events like the 2013 event,
- Not be overly conservative, to avoid projected costs for improvement that are untenable,
- Cover most plausible futures to provide confidence in the selected actions.

The 75th percentile falls close to the center of the range of plausible values for all 7 of the key metrics (see Figure 17) and by definition is as impactful or more than 75 percent of the possible futures Boulder may experience.

2.2.1 Major Storm Events in the 75th Percentile Forecast

The NOAA Atlas 14 web tool provides statistical estimates of the depth of rain that falls in 24 hours for storms of varying probability. As Table 1 shows, the 2-year storm – the storm that has a 50 percent probability of happening in any given year – has a 24-hour rain depth of 2.08 inches, while the 100-year storm – the storm that has 1 percent probability of happening in any given year – has a much higher 5.54 inch 24-hour rain depth. Referring to Figure 17, the 75th percentile forecast shows there is one storm in year 2024 that exceeds the 10-year return period threshold of 3.27 inches, while a very large storm similar to the 2013 event occurs in year 2039. These are the primary storms that will stress test the community in the simulation. At other times throughout the time line, multiple storms occur, but they are small enough to not impact buildings or the transportation system.

Table 1. Historical estimate of depth of rain that will fall over a 24-hour period vs. the probability the event will occur in any given year

Return Period (years)	**Probability** (percent)	**Rainfall** (inches)
2	50	2.08
5	20	2.71
10	10	3.27
25	4	4.11
50	2	4.80
100	1	5.54
500	0.2	7.42

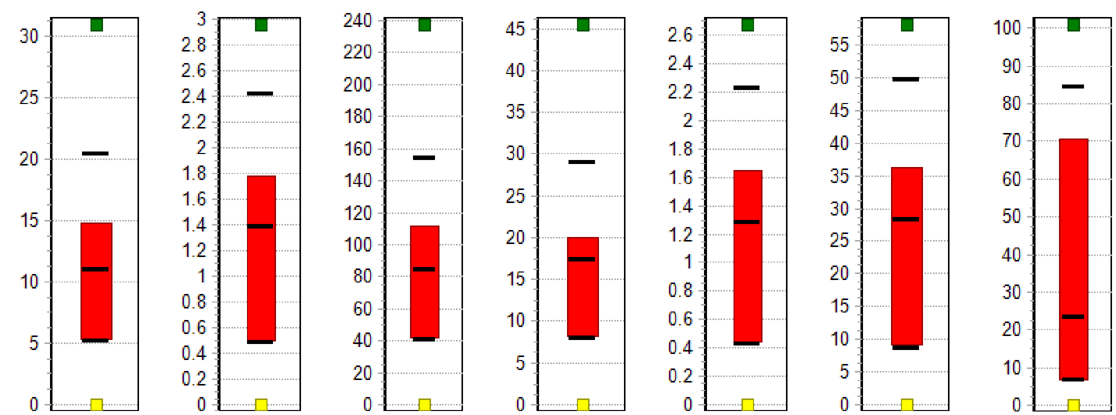
Source: Based on historical rainfall data at Boulder, Colorado (provided by NOAA Atlas 14 site).

It is important to note that the though this study uses this one realization (75th percentile) of future weather as the driver for stress testing the community, many other realizations may occur with similar probability. These realizations may include large storms in the very near future as well storms that happen in quick succession. This study does not explore the influence of storm timing and frequency on the community; future studies should explore impacts due to these variables.

Figure 18. Base Scenario Key Metrics

Building-Recovery Days	Disrupted Trips	Work Flood	Home Flood	Road Flood	Lost Production	Flood Damage
14.7 K	1.78 M	111 K	19.9 K	1.64 M	$36.3 M	$71.8 M

The top boxes give the value for the 75th percentile rainfall severity forecast. The box plots below give the range of results for the 0th (bottom point), 5th (bottom black line), 25th (bottom of the red box), 50th (middle black line), 75th (top of red box), 95th (top black line), and 100th (top point) rainfall scenarios. In the Study, the 75th percentile rainfall forecast was used to evaluate numerous top resiliency actions (see Chapter 4).

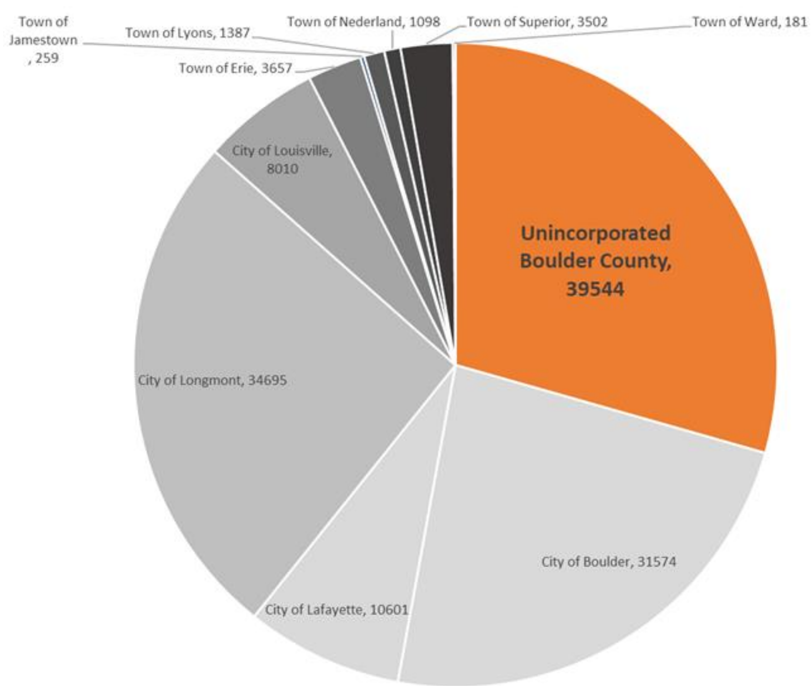


2.3 Damage to Buildings

A primary interest in this study is the vulnerability of the building stock to future flood events. According to a recent FEMA Losses Avoided Study, thousands of homes and commercial buildings were impacted in the 2013 event with approximately $112 million in property and contents damage.

Boulder County is home to 135,508 buildings, 39,544 of which are in the unincorporated county (see Figure 20). Of these, 4,343 are commercial, while 33,041 are residential. According to the county tax assessor database, the average replacement value for residential single-family homes in unincorporated Boulder County is $426,000, while the average market value is $653,000.

Figure 20. Boulder County Building Counts



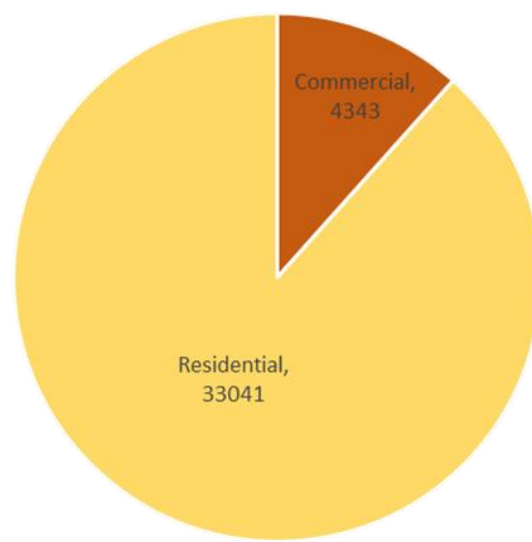


Table 2 and Figure 20 show that there are 1,642 buildings in the special flood hazard area (SFHA), while another 573 are within the 0.2 percent annual chance floodplain fringe.

14,762 of the buildings in unincorporated Boulder County have basements, or about 37 percent, a structure feature that is typically vulnerable to flood.

2.4 Growth Projections

The 32-year simulation added 117 new buildings to the SFHA flood zone, 52 new buildings to the 0.2 percent annual chance fringe, and 229 new buildings outside these zones. This resulted in 1,759 buildings in the SFHA, 625 in the 0.2 percent annual chance fringe, and 35,398 outside these zones by the year 2050 of the simulation.

As described in Appendix 3, the growth rate was adjusted to ensure that the county hit full build-out at the last year of the simulation, 2050. This resulted in a slow growth rate, which is reasonable given the zoning laws in the county.

2.5 Flooding Impacts

The base scenario revealed that widespread damage can be expected from future floods. See Sections 2.3 and 2.5 for details on the number of buildings damaged and the losses from this damage as well as the distribution of damage across the county. Key findings from the simulations are:

- 993 of the 1,759 buildings (56.4 percent) in the SFHA in unincorporated Boulder County flooded at least once between 2019 and 2050 in the simulation.
- 128 of the 625 buildings (20.4 percent) in the FEMA 0.2 percent annual chance fringe flooded at least once between 2019 and 2050.
- 161 of the 35,398 buildings (0.45 percent) outside the 0.2 percent annual chance floodplain flooded at least once between 2019 and 2050. This was due to pluvial flooding.
- Over the 32-year simulation, the two simulated major storms caused an average $83,820 in total damage per building to structures in the SFHA in Unincorporated Boulder County, or about $2,619 per year. In the 0.2 percent annual chance floodplain fringe, the average total damage per building was $63,940 or about $1,998 per year. Outside these zones, the total damage was $53,710 on average, or about $1,678 per year.

The dollar damage amounts in Table 2 are estimated by calculating the depth of flooding likely to occur in a given flooded building and then translating that into an estimate of direct physical damage to the building and damage to the contents of the building.

In unincorporated Boulder County, buildings in the Special Flood Hazard Area (SFHA) have a 56 percent chance of sustaining flood damage over the 32-year simulation.

2.5.1 Pluvial Flood Impacts

The base scenario results revealed that given the assumptions made in the simulation (Section 2.1), pluvial flooding impacts were limited in the county. As Table 2 shows, of the 35,398 buildings outside the FEMA SFHA and 0.2 percent annual chance fringe (see Figure 18), 161 were impacted by pluvial flooding.

A close investigation of the simulation results showed that this finding stemmed from:

- Setting the first-floor elevation (FFE) for each building according to the approach used in the recent FEMA losses avoided study, and
- Calibrating the simulation such that the percentage of damaged properties in the 100-year storm matched the FEMA study's 100-year storm assessment.

Both of these steps resulted in a minimum FFE of 1.0 feet above ground for any structure across the county. Many structures – like mobile homes – had FFE's at four feet or higher. These FFEs were high enough to prevent most pluvial flooding, the majority of which had ponded depth below the 1-foot mark. See Appendix 3 for more detail on the modeling assumptions made.

Table 2. Building Damage Metrics

Metric	SFHA	0.2% Annual Chance Fringe	Outside Floodplain	All Commercial and Residential
All Buildings				
Num Buildings (Base | New | Total)	1,642 | 117 | 1759	573 | 52 | 625	35,169 | 229 | 35,398	37,384 | 398 | 37,782
Average Replacement Value [$M]	$0.62	$0.50	$0.37	$0.57
Num Damaged Buildings	993	128	161	1,282
Total Loss [$M]	$233.15	$15.98	$10.57	$259.70
Average Loss [$K]	$181.61	$100.35	$62.49	$158.54
Average FFE above Ground [ft]	2.01	0.62	1.38	1.79
Commercial Buildings				
Num Buildings (Base | New | Total)	302 | 4 | 306	95 | 0 | 95	3,946 | 30 | 3,976	4,343 | 34 | 4,377
Average Replacement Value [$M]	$1.66	$1.72	$0.96	$1.61
Num Damaged Buildings	225	19	20	264
Total Loss [$M]	$146.10	$6.84	$2.49	$155.43
Average Loss [$K]	$515.39	$309.25	$124.46	$470.94
Average FFE above Ground [ft]	1.69	1.42	1.25	1.63
Residential - Single Family Home				
Num Buildings (Base | New | Total)	1,151 | 13 | 1,164	415 | 2 | 417	29,675 | 49 | 29,724	31,241 | 64 | 31,305
Average Replacement Value [$M]	$0.33	$0.31	$0.28	$0.32
Num Damaged Buildings	684	82	140	906
Total Loss [$M]	$77.17	$4.96	$7.97	$90.10
Average Loss [$K]	$83.89	$53.06	$53.52	$76.41
Average FFE above Ground [ft]	2.34	1.44	1.39	2.12
Residential - Multi-Family Home				
Num Buildings (Base | New | Total)	1 | 100 | 101	0 | 50 | 50	88 | 150 | 238	89 | 300 | 389
Average Replacement Value [$M]	$0.24	$0.25	$0.17	$0.24
Num Damaged Buildings	51	24	1	76
Total Loss [$M]	$9.65	$4.18	$0.11	$13.94
Average Loss [$K]	$129.08	$109.04	$79.38	$122.10
Average FFE above Ground [ft]	-2.19	-3.25	2	-2.47
Residential - Mobile Home				
Num Buildings (Base | New | Total)	188 | 0 | 188	63 | 0 | 63	1,460 | 0 | 1,460	1,711 | 0 | 1,711
Average Replacement Value [$M]	$0.03	$0.00	$0.00	$0.03
Num Damaged Buildings	33	3	0	36
Total Loss [$M]	$0.24	$0.00	$0.00	$0.24
Average Loss [$K]	$12.47	$0.42	$0.00	$11.46
Average FFE above Ground [ft]	3.78	4	0	3.8
Residential – All				
Num Buildings (Base | New | Total)	1,340 | 113 | 1453	478 | 52 | 530	31,223 | 199 | 31,422	33,041 | 364 | 33,405
Average Replacement Value [$M]	$0.31	$0.29	$0.28	$0.30
Num Damaged Buildings	768	109	141	1018
Total Loss [$M]	$87.06	$9.14	$8.08	$104.28
Average Loss [$K]	$83.82	$63.94	$53.71	$77.52
Average FFE above Ground [ft]	2.1	0.48	1.4	1.83

Table 3. Individual Storm Metrics

	Unincorporated Boulder County	Unincorporated Boulder County
Simulated Storm Date	9/5/2039	4/24/2025
Storm Rain Depth	9.08 Inches	3.28 Inches
Number of Buildings Damaged	1,280	166
Number of Infrastructure Assets flooded	227	104
Number of Homes Damaged	1,016	132
Number of Workplaces Damaged	264	34
Average Duration of Building Repair	16 days	11 days
Average Duration of Infrastructure Asset Repair	104 days	58 days
Total Building Damage ($ Million)	$433	$31
Total Building Damage – Residential ($ Million)	$168	$16
Total Building Damage – Commercial ($ Million)	$265	$15
Number of People Impacted by Work Flood	4,031	552
Number of People Impacted by Road Flood	68,746	51,645
Number of Working People Impacted by Home Flood	899	103
Average Depth SFHA Flooding (feet)	3.13	1.39
Average Depth 500-year Fringe Flooding (feet)	1.94	0.55
Average Depth Outside Floodplain Flooding (feet)	0.91	1.25
Number of Homes Damaged - Rain	154	53
Number of Homes Damaged - Riverine	862	79

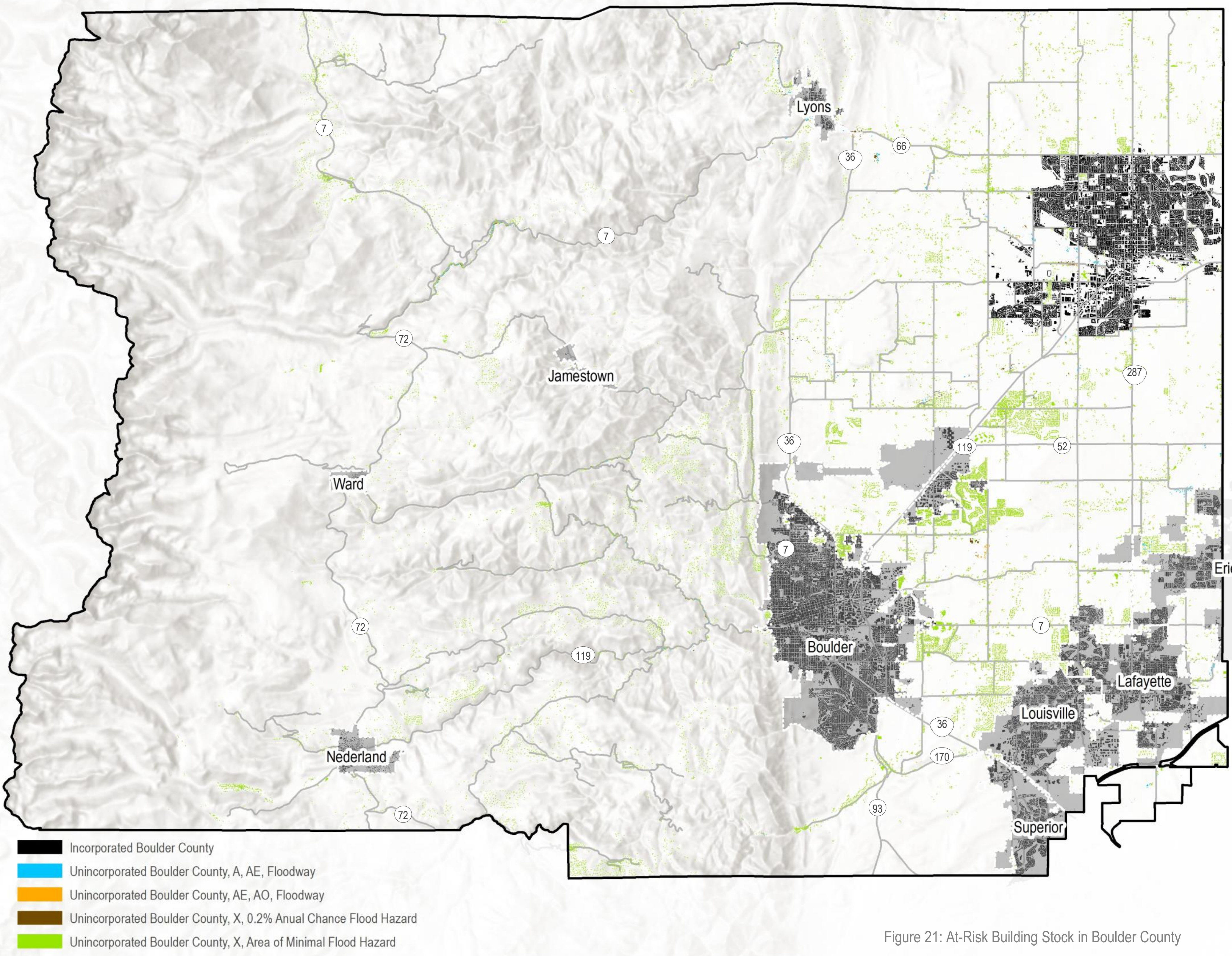


Figure 21: At-Risk Building Stock in Boulder County

2.5.2 Basements

As mentioned above, buildings with basements are a key concern in the vulnerability study. The study found the following:

- Few commercial properties had basements, and therefore the number of commercial properties with basement flooding was minimal.
- Nearly 20 percent (76 of 389) multi-family homes were damaged by flood over the course of the simulation. The average peak depth of flooding was 6.65 feet. This was due to a large percentage of these homes having basements.
- Mobile homes did see flooding above ground level but not above their FFE. The fact that these homes typically don't have basements resulted in their sustaining little damage. Of course, the depth of flooding they experienced (often 2 to 3 feet above ground) would pose a challenge to the foundations of these structures.

2.5.3 Recovery

As the simulation models both the impact of storm events and the recovery from those impacts, the study provided the opportunity to measure how long the buildings stock will take to recover in the wake of large storms.

Building stock that is unusable due to flood damage has ripple effects through the community economy, as residents or workers who use the buildings are disrupted from their normal lives. As described in sections 2.1 and 2.5, the simulation quantifies this disruption as a measure of total community productivity.

The simulation estimates recovery time as a function of the depth of flooding in the building and the quality of the building. Table 3 shows the following:

- The 2024 storm event resulted in average building recovery times of 11 days,
- The 2039 storm event resulted in average building recovery times of 16 days,
- By far, the largest reason for disruption is road flooding, which eclipses flooding of homes and work places.

2.6 Infrastructure

As Section 2.3 revealed, flooding of the county's building stock can cause considerable disruption as residents are prevented from carrying out their daily lives in their homes and workplaces. Another key cause of disruption is the impact of flooding on the transportation system. Commute paths blocked by flood and its damaging effects on transportation infrastructure can, at the least, cause travelers to detour and reduce their available productive time and, at the worst, prevent travelers from getting to work at all.

Within the vulnerability assessment, an agent-based model was created to simulate travel activity within the community over the full 2019 to 2050 time-frame. An agent-based model creates a virtual population that lives and works in the city. Each commercial building is filled with jobs, which are occupied by workers. The workers then are given homes, which range from walking distance to many miles away. Those agents that must drive are given a commute path, which is a set of road segments they must travel each day to get to work.

Through modeling the entire population and its commute behavior each day of the 2019 to 2050 timeline, the simulator can estimate vehicle miles traveled, trips taken on each road segment, carbon footprint, congestion levels, and—most germane to the Study—the disruption caused when road segments are closed due to disasters.

Using U.S. Census block-group level estimates of population and jobs, a virtual population of 325,000 people was created to match the number and distribution of people in the 203 census block groups that cover the county. The labor force was assigned places of work such that the average commute times in each block group matched the census estimates.

The commute paths for each person in the labor force were determined by a procedure called the Dykstra algorithm, which finds the shortest distance in the road network from one place (home) to another (workplace).

Along the county's road network, 255 vulnerable transportation infrastructure asset locations were identified. These included major structures such as large bridges, minor structures such as culverts, and segments of road that frequently flood.

Each of these structures was assigned an overtopping curve, which is like the rain-to-flood curves assigned to each building (see Section 2.3). The overtopping curves estimate the level of overtopping (depth of water above the road level) corresponding to the 10-, 25-, 50-, 100-, and 500-year storm events. Using these curves, the simulator can estimate the level of flooding that each of the 255 assets would experience during major storms. See Figure 22, for an illustration of how an overtopping curve is built. The water surfaces in the figure correspond to the 10-, 25-, 50-, 100-, and 500-year storms. The depth of water for each surface is extracted at the location of the bridge/culvert/frequently flooded road. The depths and their corresponding storm sizes, which are measured either as a return period (10-year, 25-year, 50 year, etc.) or as a depth of rainfall of equal return period, then make up the curve shown in the chart. The overtopping curves for the top 10 most disruptive transportation infrastructure locations are shown in Figure 25 and in the top 10 list presented later in this section.

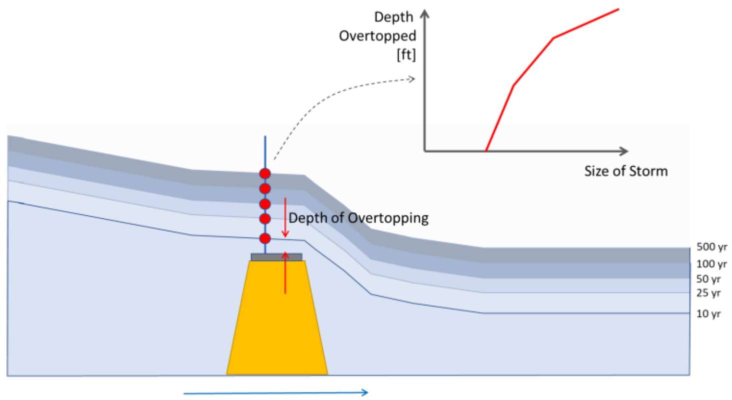
Boulder County's transportation infrastructure is also a source of vulnerability; agent-based activity modeling shows flooded streets, overtopped culverts, and washed out bridges cause even more disruption than flooded buildings.

In the vulnerability assessment, it was assumed that with up to 1 foot of overtopping, the roadway would be flooded and impassable but would recover in a matter of days. If the overtopping went higher than this threshold, it was assumed that the power of the flooding water would damage the roadway such that a significant span of time would be needed to repair it (30 days for minor structures and low road segments, 12 months for major structures).

Where the disrupted road segments were on residents' commute paths, it was assumed that all residents that take that road would be disrupted as they tried to get to work. The top disrupting transportation infrastructure assets were, therefore, those bridges, culverts, and low road segments that are both highly trafficked and frequently flooded.

Figure 24 shows a map of the 255 transportation infrastructure assets sized according to their level of disruption. As expected, the largest disruptors are in and around the urban centers in transportation infrastructure assets that are in unincorporated Boulder County but serve residents moving into and out of the cities for work.

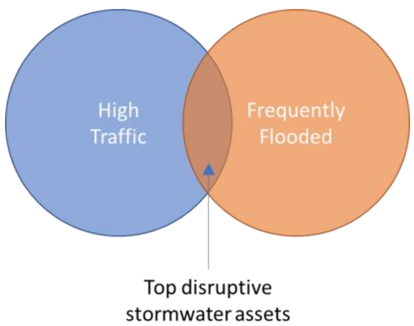
Figure 22. Diagram of Overtopping Frequency and Depth



Overtopping for each bridge, culvert, and frequently flooded road segment is estimated using the county's existing CHAMP hydraulic models. The depth of overtopping determines how badly the road is damaged and how long recovery to normal traffic will take.

Figure 25 shows the top 10 disruptors in terms of the average annual trips they block due to flooding. The table provides the type of asset, the road it impacts, and the estimated average annual trips it disrupts. In Appendix 4, additional details are provided for each disrupted infrastructure asset.

Figure 23. Top Infrastructure Assets Both Flood Frequently and Support Higher Levels of Travel



2.6.1 Estimating Impact to the Community Productivity

While flooded roads may disrupt traffic, they rarely prevent a trip to work from being made at all. Rather, they lengthen travel time as travelers must take alternate routes. In the case of remote locations, like the western portion of the county, the impact may be greater, as alternative routes may not be available.

The simulator estimates community productivity as the number of hours worked by residents multiplied by their hourly pay rates. Within this vulnerability assessment, the number of hours worked by a person disrupted by road flooding was assumed to be inversely proportional to how remote their commute is. That is, when a road segment on the commute path was blocked, if that road segment is very remote, the traveler is assumed to be highly disrupted and perhaps won't make it to work at all. On the other hand, if the road segment is surrounded by other roads, then an alternative path was assumed to be easy to find. Adopting this model required estimating the remoteness of each of the 255 transportation infrastructure assets. Figure 28 shows the remoteness index that was calculated for each asset. The surface in the map is the density of road segments. Those assets in very high-density areas had very low remoteness indexes. The opposite is true in the low-density areas.

The remoteness index was used to fit a model of number of hours worked with a length of interruption. Commuters would be interrupted a minimum of 30 minutes for urban areas and a maximum of the entire day for very remote areas, as follows:

- If the remoteness index of a damaged asset along the path of the agent is 8 or higher, then the agent misses work entirely.
- If the remoteness index is 1, then the agent misses 30 minutes of work.
- If the remoteness index is 2 through 7, then an agent misses between 1 to 8 hours, based on a remoteness index based formula.

As Figure 27 shows, the unincorporated Boulder County production is impacted greatly by flood in the base scenario. Some $33.6 million on average per year is lost due to floods occurring, and a large portion of that can be attributed to road flooding.

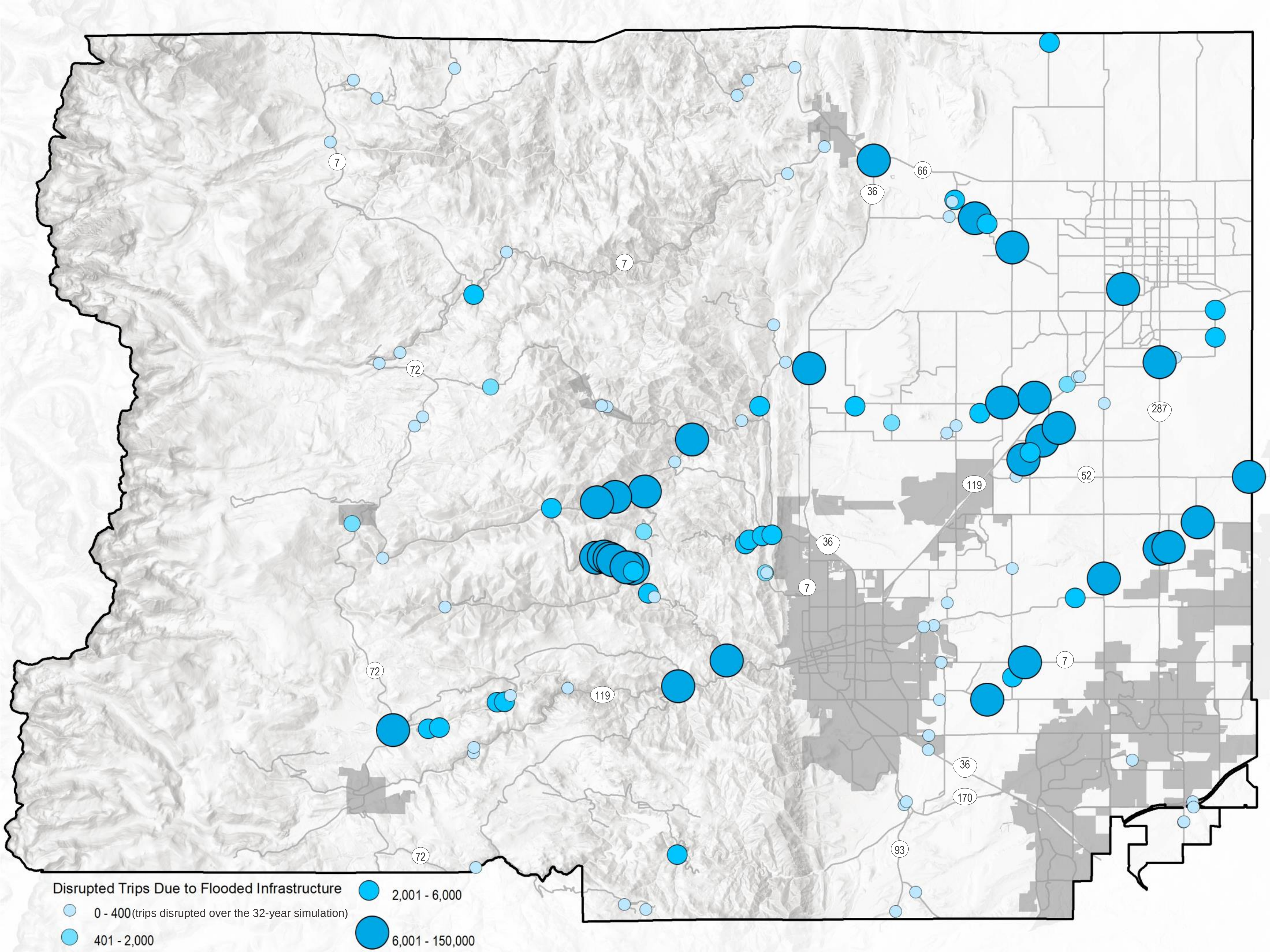


Figure 24. Infrastructure Assets by Level of Disruption

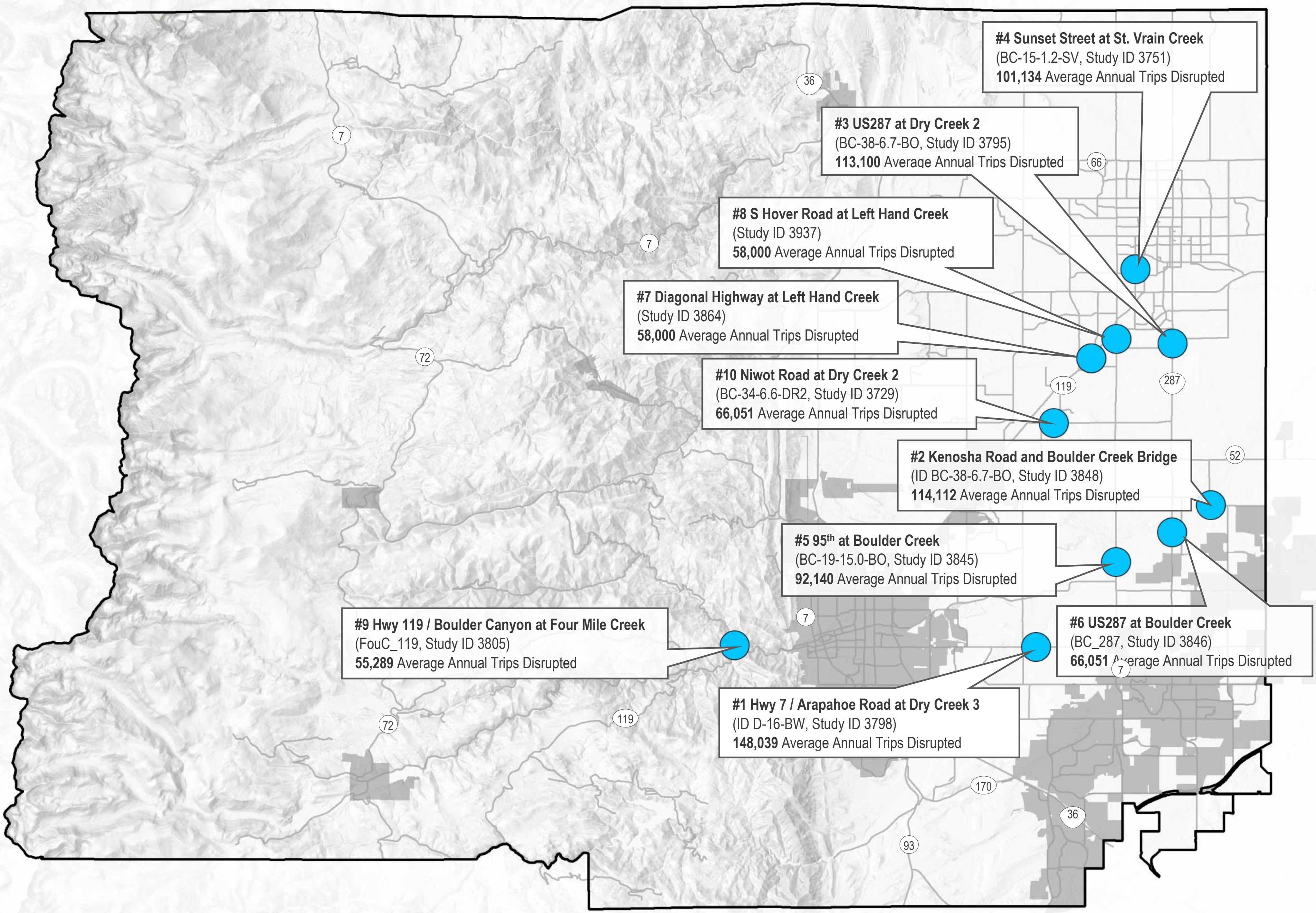


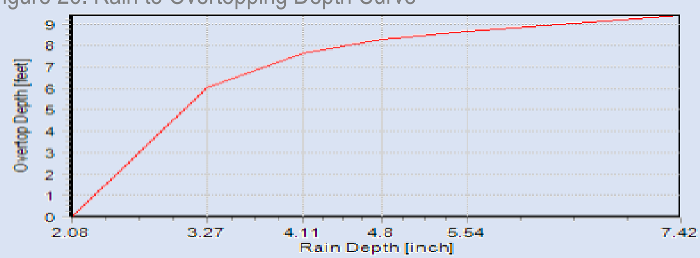
Figure 25. Top 10 Most Disrupted Transportation Infrastructure locations

Understanding Disruption Values

Figure 25 lists a "disruption" value for each of the top ten disrupted assets. Understanding these disruption values and what they tell us can help interpret the meaning of the tables and subsequent prisonization in addressing these infrastructure needs. For example, Figure 26 shows infrastructure asset number BC-38-6.7, which is a major structure on Kenosha Road that passes over Boulder Creek on the east side of the Boulder County (see Figure 25 and the maps provided in Appendix 4 for the location of the asset).

This bridge is the second highest disruptive asset county-wide, with approximately 114,000 trips disrupted on average every year. This average can be attributed to the two major storm events, which both cause a 365-day complete loss of service from this bridge as it is repaired. The approximately daily 5,000 trips that are made over this bridge are forced to find other routes to get to work and school.

Figure 26. Rain to Overtopping Depth Curve



Level of Disruption by Cause

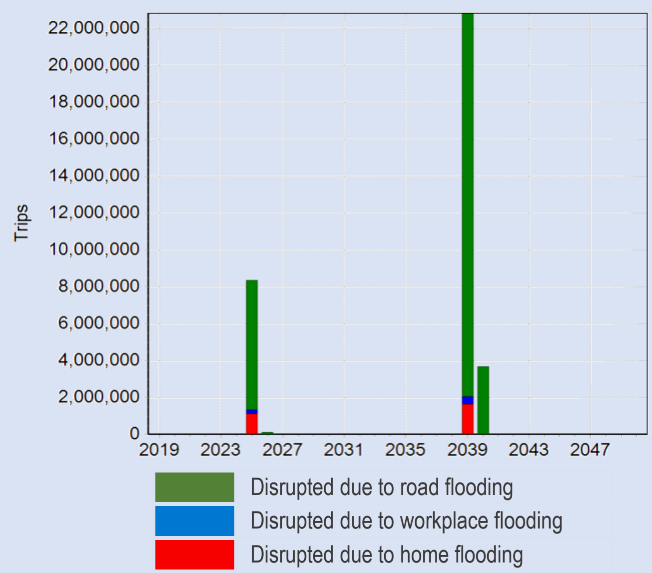
The overall level of disruption is shown in Figure 27 which is a chart of disrupted trips over the time span of the simulation. The chart shows that disruption due to road flooding is bar none the dominant disruptor to returning to productivity post-flood in the county.

The chart shows that road flooding causes a majority of disruption to day-to-day productivity in the community after each disaster. Over the course of the simulation, 90 percent of the disrupted trips can be attributed to road flooding, while 7.5 percent can be attributed to workplace flooding and 2.5 percent to home flooding.

In the case of the large event in 2039, this disruption stretches into the following year as many commuters are dependent on the major bridges that are impacted during the event, bridges that require 12 months to recover and return to service.

It should be noted that disruption can be caused by a combination of road, workplace, and home flooding. In individual cases, a person's workplace and commute path can both be flooded at the same time, for example. In these cases, the road flooding is reported as the cause. But, as Chapter 4 will report, improving the top disrupting transportation infrastructure will reduce overall disruption significantly.

Figure 27. Trip Disruption: Time series of disrupted trips over simulation time line. Disruption to community productivity is 90% caused by road flooding, as opposed to building flooding.



Top 10 asset maps, overtopping charts, and disruption totals are available in Appendix 4.

$33.6 million per year is lost in productivity is due to floods. 92 percent of losses are due to roads flooding, which disrupt 1.64 million trips per year on average.

In areas with dense road networks, residents can find other paths to work and their lost productivity is reduced. In remote areas, residents frequently do not make it to work for many days after major storm events.

2.6.2 Evacuation and Emergency Routes

The vulnerability assessment produced disruption rates for each of the transportation assets in the county. Using these, the county can either:

1. Evaluate the potential for their existing evacuation and emergency routes to be impacted in the future, and the magnitude of those impacts. They also could quantify the benefits of elevating the route to ensure it is not overtopped during disasters.
2. Isolate routes that have minimal impacts and designate these as emergency and evacuation routes, thereby reducing the needed investment to ensure viability during disaster events.

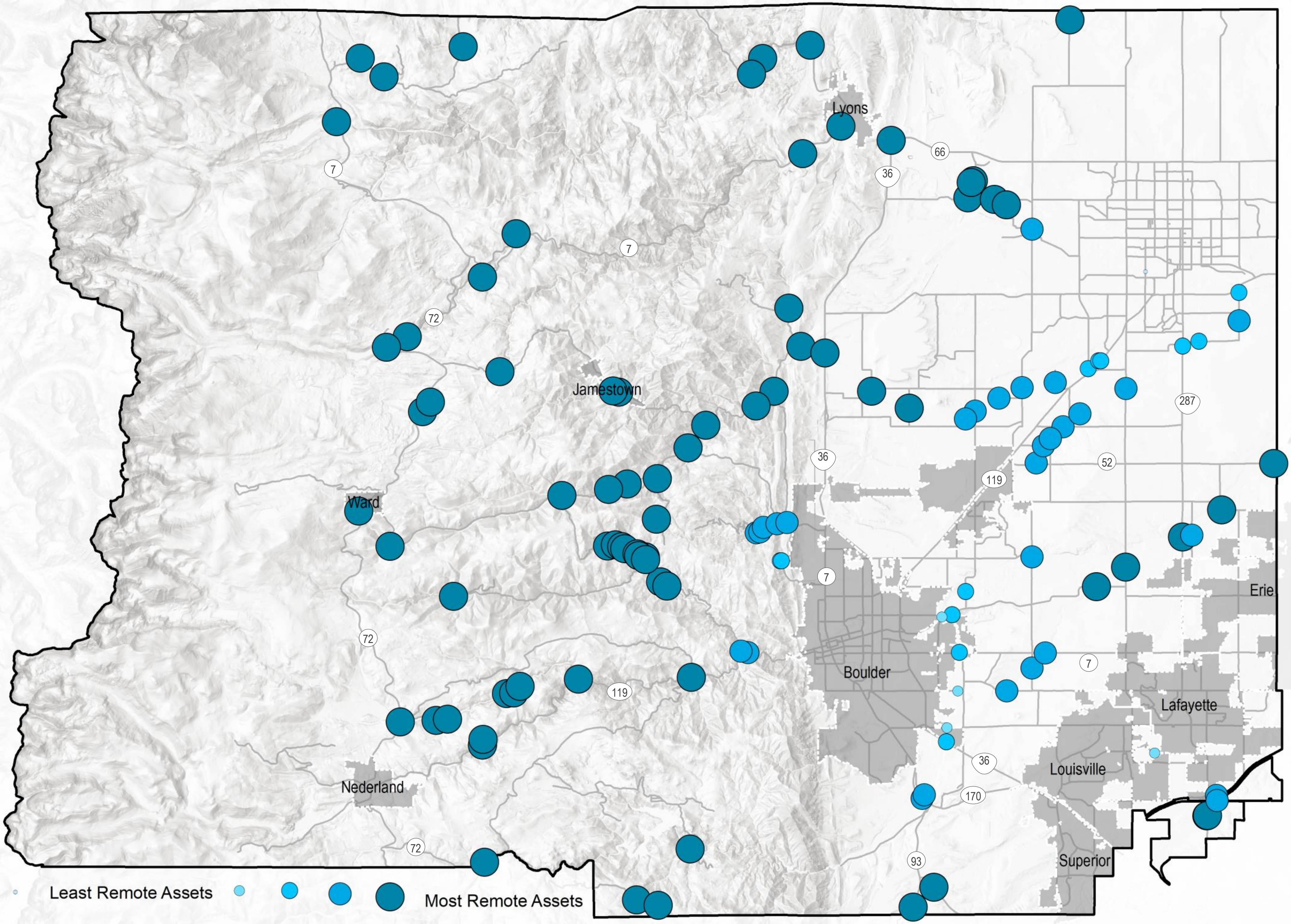
This analysis was not undertaken during the Study, but future analyses can build on the disruption data developed for each transportation asset to quickly examine these questions.

2.7 Conclusions

The vulnerability assessment generated several conclusions about impacts that Boulder County can expect to experience given simulated storm events. For example, in 40 percent of future realizations developed by the Study's City Simulator model, at least one flood event equal to, or bigger than, the 2013 event was forecasted to occur. This event was found to cause widespread damage to the county's building stock. Flood impact on transportation was found to be the largest source of disruption, pointing to a need to raise and enlarge the county's transportation infrastructure assets such as bridges, culverts, and frequently flooding road segments to ensure roads remain open.

Actions need to focus on making existing and new building stock more robust, so that initial impacts are lower. Actions should also focus on improving the transportation infrastructure, so that the community can return to operation as quickly as possible.

These conclusions point to a need for wide-ranging resiliency actions that are balanced to achieve the greatest benefit at the most manageable cost level possible. In Chapter 3 and Chapter 4, such resiliency actions are proposed and evaluated.



Lyons
Jamestown
Ward
Nederland
Boulder
Erie
Lafayette
Louisville
Superior
7
66
36
72
119
52
287
93
170
Least Remote Assets
Most Remote Assets

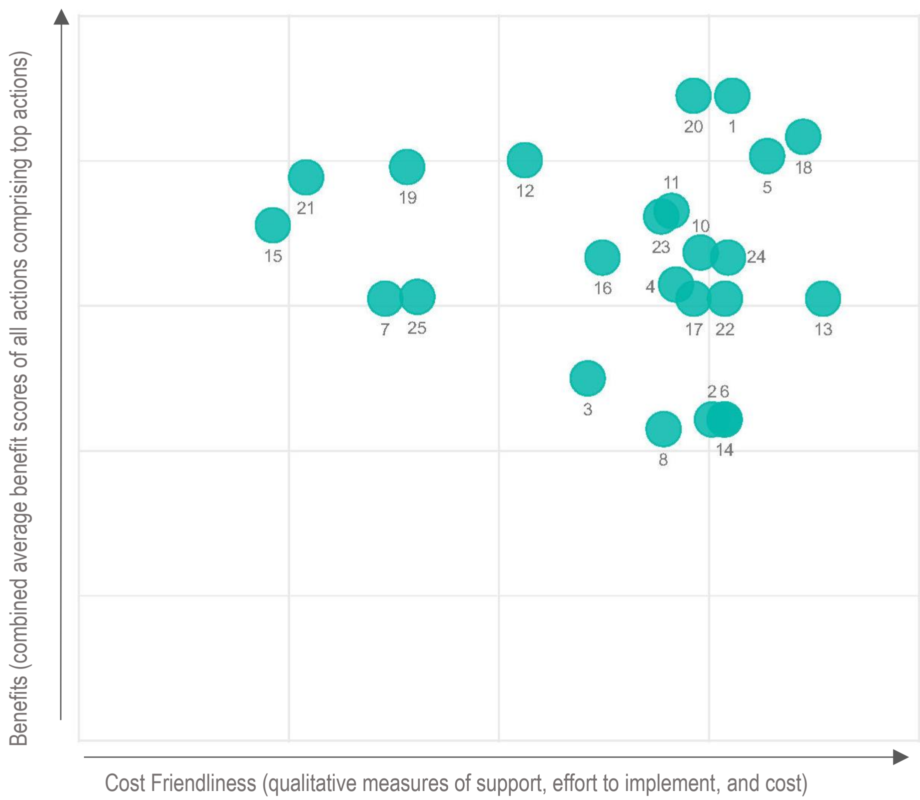
3 Identifying Top Resiliency Actions

Apple Valley Road Bridge, Lyons, Colorado. Photo: Thaddeus Road

3 Identifying Top Resiliency Actions

"Top actions" are potential resiliency actions that were shown to have the greatest potential positive impact in achieving resiliency goals and objectives. Through a qualitative analysis, these were determined to be reasonable in terms of their financial cost, level of effort to implement, and likelihood of obtaining support (see Figure 29). The selection of potential top actions considered the benefit and cost evaluation scores summarized in Figure 7 in terms of overall score, but also the composition of that score, as illustrated in Figure 29. In addition, actions with lower overall scores, but high scores for one goal (e.g., Goal 3, "respond to shocks") were elevated to top-action status.

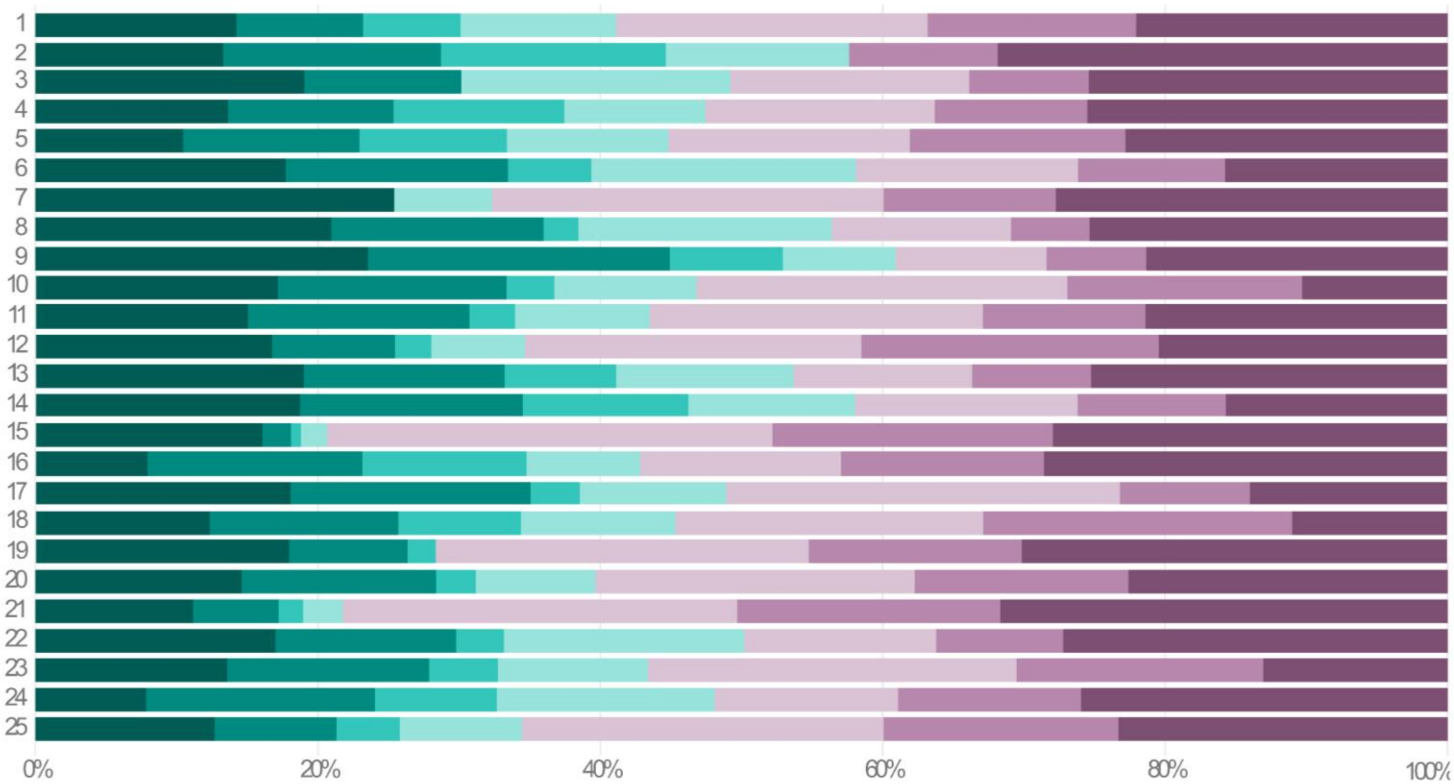
Figure 29. Top Action Candidates: High Resiliency Benefits and Reasonable Costs



Top actions are sometimes composites of several potential resiliency actions that were similar, provided greater benefits as a whole, or would be easier to implement if joined to other resiliency actions. To devise Study recommendations, top actions received additional consideration and evaluation to better define costs and benefits. For top actions that were appropriate for quantitative analysis (e.g., raising the elevation of roads that are frequently overtopped by floodwater to elevations that are higher than average flood levels to reduce the likelihood that the road is overtopped in the future), quantitative evaluations were applied via the City Simulator model. The results of this additional analysis are discussed in Chapter 4.

Top actions are discussed in Sections 3.1 through 3.4., which categorize actions by: improve building stock resiliency actions, institutionalizing resiliency actions, public infrastructure risk reduction actions, and increased community preparedness actions.

Figure 30. Composition of Top Action Benefits and Cost Friendliness



1. Create roadway redundancy policy and ensure new subdivisions have two means of evacuation
2. Develop a post-wildfire flood risk reduction program
3. Develop a structured maintenance regime that is responsive to extreme heat and periodically update design standards and maintenance regimes to account got climate change impacts
4. Develop and adopt plans, policies, and routes for emergency access and egress.
5. Develop procedures, capabilities, and Multi-Hazard Mitigation Plan recommendations to maximize infrastructure resilience funding from FEMA
6. Develop scour risk-based prioritization of bridge improvements.
7. Establish metrics for achieving community resilience
8. Flood risk tracking/mitigation tool and climate vulnerability assessments for transportation infrastructure
9. Floodplain buyout programs
10. Fortify floodplain building rules
11. Higher freeboard incentives
12. Implement project prioritization processes that include resiliency
13. Incentives for other voluntary flood protection measures
14. Include debris considerations into elevation standards
15. Increase level of knowledge and awareness of resiliency matters among County staff and elected officials
15. Increase transit service in response to economic or natural disasters
17. New and substantially improved critical facilities to be floodproofed
18. Promote having resiliency elements in local plans
19. Provide meaningful bilingual resiliency materials, engagement, and event-recovery support
20. Require dry land access during 500-year flood events
21. Resiliency-focused engagement with the community
22. Sediment/debris removal occurs when/where needed
23. Update design standards to favor bridges over multiple cell pipe culverts in critical locations
24. Vulnerable population resiliency needs assessment: transportation systems
25. Average action not selected to be a top action

Improve Building Stock Resiliency Actions

- Fortify regulatory floodplain building rules (Section 3.1.1)
- New and substantially improved critical facilities to be floodproofed (Section 3.1.2)

Initializing Resiliency Actions

- Develop procedures, capabilities, and Multi-Hazard Mitigation Plan recommendations to maximize infrastructure resilience funding from FEMA (Section 3.2.1)
- Complete watershed management planning necessary under National Flood Insurance Program Community Rating System Activity 452.b to obtain Class 2 certification (Section 3.2.2)
- Develop and adopt plans, policies, and routes for emergency access and egress in a flood (Section 3.2.3)
- Develop a post-wildfire flood risk reduction program (Section 3.2.4)
- Sediment/debris removal occurs when/where needed (Section 3.2.5)
- Establish metrics for achieving community resilience (Section 3.2.6)
- Flood risk tracking tool and climate vulnerability assessments (Section 3.2.7)
- Increase awareness of resiliency matters among County staff and elected officials (Section 3.2.8)

Public Infrastructure Risk Reduction Actions

- Improve resiliency of roads and bridge infrastructure (Section 3.3.1)
- Incorporate resiliency into project prioritization processes (Section 3.3.2)
- Develop scour risk-based prioritization of bridge improvements (Section 3.3.3)
- Update infrastructure design standards and maintenance regimes for climate change (Section 3.3.4)
- Update design standard to favor bridges over multiple-cell pipe culverts in critical locations (Section 3.3.5)

Increase Community Preparedness Actions

- Create high-risk building buyout program (Section 3.4.1)
- Low- and moderate-income resiliency needs assessment: transportation systems (Section 3.4.2)
- Incentives for voluntarily raising freeboard (Section 3.4.3)
- Incentives for other voluntary flood protection measures (Section 3.4.4)
- Resiliency-focused engagement with the community (Section 3.4.5)
- Meaningful bilingual resiliency materials, engagement, and event-recovery support (Section 3.4.6)
- Increase transit service in response to economic or natural disasters (Section 3.4.7)

3.1 Improve Building Stock Resiliency Actions

Regulatory actions describe building and development rule changes. Costs are incurred by Boulder County through losses in tax revenue caused when buildings are no longer allowed to be constructed where they are now. Costs also are experienced by builders and property owners when regulatory actions require more costly construction practices (e.g., freeboard).

3.1.1 Fortify regulatory floodplain building rules

This action focuses on potential building rules for new construction or buildings that are receiving substantial improvements in the 100-year or 500-year floodplains. Substantial improvements are defined as improvements that equal or exceed 50 percent of the market value of the structure either before the improvement or repair is started, or if the structure has been damaged and is being restored. The following palette of options is considered in this action:

› Extend freeboard (Figure 31) for new residential and non-residential structures in the 100-year or 500-year floodplains to two feet above the 500-year flood elevation or highest adjacent natural grade.

› Prohibit storage of hazardous, toxic, or explosive materials unless elevated to the 500-year floodplain plus two feet and also apply these prohibitions to critical facilities (e.g., schools, nursing homes, group home or assisted living centers, daycare facilities, etc., which are currently prohibited in the floodplain overlay below 6,000).

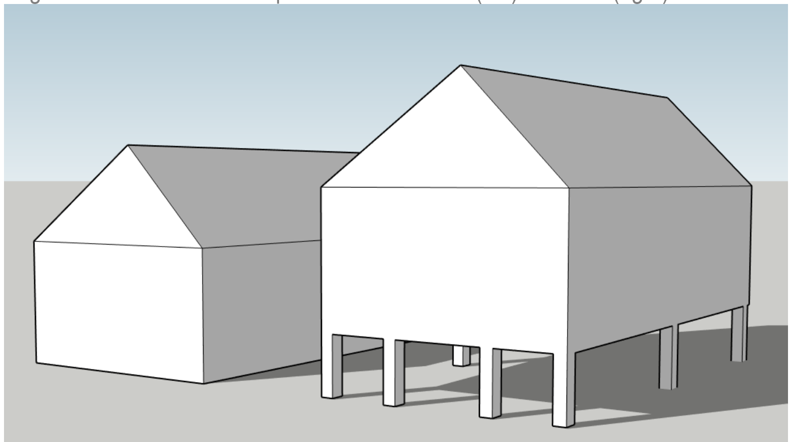
› Elevate parking areas. Require parking areas to be elevated above 100-year or 500-year floodplains for new, non-single-family buildings.

› Require setbacks for new or substantially improved buildings from the regulatory floodway boundary (or stream centerline if the floodway has not been delineated) in areas adjacent to floodplains and/or in erosion hazard areas (e.g., Fluvial Hazard Zones).

› Require floodplain buffer zones (more expansive than setbacks) along stream channels to protect banks from erosion and/or serve other natural and beneficial functions.

› Prohibit new basements in the 500-year floodplain.

Figure 31. Illustrative Example of Home without (left) and with (right) Freeboard



3.1.2 New and substantially improved critical facilities to be floodproofed

In lieu of outright prohibition, require new and substantially improved critical facilities in the 500-year floodplain to be floodproofed or constructed on properly compacted fill and have the lowest floor (including basement) elevated to at least two feet above the elevation of the 500-year floodplain.

3.2 Institutionalizing Resiliency Actions

The “institutionalize resiliency actions” goal aims to strengthen Boulder County Transportation Department and local governments’ culture and prioritization of resiliency concerns when developing project ideas. Common themes in these actions include improved coordination internally among and between departments, and externally between agencies, organizations, and the public. Institutionalizing resiliency actions also focuses on ensuring that risks are evaluated regularly and that risk-mitigating solutions are evaluated, prioritized, and implemented. Decision-making processes that entrench resiliency into Boulder County decision-making also are included in these actions.

3.2.1 Develop procedures, capabilities, and Multi-Hazard Mitigation Plan recommendations to maximize infrastructure resilience funding from FEMA

Develop pre-disaster policies and procedures that ensure hazard mitigation is incorporated into the repair, relocation, or replacement of damaged public facilities and infrastructure. This will help the county to maximize federal grant funding and, specifically, FEMA Public Assistance Section 406 (see Section 5.2.1 of this Study) following future presidentially declared disasters. FEMA Public Assistance Section 406 provides subgrantees with financial assistance not simply to restore, but to strengthen and bolster the resiliency of its assets through additional protective measures such as removing constrictions from the floodplain, upgrading undersized culverts, elevating roads and bridges, and even re-routing roads. With formal procedures in place, the county will be better positioned to take advantage of such funding opportunities. FEMA Public Assistance Section 406 often is faster than other recovery assistance programs, such as the FEMA Hazard Mitigation Grant Program (HMGP). Such procedures also could be used to leverage future funding through the National Public Infrastructure Pre-Disaster Mitigation fund as recently authorized under the Disaster Recovery Reform Act of 2018 (Section 1234).

To facilitate this effort, the current Multi-Hazard Mitigation Plan (MHMP) could benefit from further efforts to identify projects that are most likely to be implemented in the wake of a major flood, when post-disaster hazard mitigation grant funding might become available for actions such as floodplain property buyouts. The plan also will benefit from including post-disaster redevelopment planning strategies with specific policies to address projected conditions and foreseeable disaster recovery or redevelopment issues. The MHMP should identify how the county will operationally manage the range of resiliency improvements or needs following a large, destructive hazard event and should complement the Boulder County Recovery Plan (version 1.17), which also outlines the high-level roles, expectations, and authority of Boulder County in the hours, days, weeks, and months following a disaster event.

Because this action influences how damaged facilities are repaired or replaced, the action would complement the action described in Section 3.3.4, “Update infrastructure design standards and maintenance regimes for climate change.” Further, as this action also seeks to identify projects that are likely to be implemented following a disaster, there are complementary benefits to the action described in Section 3.3.2, “Incorporate resiliency into project prioritization processes”

3.2.2 Complete watershed management planning necessary under National Flood Insurance Program Community Rating System Activity 452.b to obtain Class 2 certification

The primary benefit for developing a watershed management plan (WMP) to a level that satisfies the requirements under National Flood Insurance Program (NFIP) Community Rating System (CRS) Activity 452.b is that Boulder County would meet the applicable Class 4 Prerequisite and potentially be able to go from a CRS Class 5 as it is now, to a Class 2 community (assuming other prerequisites are met, including the Activity 510 Step 2 work that is currently underway). This improvement in CRS Class would result in an additional 15-percent discount on flood insurance premiums for NFIP policyholders in the county’s unincorporated Special Flood Hazard Areas (SFHAs). Based on the latest CRS What-If Report from Insurance Services Office (March 2019), this equates to an annual average savings of $310/policyholder.

This discount is likely to induce higher flood insurance participation rates across the county.

3.2.3 Develop and adopt plans, policies, and routes for emergency access and egress in a flood

Develop an Emergency Service and Evacuation Plan/Emergency Operations Plan to address emergencies and use of emergency access and connections during and after disasters. The 2013 flood event demonstrated the importance of maintaining emergency access along the highways and other critical roadways. Accordingly, plans and policies for emergency access and egress to all residential areas before, during, and after hazard events are needed. This includes a thorough analysis to identify critical evacuation routes. Routes from likely disaster areas to shelters, critical common corridors, contraflow planning, and route modeling will be necessary. Processes will be put in place for longer-term disruptions and the steps needed to plan for more prolonged temporary access.

Identification of evacuation routes should not only be documented in an Emergency Service and Evacuation Plan, but also propagated through relevant documents and integrated into the development/site plan review process to ensure effectiveness and ongoing relevance.

Planning should extend into related program purchasing and preparation. For example:

- Purchase equipment with emergency response in mind (e.g., Alabama requires that certain classifications of vehicles purchased must double as snow plows and the state stockpiles mobile traffic control devices).
- Stockpile materials (e.g., culvert pipe, temporary bridge components, fuel) and equipment (e.g., generators, chain saws, traffic control devices) and stage them in strategic areas prior to events.

The plan must result in agreements to provide evacuation transportation to carless and less mobile populations, including the evacuation of people and animals. Boulder County should partner with stakeholders such as Via and Meals on Wheels to ensure carless and less mobile populations receive assistance during natural disasters. Via has a policy of checking in with their clients during a natural disaster; this informal courtesy should become a formal agreement.

3.2.4 Develop a post-wildfire flood risk reduction program

Develop a post-wildfire program with actions to be taken in burn areas and downstream locations that could be impacted by higher risk of flash floods and mudflows. Wildfires on mountainsides near populated areas cause many flood problems in the event aftermath. Denuded slopes carry more water flow, greatly increasing the discharge downstream. In addition, more sediment and debris is carried downstream blocking openings and causing additional problems. Post wildfire actions could include rapid, mid-term, and long-term action plans to mitigate potential flooding and mudflows from burn-areas. Such actions could include installing debris flow structures or barriers, replanting vegetation, and initiating localized evacuation planning and communication for potentially impacted downstream communities.

3.2.5 Sediment/debris removal occurs when/where needed

Implement operation- and maintenance-focused lifecycle asset management practices so that sediment removal and routine maintenance requirements for each creek in the county are determined and acted upon through a methodical process that is assured through procedures and monitoring. Asset management tools can aid in implementing such a program (co-benefit with “Action 153. Asset Management database and tools”).

The program ultimately should include inspecting both public and private drainage systems, with special attention paid to known problem and high-risk areas that may require more frequent inspections and sediment removal. A co-benefit of this program is it adds support to the county’s CRS efforts, which ultimately lower flood insurance rates for Boulder County residents. To maximize credit under the CRS program, the County should inspect and maintain all public and private components in the developed portion of the surface conveyance system, not just channels in the floodplain.

For the program to be sustainable, maintenance costs should be factored into the county's annual budgeting and/or CIP process as required. Justification may come in the form of monitoring and reporting losses caused by inadequate drainage versus the flooding of low-lying floodplain areas.

3.2.6 Establish metrics for achieving community resilience

Develop a set of performance-based benchmarks to help monitor and measure progress toward achieving the county's resiliency goals. By establishing quantifiable resilience metrics, the county will create a meaningful baseline and be better able to monitor the benefit and positive impacts of future improvements. Such metrics help decision makers prioritize resiliency improvements by allowing them to implement those that do the most to improve resilience. Metrics also help the county to better understand and evaluate the benefits and cumulative return on its resilience investments. It is recommended that the goals and objectives in this Study be used as the starting point for developing community-level metrics. This will ensure continuity with previous planning efforts and the values captured through this Study's goal-setting phase.

This action has additive benefits when combined with Action 3.2.8. With community resiliency metrics established, the tool described in Action 3.2.8 would be able to quantify community-level performance and help streamline the identification of needs that, when addressed, would improve low community resilience performance.

3.2.7 Flood risk tracking tool and climate vulnerability assessments

Use a geographic information system-based flood risk assessment and mitigation planning tool to regularly measure flood risk and prioritize mitigation measures over time. The system will assess the vulnerability of the county's existing and planned assets by determining which are most sensitive to, and at risk from, projected climate change impacts. Using best available data, including digital flood hazard data and other local data layers (buildings, parcels, land use, topology, etc.), Boulder County would maintain a dynamic tracking tool for the purpose of determining flood risk at various scales (parcel, communities, census blocks, etc.) and prioritizing flood mitigation projects based on specific community-based evaluation criteria. This tool also would be updated to reflect projects that have been implemented and evaluate how they perform after a flood event to validate the cost-benefits of resilience. Overall, this tool would be similar to the FEMA vision for a Mitigation Portfolio tool. The tool could incorporate elements of a system like City Simulator that also projects future risk.

The frequency of model run updates should be determined by the frequency at which input data are updated but should be no less frequent than every five years. Updates in data related to flood models, demographics, economics, transit service, asset conditions (road, bridge, culvert), climate, capital improvement estimates, and programmed capital improvement projects should trigger a new model run. When a flood risk tracking and climate vulnerability assessment model is established for Boulder County, updates in input data should be relatively cost-effective to reanalyze.

3.2.8 Increase awareness of resiliency matters among County staff and elected officials

Transportation Department resources and emphasis will focus on increasing awareness and urgency of resiliency within the Department. Collaboration with other county departments on resilience activities would have the additive benefit of providing a louder voice and potentially reaching a wider audience. Specific initiatives include:

- Establish a Resiliency/Climate Change Program to keep up-to-date on the latest science, best practices, and decision support tools, and disseminate findings to others.
- Enable staff to interact with climate scientists and resiliency subject matter experts as part of professional development efforts.

- Educate policy-makers and the public about the necessity of bearing the costs of improving resiliency.
- Develop a work plan to address any climate-safe infrastructure training and professional development gaps of its infrastructure-related workforce.

3.3 Public Infrastructure Risk Reduction Actions

Public infrastructure risk reduction actions focus on road, bridge, and culvert improvements that are most effective in reducing the impacts of shock events. Attention is placed on improvements that are socially equitable so that low-income populations benefit from reduced flood risk and transportation system stresses.

3.3.1 Improve resiliency of roads and bridge infrastructure

The action identifies roads, bridges, and culverts that best connect residents to employment destinations and critical services. The process uses traffic volumes and a remoteness measure to identify high benefit infrastructure improvement opportunities. Analysis of the action includes quantifying the benefits and costs of improving critical infrastructure to better withstand flooding.

3.3.2 Incorporate resiliency into project prioritization processes

Update the process for funding and implementation of transportation infrastructure to include resiliency. This action would add resiliency as an explicit benefit to projects being selected for funding and implementation. Such a system would align with the Resilient Design Performance Standard that builds upon the Resilience Prioritization Criteria outlined in the Colorado Resiliency Framework.

By incorporating these criteria, each infrastructure project designed using the Resilient Design Performance Standard will contribute to achieving the State of Colorado's vision and goals for resiliency. Project prioritization should be heavily based on a cost-benefit review and for those activities which increase the long-term service reliability for the transportation project or improvement.

3.3.3 Develop scour risk-based prioritization of bridge improvements

In "The Impact of Climate Change: Projected Adaptation Costs for Boulder County, Colorado" study, impacts on bridge performance were analyzed based on changes in peak river flow due to climate change and the potential for resulting increases in scour. The study analyzed 238 Boulder County bridges and outlined costs for upgrading the bridges identified as vulnerable to scour. This action involves implementing the Study's recommended diversionary approaches or concrete strengthening depending on the increase of flows identified for the body of water that the bridges cross.

3.3.4 Update infrastructure design standards and maintenance regimes for climate change

Through this action, the county would develop infrastructure design standards and maintenance regimes that are responsive to anticipated impacts of climate change. For example, increases in temperature can exceed design standards and create excess cracking that must be repaired. Similarly, increases in precipitation will increase cracking by impacting the strength of the roadbed while also causing additional erosion along the edges of some roadways.

With changing climate increasing the likelihood of larger storms in the future, periodic reassessment of the 1 percent chance (100-year) flood levels should be conducted and design standards should be adjusted to ensure infrastructure is ready for projected future 1 percent events over its lifespan.

The action includes the development of best practices and guidelines for resilient design. These designs would be incorporated into projects being prioritized through a revised resiliency-inclusive project prioritization process (the subject of Action 3.3.2, "Incorporate resiliency into project prioritization processes"). As the county continues to make future adjustments to its design parameters that incorporate hazard mitigation and climate change adaptation, the Transportation Department should research and leverage existing best practices from other similar organizations or departments of transportation. Example changes in an updated infrastructure design standard could include low-water crossings. Suggested suitable low-water crossing locations are identified in Appendix 4. Suitable locations are road and stream crossings where the road is locally owned, low volume, and is not the only road connecting a community so that alternative routes were available if an evacuation becomes necessary.

3.3.5 Update design standard to favor bridges over multiple-cell pipe culverts in critical locations

Identify areas and/or conditions where bridge infrastructure would be preferable to pipes, culverts, and other structures. Bridge infrastructure provides an added degree of resilience over multiple-cell pipe culverts. Bridges are less susceptible to clogging and failure from upstream debris collection, while also being compatible with the ecologic and geomorphic concepts.

Alternatively, culvert systems should consider the use of floodplain culverts to provide additional hydraulic capacity and limit downstream scour and erosion at the main culvert. Updated standards should consider designs that provide adequate flow conveyance, effective sediment and debris transport, and aquatic organism passage at new or improved stream crossings. In this action, the county would incorporate standards that favor stream-friendly, sustainable, resilient bridge and culvert design, which could reduce flood damage and maintenance requirements.

3.4 Increase Community Preparedness Actions

While the previous category of actions focused on infrastructure assets, community preparedness actions focus on interventions that Boulder County, property owners, and residents can take to reduce community and individual property risks. Approaches to attain these end goals vary, where some actions are Boulder County-led programs, whereas others are optional actions that can be taken by the public with Boulder County support.

3.4.1 Create high-risk building buyout program

This action would develop a locally financed floodplain pre-flood and post-flood buyout program. Ideally, the program would be supplemented with additional outside funding, but the core of this program is intended to be reliable local funding. Accordingly, it is among the most expensive actions proposed in this Study.

The post-flood buyout program would work in tandem with other land acquisition tools to purchase flood-prone properties (and/or their development rights) that may not qualify for existing grant programs (e.g., FEMA Hazard Mitigation Assistance, HUD CDBG-DR, etc., see 0). If there is a presidentially declared disaster, and federal funds are allocated for property buyouts, the local funds also could be used to match federal funds. A locally financed "quick buy" program should acquire eligible high-risk homes and businesses from willing sellers before major flood damage is repaired. This would help eliminate the need for property owners of flood-damaged structures to make temporary or permanent repairs while waiting or hoping for a buyout through long-term recovery programs (e.g., HMGP, CDBG-DR), which could lead to applicants losing interest and dropping out of the program.

Analysis of this action in Chapter 2 predicts which homes would be damaged and purchased over a 32 year timeframe. The analysis quantifies the benefits of removing these buildings so that they are not damaged by subsequent flooding events.

A pre-flood buyout program would focus on the purchase and removal of buildings at the greatest risk of flooding before a flood occurs. The approach reduces flood damage, displacements, economic disruptions, and social hardships experienced following the destruction of one’s home or place of work. Additional analysis of this action in Chapter 4 identifies buildings at the highest risk of being flooded, and the quantitative benefit of purchasing and removing them before they are damaged by a flood.

Acquired land also could be used to expand resiliency co-benefits through greenway trails, which adds transportation redundancy and would increase public green space, which improves quality of life and recreation opportunities and increases stormwater retention opportunities.

The benefits and costs of this top action are analyzed further in Chapter 4.

3.4.2 Low- and moderate-income resiliency needs assessment: transportation systems

Develop a detailed countywide study that assesses the risks and stresses facing low- and moderate-income neighborhoods and propose improvements to make these communities more resilient in terms of multimodal transportation mobility and emergency access following shocks. Better understanding of critical destinations, assets, facilities, and services is a necessary outcome of this needs assessment. The assessment should work with cultural brokers to identify risks and stresses and should include mapping of communities with access challenges.

3.4.3 Incentives for voluntarily raising freeboard

The action is to develop and promote incentives for builders or property owners who voluntarily add freeboard and/or go beyond current regulatory freeboard requirements (two feet) for structures. Incentives may include permit fee waivers, discounts, and rebates. Significant public outreach and education on the financial and risk reduction benefits of going beyond existing requirements, with emphasis on lower flood insurance premiums and lower levels of predicted flood damage, can be effective in generating interest in the program.

This action includes removing regulatory barriers and/or potential disincentives to voluntarily apply flood protection measures above the Flood Protection Elevation (FPE). This includes addressing the county's building height restrictions to accommodate freeboard up to a certain elevation (i.e., amend the Land Use Code to allow for authorized exemptions for increased flood protection).

This action shares similarities to Action 3.1.1, "Fortify regulatory floodplain building rules" in that an outcome is higher freeboard. This action, however, differs in that the outcome is achieved by incentivizing the action to be implemented voluntarily rather than being required through regulation.

The benefits of voluntarily raising freeboard were analyzed by City Simulator and are discussed in Section 4.2.

3.4.4 Incentives for other voluntary flood protection measures

Provide financial incentives for adding flood protection measures to new and renovated buildings in the 100-year floodplain, 500-year floodplain, or outside of the 500-year floodplain. Incentives could be provided by Boulder County through direct cost-sharing programs for property owners. Reducing permit fees is another practical way to influence development to reduce flooding risk, while not imposing new restrictions. Likewise, the county could remove regulatory barriers and/or potential disincentives to voluntarily apply flood protection measures (e.g., height restrictions that would prevent a building from adding freeboard). This includes addressing measures that may not require a building permit and/or could potentially be excluded in calculating whether a project triggers the cumulative substantial damage/ substantial improvement (SD/SI) rule, such as many recommended in FEMA's brochure titled "Protect Your Home from Flooding: Low-Cost Projects You Can Do Yourself."

Boulder County residents also should be made aware of benefits and discounts they are eligible to receive, such as purchasing CRS-program discounted flood insurance (promoting the voluntary purchase of flood insurance for all property owners is included in Action 3.4.5, below). Incentives to make flood protection improvements are most effective when coupled with educational efforts to communicate the need and benefit of making such improvements (e.g., discounted insurance).

3.4.5 Resiliency-focused engagement with the community

A common element in several other resiliency actions is a reliance on improved communication with the public. The first step would be to develop a strategic public communications plan for Boulder County Transportation Department. The plan would provide a roadmap for achieving the following engagement objectives:

- Promote flood insurance.
- Increase stakeholder engagement for the Multi-Hazard Mitigation Plan update process.
- Promote "do it yourself" flood mitigation measures.
- Deliver a more cohesive flood risk education and outreach program.
- Develop natural hazard risk communications strategies and plans.
- Develop materials to educate occupants at education facilities and workplaces about site-specific risks.
- Develop a resiliency how-to planning guide.

Given limited Transportation Department resources but a strong desire to implement the most effective community engagement program possible, Boulder County should (1) confirm and prioritize its objectives for public education and outreach (bullets above); and (2) develop and deliver the program components to achieve those goals. As the objectives are far-reaching and broadly applicable to Boulder County entities, coordination with other departments may provide additive benefits and strengthen the positive benefits of this action. Other departments may have inroads to target audiences, lessons learned, and other insights that can guide Transportation Department resiliency-focused engagement. There are additive benefits of implementing this action in parallel with Action 3.4.2.

3.4.6 Meaningful bilingual resiliency materials, engagement, and event-recovery support

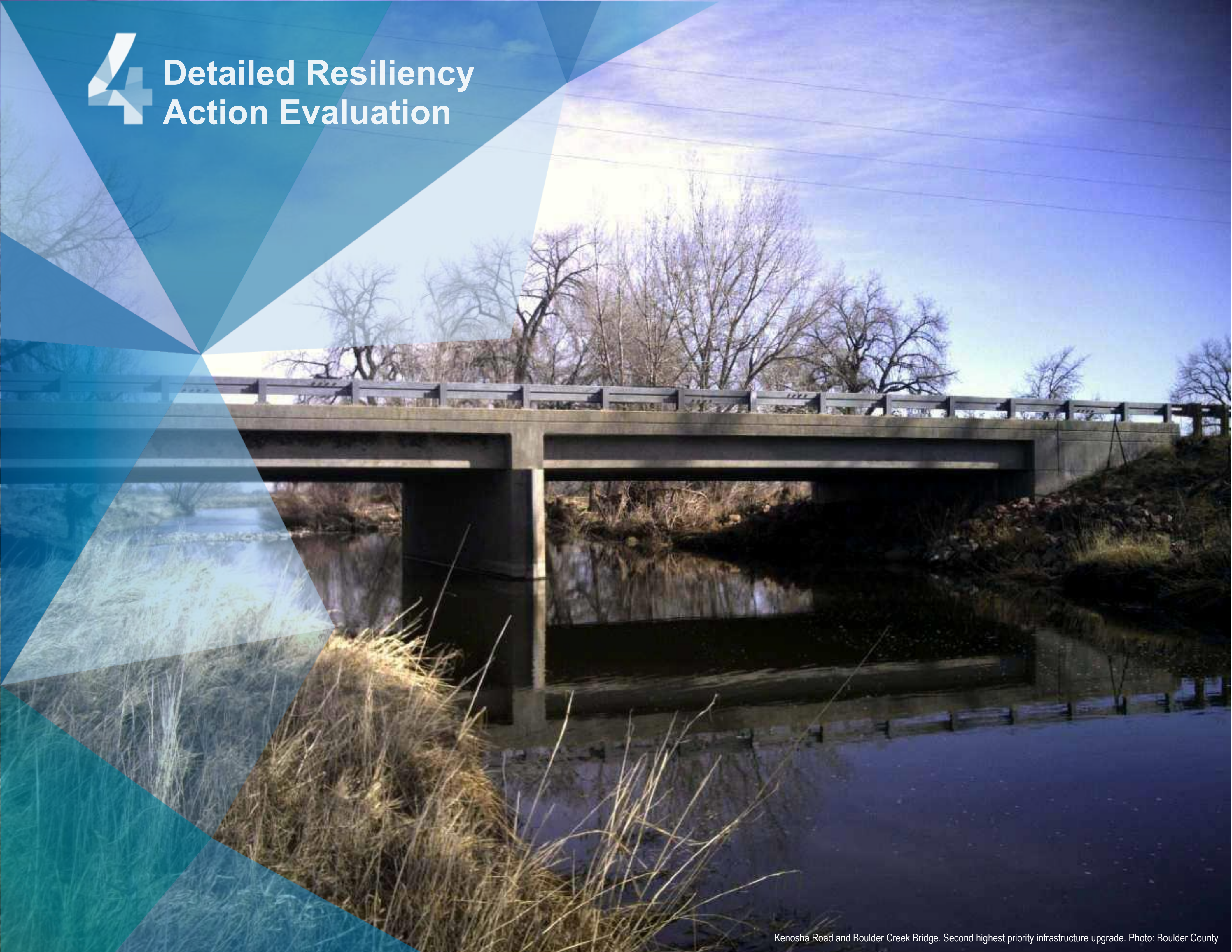
Require that Boulder County Transportation Department meaningfully engage with Spanish speaking, and other non-English speaking, communities regarding Boulder County's transportation mobility programs, flood risk, and other important information that would be needed during a natural disaster or other emergency. Based on lessons learned, the Transportation Department should be responsive to the finding that monolingual Spanish speakers do not access information the same way as monolingual English Speakers. Non-English speakers in Boulder County need additional levels of support in terms of community education, outreach, and marketing related to community resiliency. "Typical" outreach strategies do not often reach vulnerable populations. It is recognized that people who are undocumented and/or people whose first language is not English often do not receive the same resources during natural disasters. Often, these individuals do not seek government resources for fear of being deported.

3.4.7 Increase transit service in response to economic or natural disasters

Increasing transit service during economic crises or natural disasters can help to protect vulnerable populations. Vulnerable populations become increasingly reliant on transit during economic crises, at the same time when transit providers may be trying to cut services as a cost-saving measure. Through this resiliency action, the county would craft policies and plans to ensure that during an economic crisis, transit services remain in place or are increased for transit-reliant communities.

Also included in this action is development of agreements/partnerships with transit providers to establish post-disaster transit service plans. Currently, there are unofficial agreements with Boulder Valley School District and St. Vrain Valley School District and Regional Transportation District (RTD) to evacuate people when needed. However, written agreements resolving any logistical or payment arrangements should be resolved ahead of time.

4 Detailed Resiliency Action Evaluation



Kenosha Road and Boulder Creek Bridge. Second highest priority infrastructure upgrade. Photo: Boulder County

4 Quantitative Resiliency Action Evaluation

The objective of the resiliency action analysis process is to explore resiliency actions in detail, to quantify the degree to which they will benefit the county and their likely costs.

In Chapter 2, the vulnerability study established a base scenario, which included preventing building in the Boulder County flood overlay district and requiring 2 feet of freeboard for substantially improved and new buildings in the Special Flood Hazard Area (SFHA). These are actions that are currently enforced by unincorporated Boulder County.

In this assessment, additional scenarios were created that added several of the proposed action in Chapter 3 to the base scenario. These scenarios were then simulated using the City Simulator and the resulting metrics were then compared to the base scenario metrics to evaluate the efficacy of the actions.

Figure 8 shows the process undertaken. The upper row of this process was described in Chapter 2. In this part of the analysis, the process outlined in the lower row of boxes was repeated for multiple top actions.

The quantitative evaluation undertaken by City Simulator model focused on four scenarios:

Scenario 1. Improve Resilience of Transportation Infrastructure

Replace and upsize at-risk infrastructure to better withstand flood events and other natural disasters. This scenario models the direct benefit of the following top actions:

- Improve resiliency of roads and bridge infrastructure (Section 3.3.1)
- Incorporate resiliency into project prioritization processes (Section 3.3.2)

While not part of the quantitative evaluation, other top actions indirectly support the tenets of this scenario by ensuring that the most critical infrastructure is being identified and implemented regularly and over time. These top actions include:

- Flood risk tracking tool and climate vulnerability assessments (Section 3.2.7)
- Increase awareness of resiliency matters among County staff and elected officials (Section 3.2.8)
- Update infrastructure design standards and maintenance regimes for climate change (Section 3.3.4)
- Update design standard to favor bridges over multiple-cell pipe culverts in critical locations (Section 3.3.5)
- Low- and moderate-income resiliency needs assessment: transportation systems (Section 3.4.2)

Scenario 2. Incentivizing Flood Protection Projects

Provide enticements such as, discounts or subsidies, to property owners who elect to add flood protections to their homes. The following top actions are the basis for this scenario and quantitative evaluation.

- Incentives for voluntarily raising freeboard (Section 3.4.3)
- Incentives for other voluntary flood protection measures (Section 3.4.4)

Other complementary top actions, but not quantitatively tested, top actions include the following. These actions could expand the benefit of the scenario by building awareness of, and participation in, an incentive program.

- Resiliency-focused engagement with the community (Section 3.4.5)
- Meaningful bilingual resiliency materials, engagement, and event-recovery support (Section 3.4.6)

Scenario 3. Home Buyout Program

Offer a program to buy houses with demonstrated risk and mandate no building is allowed in remaining lots. The scenario is based on the "Create high-risk building buyout program" summarized in Section 3.4.1.

Scenario 4. Regulate Residential and Commercial Construction in Areas At-Risk for Flood

Prevent building in various flood zones of 1) critical and at-risk population facilities and 2) all building in the SFHA and 0.2 percent annual chance fringe. The scenario also includes expanding the geographic reach of requirements to raise home elevations and remove basements when substantial improvements are made. The scenario also expands Boulder County's limiting of new critical and at-risk population facilities in flood prone areas. The scenario is based on the following top actions:

- Fortify regulatory floodplain building rules (Section 3.1.1)
- New and substantially improved critical facilities to be floodproofed (Section 3.1.2)

While not part of the scenario's quantitative evaluation, the top action to create a flood risk tracking tool and climate vulnerability assessments (Section 3.2.7) would ensure that at-risk buildings would be identified on a regular basis and with greater accuracy as data improves and on-the-ground conditions change.

Each of these four assessments involved running multiple scenarios as the objective was to find the highest benefit approach to implementing the action at the most manageable cost. For example, in improving transportation infrastructure there are multiple choices in how the improvements are implemented, including when the improvements are made and the level of protection the action is trying to achieve.

For each action, sensitivity analyses helped to understand which choice to make in implementing the action. These results are described in the following four sections.

4.1 Improve Transportation Infrastructure Resiliency

The results of the vulnerability analysis (Chapter 2) finds that flooding of the transportation system is a major disruptor to the county. Impacts from overtopping of roads at bridge and culvert locations and frequent flooding of low-lying segments of road was forecasted to disrupt millions of commutes over the course of the next thirty years.

4.1.1 Scenarios

Actions to improve transportation infrastructure resiliency center on replacing and/or elevating at-risk roads and bridges to provide more flow through them while also elevating the overlying road. Assets were elevated in order of decreasing level of disruption, so that the most critical assets are addressed first.

The scenarios tested several aspects of the implementation, including:

- **When the projects would be executed**—Scenarios included:
  - Assume all infrastructure improvements are completed within the first year,
  - Resiliency improvements are made over time through a regular annual process with dedicated funding, and
  - Improvements are made when replacement is needed following major flood events.
- **Protection level**—scenarios focused on improving a:
  - 100-year storm
  - 50-year storm

Each of the six separate scenarios were run through the resiliency model to understand the relative resiliency benefit in terms of reducing disruption.

Preparedness pays off by improving transportation infrastructure. Improving all disruptive infrastructure in the first year of the simulation results in a 39-percent reduction in disrupted trips—nearly four times the reduction compared to waiting to repair until after floods.

4.1.2 Costs for Improvement

Costs for replacement of each transportation asset were developed through one of three methods:

- Two cost estimates were developed for major Boulder County and Colorado Department of Transportation structures with high disruption. One to withstand to the 50-year event and a second to provide a 100-year protection level.
- For the remaining locations, a simple cost estimation procedure developed by the California Department of Transportation (Caltrans) was used. This method uses the area of the bridge deck in square feet as the driving parameter for estimation of cost to estimate replacement or improvement costs.
- For the low-lying road segments, a separate cost estimation procedure was developed based on the length of road and number of travel lanes.

A large investment of $375 million to improve infrastructure resiliency in the first year of the study timeline could reduce disrupted trips in the county by 39 percent. Investing $8.875 million per year for 32 years results in a 19 percent reduction in disruption over that same 30 year timeframe.

Figure 32, shows the complete picture. The bottom axis shows the total cost over 32 years required to implement the improvement program and the left axis shows the reduction in disruption achieved compared to the base run. Each scenario is represented as a point on the chart. The points are colored according to their protection level. The timing of the installation is provided as a label on the chart.

4.1.3 Findings

Analysis of the scenarios produced the following findings:

- Installing all assets as quickly as possible and with 100-year protection level gives the highest level of disruption avoided, 39 percent. This option has the highest cost ($375 million) because every asset in the county that causes disruption would require some level of investment. If the funding were to be borrowed, the costs could be spread out over a multi-year time frame, but any interest payments would need to be added to the total cost estimate, increasing the cost further.
- Even with 100-year protection, there is still considerable disruption. This is because the 75th percentile rain forecast includes a large storm of 9.1 inches (similar to the 2013 event), which is far above the 100-year protection level. This storm still would do considerable damage even with infrastructure built to withstand a 100-year storm event. Accordingly, constructing assets to even higher standards can be a prudent countermeasure.
- The next level down in terms of cost is the annual investment approach. This achieves only about half of the disruption avoided (19 percent) because the major floods in the simulation occur before many of the structures are improved, leaving the county unprepared.
- If the cost per trip-disrupted avoided is calculated, the lowest unit cost is the all-in-first-year scenario, which has costs of $18.08 per trip for the 100-year protection level and $15.79 per trip for the 50-year protection level. This contrasts with the annual ($28.90 for 100-year, $28.63 for 50-year) and post-disaster ($32.55 for 100-year, and $30.83 for 50-year) scenarios.
- Installing post-disaster has the lowest reduction of disruption (9 percent) because this strategy does the least

to prepare the county ahead of floods. This method does have the lowest cost, however. In addition, funding is often more available after disasters have occurred, so the option isn't to be ruled out and the county should be prepared to utilize available funding if a disaster occurs by ensuring projects are included in the county's Multi-Hazard Mitigation Plan and that the county codes and standards outline processes for increasing resilience.

- The difference between the 50- and 100-year protection level in each set of scenarios is not significantly large, with the possible exception of the all-in-first-year scenario. This underscores the power of the large 9.1-inch rain event, as it does almost the same damage to infrastructure at either protection level.

The assessment revealed that using a large influx of investment in the first year to improve the infrastructure to withstand the 100-year storm could reduce disrupted trips in the county by 39 percent. But at $375 million, the cost is high. A more modest annual improvement program would keep the required investment at a total of $284 million, or $8.875 million per year and result in a 19 percent reduction in disruption over the next three decades.

4.1.4 Recommendations

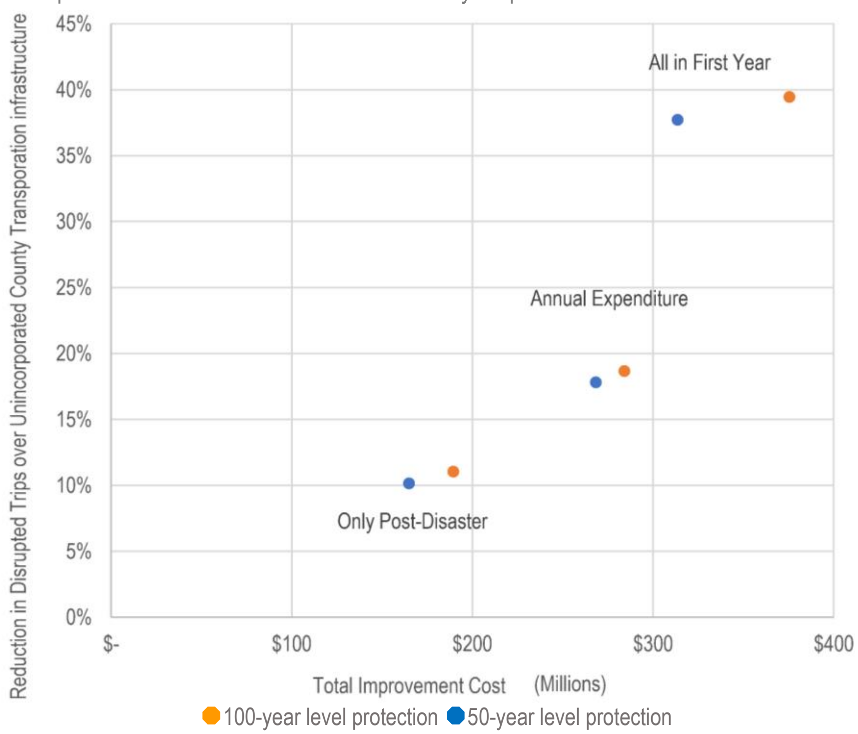
Taken together, the findings show that the faster the county can get prepared by bringing the under-sized elements of the transportation system to as high a protection level as possible, the more resilient the county will be, and the less it will spend per trip on avoiding disruption.

Even if an influx of investment dollars is not available within the next few years, steady investment in improving disruptive infrastructure will be more than twice as effective as waiting to improve post-disaster.

The 100-year protection level is defined relative to a point in time, and the assessment found even if all disruptive assets are brought up to a level where they won't be impacted by the 2019 100-year event, there is a high chance that a storm in the next 32 years will be larger than the 2019 100-year event and still cause disruption. For this reason, considering an even higher level of protection is well-advised.

Capital improvement projects should be designed to enlarge, elevate, and increase the strength of at-risk infrastructure assets (Section 2.6 and Appendix 4), as increasing their robustness first is likely to have the highest return on investment. The county should use the full disruptive asset table in Appendix 4 as a to-do list. It is recommended that the county progressively work through each disruptive asset as

Figure 32. Reduction in Disruption provided vs total cost for scenarios improving all disruptive infrastructure assets to 50- and 100-year protection levels



budget allows and with consideration of remoteness factors such as the existence or viability of bypass routes in the case that an infrastructure asset is damaged and made unusable. Other factors can influence the sequencing of infrastructure improvements including ownership, cost, location, equity, and other tenets represented in the Study goals (Section 1.2).

4.1.5 Recommendations for Further Assessment

This analysis has revealed the power of preparedness in the face of an uncertain and climate-change influenced future. Two recommendations for further analysis include:

- The assessment evaluated the efficacy of improving all disruptive assets up to the 2019 50-year and 100-year protection levels and showed that, even at today's present day 100-year level, only 39 percent of disrupted future trips would be avoided. Infrastructure standards for building to withstand 1 percent chance storms should be revaluated over time account for any increases in intensity and frequency. This recommendation is incorporated into the action to update infrastructure design standards and maintenance regimes to account for climate change (Section 3.3.5).
- The assessment did not consider the role of adding water-impeding elements like green infrastructure (rain gardens, swales, etc.), and additional gray infrastructure (channels, detention ponds, etc.) (see action 10. Develop a Green Infrastructure Guide in Appendix 5). These elements, when designed on a county-wide scale, could effectively reduce flood levels at the culverts, bridges, and frequently flooded road segments, reducing the levels to which they would need to be improved. An assessment that blends this infrastructure and accounts for its impact on overland flow is advised.

Table 4. Top 10 Most Disrupted Infrastructure Assets

Disruption Ranking	Study ID	Boulder County ID	Type	Road	Water Course	Estimate Average Annual Trips Disrupted
1	3798	D-16-BW	Major Structure	Hwy 7/Arapahoe Rd	Dry Creek 3	148,039
2	3848	BC-38-6.7-BO	Major Structure	Kenosha Rd	Boulder Creek	114,112
3	3795	D-16-DN	Major Structure	US 287	Dry Creek 2	113,100
4	3751	BC-15-1.2-SV	Major Structure	S. Sunset St	St. Vrain Creek	101,534
5	3845	BC-19-15.0-BO	Major Structure	N 95th St	Boulder Creek	92,140
6	3846	CDOT_BC_287	Major Structure	US 287	Boulder Creek	66,051
7	3864	ROAD_3864	Road	Diagonal Hwy	Left Hand Creek	58,222
8	3937	ROAD_3937	Road	Diagonal Hwy	Left Hand Creek	57,716
9	3805	CDOT_FouC_119	Major Structure	Hwy 119 / Boulder Canyon Drive	Four Mile Creek	55,289
10	3729	BC-34-6.6-DR2	Major Structure	Niwot Rd	Dry Creek 2	48,792

The following assets were excluded from the analysis:120th Street at Coal Creek (Lafayette), East County Line Road at Dry Creek 2, East County Line Road at Boulder Creek, and East County Line Road at Coal Creek (Erie).

4.2 Incentivize Flood Protection Projects

Many county residents are making pro-active moves to protect their homes and businesses from future flooding. This assessment explores the benefits of taking actions to increase voluntary flood protection, as part of home renovation projections. These actions may include reducing or waiving permit fees, subsidizing improvement costs, increasing awareness of the value of flood protection, or several of the other actions described in Chapter 3. Given these actions are taken, this assessment postulates incentivized flood protection actions taken increase the number of improvement projects or renovation projects that include flood protection by 50 percent in future years and assesses the benefit of this increase.

The following top actions are the basis for this scenario and quantitative evaluation.

- Incentives for voluntarily raising freeboard (Section 3.4.3)
- Incentives for other voluntary flood protection measures (Section 3.4.4)

Other top actions complement the aims of this scenario evaluation, but were not quantitatively tested. These actions could expand the benefit of the scenario by building awareness of, and participation in, incentive programs. These actions include:

- Resiliency-focused engagement with the community (Section 3.4.5)
- Meaningful bilingual resiliency materials, engagement, and event-recovery support (Section 3.4.6)

4.2.1 Scenarios

Scenarios were created to evaluate a 50 percent increase in incentivized flood protection in the following flood zones:

- SFHA only
- SFHA + 500-year fringe
- SFHA + 500-year fringe + any home considered at risk for pluvial flooding outside the floodplain.

The key metric used to gage the benefits of this increase was number of homes protected from flood. These are assumed to be homes that have undergone some degree of flood protection, so that future floods up to and including the 100-year storm will likely cause them no damage. It's important to note that *protected* does not mean the home is "flood proof" and will survive any flood of the future.

This is particularly relevant to the rain forecast used in the simulation (see section 2.2 for detail), as the forecast includes a storm larger than the 100-year.

Participation of Boulder County homeowners is key to future resilience. Actions that increase the voluntary rate of home improvement and flood protection could yield a near county-wide level of protection over the next thirty-two years.

4.2.2 Methods

To simulate an increase in voluntary flood protection, the base scenario assumption that one percent of homes improve flood protections each year was increased to 1.5 percent. The same process for selecting the specific homes that receive flood protection was used. To make scenarios comparable, this process ranks the homes according to the smallest storm that will trigger a flood in them. It then splits the homes into three groups, high risk, medium risk, and low risk. Then it builds a collection of potential flood protection, selecting from the three groups at regular intervals, with high risk homes being selected more often than medium risk homes, which are in turn selected more often than low risk. This results in a flood protection queue that is progressively selected from one-by-one each year throughout the simulation. When a home is selected from the queue, it is designated as "flood protected," and is no longer eligible to be improved with flood protections for the remainder of the simulation.

Selecting the higher risk homes for flood protection more frequently, resulted in a high number of the flood protection renovations occurring in the SFHA or the 0.2 percent annual chance fringe. This was determined to be a reasonable assumption given that these homes have the highest risk. However, the approach makes the implicit assumption that homeowners will have the funding and will make flood protections.

4.2.3 Findings

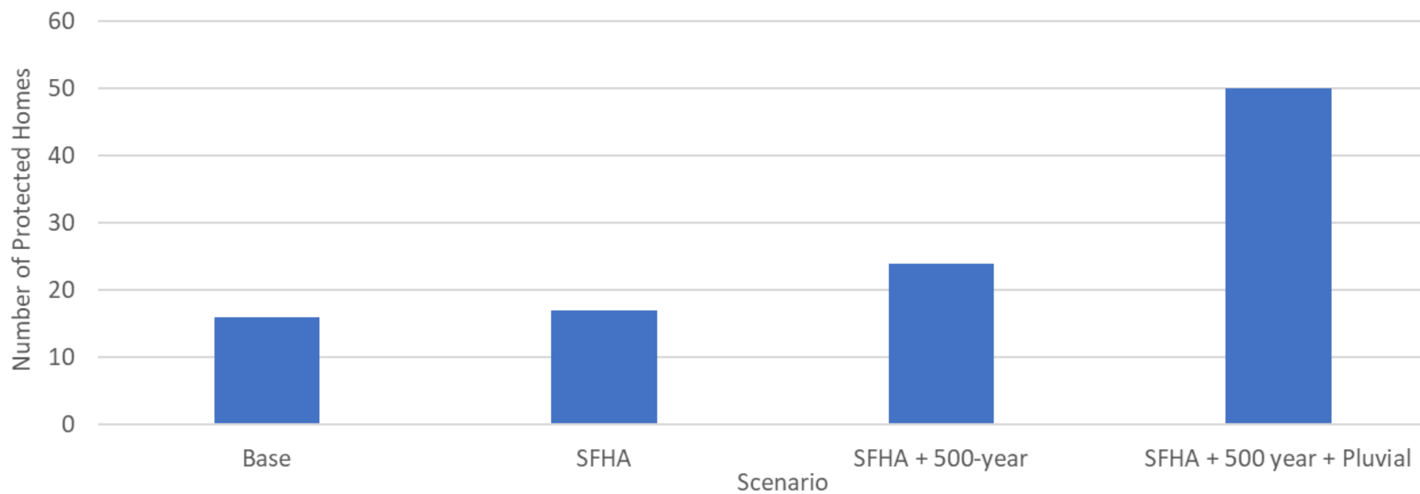
The base scenario had an annual average of 15 homes protected per year. More than 14 of these homes on average were in the SFHA. This was the result of the assumed baseline of 1 percent of homes at risk for flood electing to improve their flood protection level each year.

When it was assumed that the community's actions increased voluntary flood protection both in the SFHA and the 0.5 percent chance floodplain fringe, the number of homes improved per year jumped to 24, reflecting more homes in the fringe that were not being voluntarily protected when the rate was at 1 percent.

When the 1.5 percent rate was assumed to occur across the county, the number of homes being improved jumped to 50 per year, which essentially meant that by 2050, all at-risk homes (from riverine and pluvial flooding) had been voluntarily protected. Figure 33 shows the result of the assessment.

Taking actions that increase the level of voluntary flood protection increase the annual average number of homes that are made more secure from 15 in the base scenario to 50 if the voluntary rate of flood protection is 1.5 percent of homes per year.

Figure 33. Average Annual Protected Home with Increased Incentivized Flood Protection



4.3 Home Buyout Program

For homes that are repeatedly damaged by flood, a voluntary buyout program is often a good solution.

A buyout program is a practical way for Boulder County to reduce exposure to flood. By steadily buying the most at-risk homes and allowing streams to recapture the floodplain in those areas, up to $9 million of flood damage can be avoided over the next thirty years.

Definition of At-Risk

As the scenarios below state, at-risk properties are the best candidates for buyout. Within this study, at-risk is defined as having a threshold storm that is at or below the 100-year storm, either riverine or pluvial. In other words, if the flood models say that a property will flood with a storm up to the size of the 100-year rain storm, then the property is considered for buyout within the scenario.

4.3.1 Scenarios

Within this study, the actions tested focused on:

- **When** buyouts occur - scenarios included:
  - Buy three at-risk homes per year,
  - Only buy after major floods up to a maximum of $20 million per event.
- **Where** buyouts occur - scenarios included:
  - Within the SFHA only
  - Within the SFHA and 0.2 percent annual chance fringe.

These options equated to four separate scenarios, which were all evaluated.

The proposed buy-out program is voluntary; that is, property owners must elect to make use of the program and must demonstrate their property is sufficiently at risk to merit buy-out. For the purposes of the simulation, we assumed the most at-risk properties would elect for buy-out first. The properties were ranked in order of the lowest storm size that would cause flood and processed in that order.

4.3.2 Cost

Cost for each buyout was estimated as the total value reported in the County Tax Assessor database (building value + land value). The average cost of all homes considered was $625,000.

The assessment found a buyout program would result in losses avoided, particularly when focused on the most at-risk homes.

4.3.3 Findings

The simulation produced the following findings:

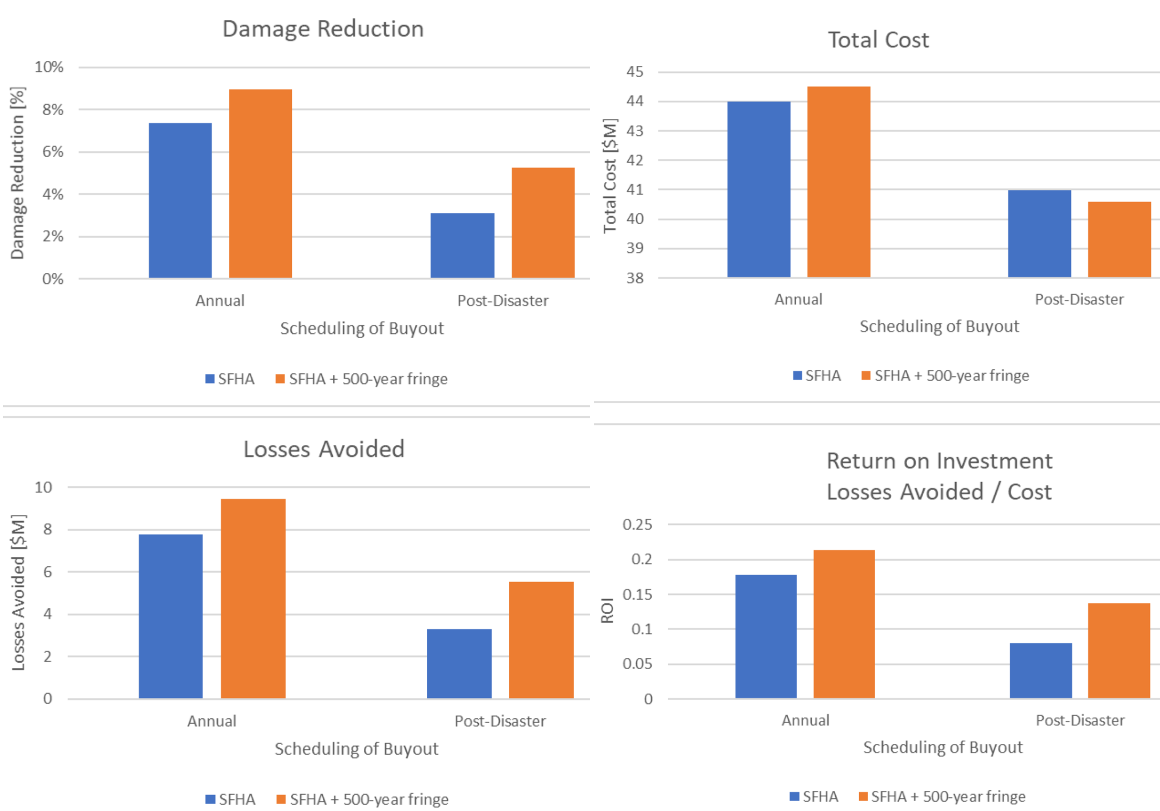
- With the scenarios defined, the buyout rates ranged from 3 homes per year to a bulk purchase of 30-50 homes after each of the major storms that occur in the simulation.
- The assessment found a buyout program would result in avoiding damages from flood, where losses avoided are defined as the dollar damage that would have resulted if the homes had been left in place and damaged by future floods. The dollar damage avoided ranged from $8-9M for the 32-year time frame if the homes were purchased annually, and from $3 million to $5.5 million if the homes were purchased post-disaster.
- The damage reduction ranged from 7.5 percent to 9 percent if the homes were purchased annually and 3 percent to 5 percent if the homes were purchased post disaster.
- The total cost of the program was projected to be approximately $44 million over the 32-year time frame if

done annually and approximately $41 million if completed post-disaster.

- When viewed from the perspective of return on investment (ROI), where ROI is defined as the losses avoided divided by the cost, the ROI range ranges from 0.17 to 0.21 for the annual purchase program and 0.08 to 0.14 for the post-disaster purchase program.

The results are shown in Figure 34. The total cost, losses avoided, percent decrease in damages compared to the base scenario, and the return on investment are presented, where ROI is defined as the total losses avoided divided by the total cost.

Figure 34. Damage Reduction, Losses Avoided, Cost, & Return on Investment



4.3.4 Conclusions

Conclusions that can be taken from these findings are:

- Losses avoided are achieved through acquiring homes and removing them.
- Preparedness is key in maximizing losses avoided. By using the annual buy out process, instead of waiting for disasters to strike, the losses avoided are approximately doubled.
- The losses avoided are significantly lower than the cost of buyout, primarily due to the high cost of land in the county.

4.3.5 Role of ROI in Qualifying Buyout Candidates

The highest ROI achieved (0.21) is with the scenario where homes are bought annually in the SFHA+0.2% Annual Change Fringe.

For the Study, a ROI of 1.0 or higher is the point where the cost is justified, we see that none of the scenarios reaches cost justification. This is easy to understand because there are only two major storms in the forecast, the first of which is a 10-year storm and causes little damage in most at-risk properties and the second of which is much larger than the 100-year storm and results in losses equal to the replacement cost of most at-risk properties. Given replacement value is lower than market value for most homes, it is understandable that the ROI is less than 1.0. In order to achieve an above 1.0 ROI, the properties selected for buy out would necessarily need to suffer multiple losses over the time-line of the simulation, such that the cumulative damage is higher than the replacement value of the building.

Currently, there are approximately ten properties that are documented as repetitive loss properties in unincorporated Boulder County. However, with changing climate and the potential for very large future storms, this number could increase. This establishes a need for forecasting which properties are likely to suffer repetitive losses in the future. Those properties will be prime candidates for a buyout program should one be implemented.

4.4 Regulate Construction in Flood Risk Areas

This set of actions looks at modifying and adding regulations to reduce flood risk. The actions assessed include preventing building in high risk areas and requiring risk-reducing building measures for existing homes that are substantially improved.

4.4.1 Scenarios

The actions evaluated included:

- Preventing building new critical facilities, such as police and fire stations, and at-risk population facilities, such as nursing homes in the 0.2-percent annual chance fringe, in addition to the SFHA which is current policy
- Preventing all building in the:
    - SFHA
    - SHFA and the 0.2 percent annual chance fringe
- Requiring removal of basements when substantial improvements are made to homes in the 0.2-percent annual chance fringe, in addition to the SFHA which is required under current policy.
- Requiring 2 feet of elevation of the FFE when substantial improvements are made to homes:
    - 0.2 percent annual chance fringe in addition to above BFE in the SFHA which is required under current policy (freeboard)
    - Above ground in areas at risk for pluvial flooding

These actions equated to eight separate scenarios, all of which were evaluated.

Preventing building in the FEMA SFHA and 0.2-percent annual chance fringe helps to avoid future flood damage, while requiring freeboard (elevating) for homes with large renovations decreases the number of damaged homes. A blend of these actions could reduce damaged homes by approximately 10 percent in these flood zones

4.4.2 Simulation Methods

The land development process is simulated in the City Simulator model by allocating new buildings each year in locations that are vacant and developable according to zoning rules. The simulator works from the areas of highest likelihood to lowest likelihood over the course of the simulation, where likelihood is determined as a weighted sum of factors like proximity to major roadways and density of like land use in the proposed area. See Chapter 2 for specifics on the factors and weights used in this Study.

Preventing Building in National Flood Insurance Program (NFIP) zones

Simulating preventing building in NFIP zones required development of a county-wide NFIP zone map that included the regulatory floodway, special flood hazard area, 0.2 percent annual chance fringe, and the area outside the 0.2 percent annual chance floodplain. This map was developed using Boulder County enhanced NFIP GIS layers merged into a single GIS layer. As new buildings were allocated in the simulation, their NFIP zone was estimated by finding the zone in which the centroid of the proposed building was located. When a building prevention action was in place, the proposed location was switched with the next most likely location for development. This process continued until a location that was not in a banned zone was found.

Two types of prevention were simulated: all buildings, and critical and at-risk population facilities. For the “all buildings” scenario, every proposed new building had the above filter applied, to ensure no new buildings were added in banned zones. For the “critical and at-risk population facilities” scenario, it was assumed that 1 percent of new buildings are critical facilities or at-risk population facilities. The simulator would designate every hundredth new structure as one of these facilities and would avoid banned zones in placing the structure.

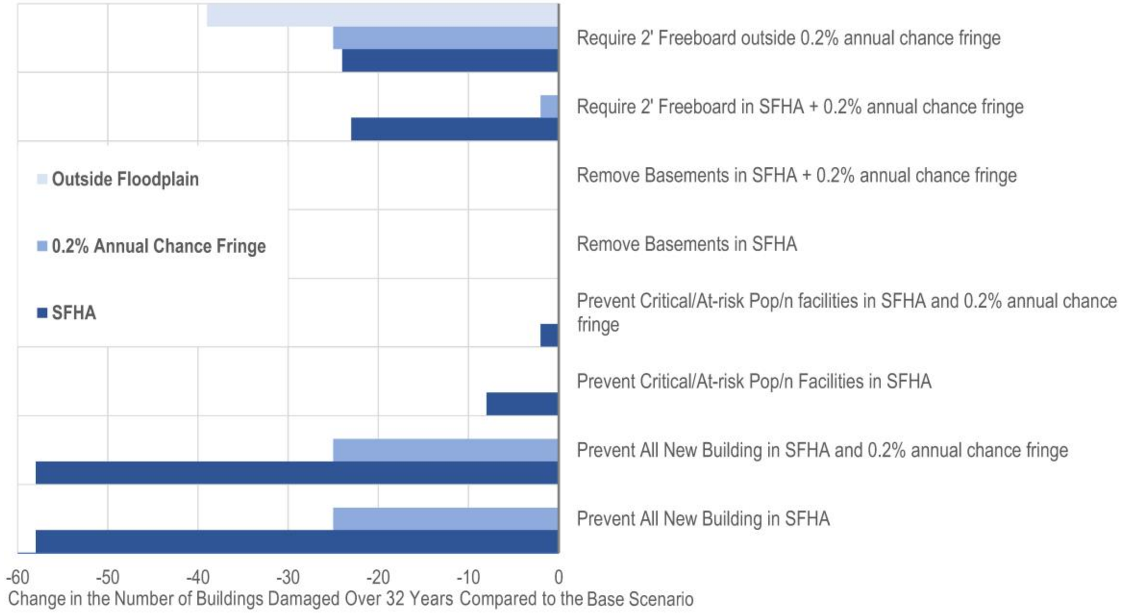
Removing Basements and Freeboard

To simulate these actions, which are applied to existing residential building stock, it was assumed that a baseline 1 percent of residential buildings in each year are substantially improved, where substantial improvement means that a renovation project occurs that costs more than 50 percent of the value of the existing building. When these projects occur, if the building is in the specified zone (SFHA, 0.2-percent annual chance fringe, or both), the simulation would raise the building to required freeboard and/or remove the building’s basement should it have one. The specific buildings that received the renovations were selected based on their risk level—the higher their risk, the more likely they were to be renovated. Risk level was estimated as the lowest level rain depth required to trigger a flood in the building. The building rain-to-flood curves in combination with the building FFE were used to determine this trigger level.

Removing Basements

When a “remove basement” action was in place, the building’s basement was assumed to be filled in, such that flooding would only occur in the building if the flood levels were above the FFE, and the flood depth would be the level of flooding above the FFE only. The basement-specific depth-damage curves (see Chapter 2) were switched to the non-basement curves for buildings where this action had taken place.

Figure 35. Change in Number of Buildings Compared to Base Scenario Over 32 Years by Scenario



Freeboard

When a freeboard requirement was in place, the building was assumed to be elevated such that the FFE was at the required elevation. In this Study, the required FFE was set at 2 feet above the building’s base flood elevation (BFE), which was evaluated by finding the value of the 100-year flood depth raster at the location of the building centroid. The new FFE then was used to evaluate building flooding in the remainder of the simulation. For homes outside the floodplain, the BFE was assumed to be the ground level, meaning that homes with FFE below 2 feet above the ground, were required to be raised to FFE at 2 feet above ground level.

4.4.3 Findings

The key metric used to measure the benefits of the actions was reduction in the number of damaged buildings relative to the base scenario. Figure 35 shows this metric for unincorporated Boulder County for the NFIP SFHA, 0.2-percent annual chance fringe, and outside the 0.2-percent annual chance floodplain.

For reference, the total number of buildings in the SFHA in unincorporated Boulder County in the base year is 1,642, while the 0.2-percent annual chance fringe contains 573 buildings. The number of damaged buildings is 993 and 128 for the two zones, respectively. Key findings include:

- The highest reduction in damaged buildings comes from the action to prevent building in the SFHA and 0.2-percent annual chance fringe, with a reduction of 58 damaged buildings in the SFHA and 25 damaged buildings in the 0.2-percent annual chance fringe over the 32-year course of the simulation. This represents a 7.5 percent reduction in damaged building in these zones compared to the base scenario.
- This level of damage reduction occurs entirely within the SFHA, primarily because there are more flood-prone buildings in this zone and their risk level is higher.
- The action to prevent critical and at-risk population facilities resulted in comparatively little damage reduction. When applied to the SFHA only, the number of damaged buildings was reduced by 8. When applied to both the SFHA and 0.2-percent annual chance fringe, the number was reduced by 2. This relatively low impact is because only 1 percent of new buildings is assumed to be a critical or at-risk population facility. With the limited developable and vacant land in the flood zones, very few buildings of this type are built in these zones over the 32-year timeline.
- The freeboard requirement also has an impact, reducing the damaged building count by 23 when applied within the SFHA and 0.2-percent annual chance fringe and by 24 when applied outside the 0.2-percent annual chance floodplain.
- The action to require 2 feet of elevation above ground for renovated buildings outside the 0.2-percent annual chance floodplain resulted in 39 fewer buildings being damaged over the course of the simulation.
- The action to remove basements had zero impact in either the SFHA or 0.2-percent annual chance fringe in terms of the number of buildings damaged. This is because the large storm simulated in 2039 flooded all buildings that had basements removed up to that point. Looking more closely, the simulation showed that the basement removals did have an impact in terms of the dollar damage. The per unit average damage (direct and contents) over the simulation timeframe was $200,010 lower for buildings with basement removed as compared to if the basements had been retained.

4.4.4 Conclusions

The assessment shows that regulations can reduce flood damage. If the single action of preventing building in the SFHA and 0.2-percent annual chance fringe is implemented, there is a 7.5-percent reduction in damage compared to the base scenario. If that action were combined with other regulations, like requiring 2 feet of freeboard for substantially improved existing homes both in the SFHA and the 0.2-percent annual chance fringe, then this level could be increased even further, up to a total of 9.6 percent.

Although measures that increase robustness of existing building stock may not prevent flooding altogether, these measures will reduce the likely dollar damage, especially if very large flood events occur. Removing basements, for example, reduces the per unit average damage by just over $200,000 over the course of the simulation.

Preventing critical and at-risk population facilities from being built in the flood zones resulted in little change in the number of damaged buildings, because there are relatively few of these structures being built on vacant and developable land. In Boulder County especially, where available developable land is limited, the simulation runs into few cases where these facilities are built in flood prone zones. Regardless, construction of these facilities should take into consideration their accessibility in addition to their flood potential, as they only fulfill their vital function when they remain accessible from the road network. This likely provides sufficient justification for preventing their development in the SFHA and 0.2-percent annual chance fringe as well.

4.5 Conclusions

The Chapter 4 scenarios, and the actions which define them, each had beneficial impacts on the county's resilience.

- The transportation focused actions reduced disruption to daily travel, with some providing almost as much as a 40 percent reduction in the number of trips disrupted over the 32-year simulation timeframe.
- The buyout program revealed that with high land values in the county, a strong focus should be placed on properties with forecasted repetitive loses to show a good return on investment.
- Regulation, through preventing building in high risk zones, requiring freeboard, and requiring removal of basements in cases of substantial improvement results in more protected homes and avoided loss, particularly for new homes.
- Preparedness proved to be highly valuable across the action assessments. Acting in the first year, or at least on an annual basis, without waiting for the disasters to trigger the response resulted in lower damages and disruption in all cases.

The assessment also revealed many opportunities for deeper analysis that will help to better understand county risk dynamics, and possible avenues for maximizing return on investment.

- Instead of ranking the transportation assets simply by their level of disruption, they could be jointly ranked by disruption and cost to improve. This might provide the opportunity to lump many lower-cost improvement projects – the low hanging fruit - into a single year, reducing disruption in many areas while benefiting from construction economies of scale.
- Pluvial modeling has high potential for allowing the county to better understand flooding outside the floodplain. The Telemac 2D pluvial model results used in this study do not take into account the county stormwater system, and its ability to dispose of high flows when they occur. By adding the county stormwater system into the Telemac model, a more accurate depiction of pluvial flooding may be possible.
- Finally, it would be helpful to develop a scenario that blends the actions together into a realistic representation of how the county will manage for resiliency in the future. As there is interplay between the actions, this is the only way to estimate the real impact on resiliency future management will have.

5 Recommendations

5 Recommendations

The top actions represent resiliency actions that have the greatest potential to achieve resiliency goals and objectives. These actions have proven to be reasonable in terms of their financial cost, level of effort to implement, and likelihood of obtaining support. “Reasonable” in this sense means that the cost of implementing an action is outweighed by the resiliency benefits gained. While all top actions have been deemed reasonable, not all are recommended for implementation at this time. Implementation of all actions at once is not feasible. To that end, Chapter 5 offers strategies for prioritizing implementation of actions based on available resources and other mitigating factors.

5.1 Implementation Plans

For the purposes of the implementation plan, timeframe, financial cost, staff effort, and level of support are the key levers that determine recommendations for implementation and focuses on actions that can be implemented based on the resources available over time. These focus areas, and their implications on implementation, are described in Sections 5.1.1 through 5.1.3. This strategy also identifies gaps in what the county is able to achieve with existing resources so that reallocations of time, budget, and focus can be made to compensate (e.g., prolonged gaps in funding may require Boulder County to shift resources to pursue more competitive grant funding to compensate for the shortfall). Based on these financial costs, staff effort, and level of support levers, the following strategies have been devised for actions whose drivers are most closely associated with these focus areas. While there are elements of all three of these focus areas in each action, the noted focus areas capture the *primary* driver for implementation. Table 5 summarizes the primary driver focus area of each action. The table also summarizes final recommendations, the rationale, and the implementation timeframe.

5.1.1 Financially Focused Actions

Financially focused actions are long-term investments that take significant capital investment and potentially years of scoping, planning, design, and implementation. They tend to be both high cost and high benefit. Such actions rely on the ability of the county to obtain new funding or to redirect existing funding sources. There is also a strong connection to non-financial focused actions, including, 3.3.3 “Develop scour risk-based prioritization of bridge improvements” and 3.3.2 “Incorporate resiliency into project prioritization processes”

While all top actions have been determined to have reasonable costs in relation to their benefits, as discussed in Chapter 4, high-cost actions have the greatest downside risk if resiliency benefits fail to meet expectations or costs far exceed estimates. As such, these actions have received more detailed analysis (in Chapter 4) to ensure that benefits are likely to be obtained. Furthermore, the value of these actions will continue to be verified as action ideas become projects and continue to receive more thorough examination and scrutiny as they move toward implementation (through scoping, design, estimation, permitting, etc.). If this process determines that an action’s costs are significantly higher than estimated, or if resiliency benefits are less than forecasted in this Study, implementation should be reconsidered.

Financially focused top actions are closely tied to the success of the recommended costly infrastructure-focused actions. The greater ability Boulder County has to increase revenue, the greater ability it has to implement top actions that require substantial capital funds.

5.1.2 Staff Effort-Focused Actions

Staff effort-focused actions are implemented by Boulder County staff. These actions have lower financial costs, but would require staff resources and result in reprioritization of other activities. Nevertheless, many of these actions are critical to obtaining Study goals, and the possible implementation of cost- and support-focused actions (e.g., changing project priority processes) may allow recommended resiliency cost-focused actions to be selected and funded for implementation (e.g., top actions in Sections 3.2.6 and 3.3.2). Many staff effort-focused actions provide “quick wins” and are things that can begin immediately and provide instant benefit.

5.1.3 Support-Focused Actions

Support-focused actions are those that may not be supported by the public and/or elected officials initially, but which provide extensive benefits. The success of these actions is highly dependent on timing and internal Boulder County champions making the case to act upon these actions. Internal champions can build support for seemingly unpopular actions through education.

5.1.4 Connection between Resiliency Actions and Key Boulder County Plans, Codes, and Standards

Implementation of recommended actions will have implications to Boulder County plans, codes, and standards. Recommended actions will require select documents to be updated to reflect the findings and decisions presented in this Study. Table 7 summarizes which documents are impacted by each recommended action.

Table 5. Recommended Actions

Recommended Actions, by Category	Comments	Implementation Timeframe				Focus Area		
		Immediate Term	Mid Term	Long Term	Continuous	Financial Focus	Staff Effort Focus	Support Focus
Improve Building Stock Resiliency								
3.1.1 Fortify regulatory floodplain building rules 3.1.2 New and substantially improved critical facilities to be floodproofed	These are high-benefit and low-cost action as determined through the City Simulator analysis.	✓						✓
Institutionalize Resilience								
3.2.2 Complete watershed management planning necessary under National Flood Insurance Program Community Rating System Activity 452.b to obtain Class 2 certification	Additional 15 percent NFIP flood insurance premium discounts obtained through Class 2 certification. Urgency is high because work has been completed in this area recently, and momentum will be key to seeing the action through.	✓					✓	
3.2.7 Flood risk tracking tool and climate vulnerability assessments	Recommended to identify risk, solutions, and test project ideas. Other actions have synergistic connections to this action.	✓					✓	
3.2.5 Sediment/debris removal occurs when/where needed	Recommended as part the wholistic and life-cycle approach to ensuring assets are performing as designed and intended.		✓			*	✓	
3.2.6 Establish metrics for achieving community resilience	This action furthers the institutionalize resiliency goal of this Study, informs future decision-making, and quantifies progress made over time.		✓				✓	
3.2.3 Develop and adopt plans, policies, and routes for emergency access and egress in a flood	This action can be viewed as an opportunistic project—one that leverages outside funding (0) when offerings become available and/or elements are incorporated into other planning efforts (e.g., network analysis incorporated into TMP update).			✓			✓	
3.2.4 Develop a post-wildfire flood risk reduction program	Public input and Steering Committee input elevated the importance and recommendation of this action.			✓			✓	
3.2.1 Develop procedures, capabilities, and Multi-Hazard Mitigation Plan recommendations to maximize infrastructure resilience funding from FEMA	Action institutionalizes good practices and positions the county for the next disaster.				✓		✓	
3.2.8 Increase awareness of resiliency matters among county staff and elected officials	Recommended lower-cost and high-benefit action				✓			✓
Public Infrastructure Risk Reduction								
3.3.1 Improve critical high-risk roads, bridges, and culverts	Provides the greatest benefit of all other actions. City Simulator modeling shows that improving infrastructure before it is flooded can result in a 39-percent reduction in disrupted trips, nearly four times the reduction compared to waiting to repair until after floods.	✓				✓		
3.3.2 Implement project prioritization processes that include resiliency 3.3.3 Develop scour risk-based prioritization of bridge improvements	Essential for ensuring that high-benefit projects are implemented over time		✓			*	✓	
3.3.4 Update infrastructure design standards and maintenance regimes to account for climate change 3.3.5 Update design standard to favor bridges over multiple cell pipe culverts in critical locations	Prudent action to facilitate the high-value improve critical high-risk roads, bridges, and culvert action		✓			*	✓	
Increase Community Preparedness								

Recommended Actions, by Category	Comments	Implementation Timeframe: Immediate Term	Mid Term	Long Term	Continuous	Focus Area: Financial Focus	Staff Effort Focus	Support Focus
3.4.1 Create high-risk building buyout program	Recommended due to efficacy in avoiding losses. City Simulator modeling shows that by steadily buying the most at-risk homes and allowing the stream to recapture the floodplain in those areas, up to $9M of flood damage can be avoided over the next 30 years. Dependent on increased funding.		✓			✓		
3.4.3 Incentives for voluntarily raising freeboard 3.4.4 Incentives for other voluntary flood protection measures	City Simulator found this to be a high-benefit action.	✓				✓		
3.4.2 Low- and moderate-income resiliency needs assessment: transportation systems	Public input and Steering Committee input elevated the importance and recommendation of this action. This action benefits both prepare for shocks and institutionalize resiliency Study goals and addresses a data gap.		✓					
3.4.7 Increase transit service in response to economic or natural disasters	Steering Committee input elevated the importance and recommendation of this action. This action benefits both respond to shock Study goals as well as equity objectives.	✓			✓ As needed		✓	
3.4.5 Resiliency-focused engagement with the community 3.4.6 Provide meaningful bilingual resiliency materials, engagement, and event-recovery support	Necessary actions to achieve Study equity objectives	✓			✓	✓		

** While the driver of the action is not finance focused, ensuring actions would be (e.g., updating design standards is not costly, but the implications of recommending higher bridges, larger culverts, etc., would increase asset replacement costs)*

Table 6. Connection between Resiliency Actions and Key Boulder County Plans, Codes, and Standards

	Transportation Master Plan	Boulder County Comprehensive Plan	Land Use Code	Multimodal Transportation Standards	Storm Drainage Criteria Manual	Multi-Hazard Mitigation Plan	Drainage Plans
Improve Building Stock Resiliency							
3.1.1 Fortify regulatory floodplain building rules		*	✓				
3.1.2 New and substantially improved critical facilities to be floodproofed		*	✓				
Institutionalize Resilience							
3.2.2 Complete watershed management planning necessary under National Flood Insurance Program Community Rating System Activity 452.b to obtain Class 2 certification							✓
3.2.7 Flood risk tracking tool and climate vulnerability assessments	✓						
3.2.5 Sediment/debris removal occurs when/where needed							
3.2.6 Establish metrics for achieving community resilience							
3.2.3 Develop and adopt plans, policies, and routes for emergency access and egress in a flood	✓						
3.2.4 Develop a post-wildfire flood risk reduction program			✓			✓	
3.2.1 Develop procedures, capabilities, and Multi-Hazard Mitigation Plan recommendations to maximize infrastructure resilience funding from FEMA				✓	✓	✓	
3.2.8 Increase awareness of resiliency matters among county staff and elected officials	✓	✓					

	Transportation Master Plan	Boulder County Comprehensive Plan	Land Use Code	Multimodal Transportation Standards	Storm Drainage Criteria Manual	Multi-Hazard Mitigation Plan	Drainage Plans
Public Infrastructure Risk Reduction							
3.3.1 Improve critical high-risk roads, bridges, and culverts	✓			✓	✓	✓	
3.3.2 Implement project prioritization processes that include resiliency	✓						
3.3.3 Develop scour risk-based prioritization of bridge improvements	✓						
3.3.4 Update infrastructure design standards and maintenance regimes to account for climate change	✓			✓	✓		
3.3.5 Update design standard to favor bridges over multiple cell pipe culverts in critical locations	✓			✓	✓		
Increase Community Preparedness							
3.4.1 Create high-risk building buyout program			✓				
3.4.3 Incentives for voluntarily raising freeboard		✓	✓				
3.4.4 Incentives for other voluntary flood protection measures			✓				
3.4.2 Low- and moderate-income resiliency needs assessment: transportation systems	✓						
3.4.7 Increase transit service in response to economic or natural disasters	✓						
3.4.5 Resiliency-focused engagement with the community	✓	✓					
3.4.6 Provide meaningful bilingual resiliency materials, engagement, and event-recovery support	✓	✓					

** Incorporate general policy into the Boulder County Comprehensive Plan to establish that the county accounts for flood risk by requiring development to be built to withstand a 100 year flood, and encouraging through information and resources that development be built to withstand a 500-year flood.*

Table 7. Recommended Actions Organized by Implementation Timeframe and Primary Driver

	Immediate-Term	Mid-Term	Long-Term	Continuous
Financial Focus	• Improve critical high-risk roads, bridges, and culverts • Incentives for voluntarily raising freeboard • Incentives for other voluntary flood protection measures	• Create high-risk building buyout program		
Staff Effort	• Complete watershed management planning necessary under National Flood Insurance Program Community Rating System Activity 452.b to obtain Class 2 certification • Flood risk tracking tool and climate vulnerability assessments • Implement project prioritization processes that include resiliency	• Sediment/debris removal occurs when/where needed • Establish metrics for achieving community resilience • Develop scour risk-based prioritization of bridge improvements • Update infrastructure design standards and maintenance regimes to account for climate change • Update design standard to favor bridges over multiple-cell pipe culverts in critical locations • Low and moderate income resiliency needs assessment: transportation systems	• Develop and adopt plans, policies, and routes for emergency access and egress in a flood • Develop a post-wildfire flood risk reduction program	• Develop procedures, capabilities, and Multi-Hazard Mitigation Plan recommendations to maximize infrastructure resilience funding from FEMA • Resiliency-focused engagement with the community • Provide meaningful bilingual resiliency materials, engagement, and event-recovery support • Increase transit service in response to economic or natural disasters
Support	• Fortify regulatory floodplain building rules • New and substantially improved critical facilities to be floodproofed			• Increase awareness of resiliency matters among county staff and elected officials

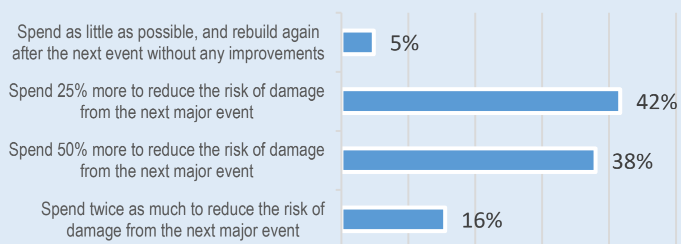
5.2 Potential Funding Mechanisms

The need for greater investment in resiliency is confirmed by analysis conducted on behalf of this Study, and widely supported by Boulder County communities (see Figure 36), which indicate 96-percent support for increasing risk-reducing road and bridge investments by at least 25 percent. In fact, three times more survey respondents support a 100-percent investment increase than prefer investing as little as possible. While there is little debate about the need for resiliency-focused investments, the sources of funding to support investment is less clear. To that end, the following options are available to Boulder County to increase revenue (Section 5.2.1) and obtain outside funds from competitive funding sources (Section 5.2.2).

Public input on spending more on roads and bridges to reduce damage risk

Of the 329 survey respondents who answered, "…what level of increased spending on road and bridges would you support?" **only 5 percent** were unsupportive of increasing spending to reduce the risk of damage to replacement or reconstructed roads and bridges.

Figure 36. Public Input on Spending More on Roads and Bridges



Source: Public Survey Summary, Appendix 1

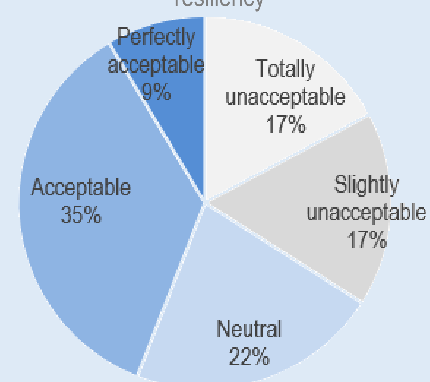
5.2.1 Strengthen Revenue Streams

Increasing taxes or fees is the most direct way of funding Boulder County's resiliency-focused investments, including capital improvements. Reliable funding streams can be directed toward recommended resiliency actions and can be an opportunity to leverage outside competitive funding. Pursuing new revenues has political and public challenges. However, feedback received as part of this plan (see 0) suggests that increasing revenue through taxes or fees could be an acceptable mechanism for achieving higher levels of resiliency in county facilities and programs (see Figure 37).

Public input on increasing taxes or fees for improving resiliency

Of the 339 survey respondents who answered, "which are acceptable trade-offs for having greater resiliency when considering potential catastrophic disasters?" **66 percent** of respondents either supported or were neutral to increasing taxes or fees.

Figure 37. Public input on increasing taxes or fees to improve resiliency



Source: Public Survey Summary, Appendix 1

Property Tax

While challenging to enact, property tax is a reliable and flexible funding stream for funding resiliency actions. This option would be beneficial to the tenets of Goal 1 ("institutionalize resiliency") of this Study. This funding approach would enable resiliency to become more fully integrated into project prioritization processes and imbedded as a facet in all projects as a result. This funding option avoids the downsides of other funding tools, which require identifying individual "resiliency projects" that may provide standalone physical resiliency-related benefits, but does not entrench resiliency-focused practices into day-to-day practices and decision-making, nor does it provide for opportunistic investment (e.g., Quick Buy program, leveraging partnership matching funds, etc.).

Sales Tax

Given the public's awareness of resiliency spending shortfalls (illustrated in Figure 36) and willingness to increase revenue for increased resiliency benefits (shown in Figure 37), a resiliency-focused sales tax would be a viable source of increased revenue. A new or redirected countywide sales tax would allow Boulder County to showcase key resiliency projects and initiatives to voters for their consideration and support. Renewing or increasing the one-tenth of a percent Countywide Transportation Sales tax could fund new transportation projects focused on resiliency benefits.

An extension of the 2015 Flood Recovery Sales Tax Fund would provide a consistent baseline to continue ongoing flood recovery work in the county that is not covered by reimbursement from other agencies (e.g., FEMA) and fund proactive resiliency actions recommended in this Study.

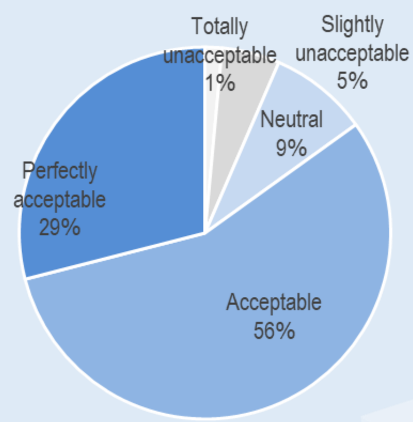
General Obligation Bond

Increasing Boulder County resiliency requires considerable upfront investment, and the benefits are realized over a long timeframe. Accordingly, financing with long-term bonds is an attractive funding option. A general obligation bond for transportation targeting resiliency projects with high value and high public support could be successful. Based on public input obtained through the course of this Study, there is overwhelming support for spending more on increased infrastructure and construction if it results in greater resiliency to Boulder County. Of those who answered the Study's survey question about acceptable trade-offs for achieving greater resiliency, 94 percent felt neutral or even more favorable about increasing spending (Figure 38).

Public input on increasing infrastructure spending and construction

Of the Boulder County 339 survey respondents who answered, "which are acceptable trade-offs for having greater resiliency when considering potential catastrophic disasters?" **94 percent** of viewpoints ranged from "perfectly acceptable" to "neutral" for increasing public infrastructure spending and construction.

Figure 38. Public input on increasing infrastructure spending and construction



Source: Public Survey Summary, Appendix 1.

Stormwater Retention Credit Trading Program

A Stormwater Retention Credit Trading Program would allow developers and property owners to generate and sell Stormwater Retention Credits (SRCs) to earn revenue for projects that reduce harmful stormwater runoff by installing green infrastructure or by removing impervious surfaces. Similar examples of financial incentives exist for communities in the form of tax credits or fee reductions, but Boulder County also can offer other types of incentives through existing planning mechanisms (e.g., transfer of development rights). Another good example is the “resilience quotient” system being implemented in Norfolk, Virginia, through its zoning ordinance, where developers earn points for adopting different resilient measures that promote flood risk reduction, stormwater management, and energy resilience, among other practices. New developments are required to meet different resilience point values based on the development type (e.g., residential, non-residential, mixed-use) and development size, unless the developer chooses to meet specified standards for elevation and drainage.

5.2.2 Competitive Sources

Competitive funding sources represent critical resiliency-supportive funding that Boulder County has been successful at leveraging in the past. Continued focus on obtaining funds from these competitive funding programs is essential for implementing the broad range of recommended resiliency actions being proposed in this Study. The mix of innovative and lower-cost planning, study, and analytical tool-focused actions mixed with greater-intensity infrastructure-focused actions provides a rich palette of projects to submit as candidates for funding from the wide array of competitive grant-funding sources available to Boulder County.

An essential element of the implementation plan (Section 5.1) is to continue Boulder County’s track record of seeking and being awarded key competitive grants like the Hazard Mitigation Grant Program (HMGP); Pre-Disaster Mitigation program’s replacement, Building Resilient Infrastructure and Communities (BRIC); Flood Mitigation Assistance (FMA), Community Development Block Grant-Disaster Recovery (CDBG-DR), etc.). A comprehensive list of candidate competitive funding sources is documented in Appendix 7. A summary of these funding sources, and their potential applicability to top actions is summarized in the following table.

Table 8. Potential Competitive Funding Sources for Top Resiliency Actions

Top Action by Category	BLM Wildland-Urban Interface Community and Rural Fire Assistance	CDPHE Section 319/Nonpoint Source Program Grant Program	CSFS Forest Restoration & Wildfire Risk Mitigation Grant Program	CSFS Colorado Forest Legacy Program	CSFS Restoring Colorado's Forests Fund	DOLA Conservation Trust Fund	DOLA Energy and Mineral Impact Assistance Fund	DOLA Rural Economic Development Initiative	EDA Economic Development Administration Planning and Local Technical Assistance Programs	FEMA Emergency Management Performance Grants Program	FEMA Hazard Mitigation Assistance	FEMA Building Resilient Infrastructure and Communities	FEMA Flood Mitigation Assistance Program	FEMA Hazard Mitigation Funding Under Public Assistance, Section 406	FEMA Hazard Mitigation Grant Program	FHWA Emergency Relief Program and Resilience	FHWA Federal Lands Access Program	HUD Community Development Block Grant	HUD Community Development Block Grant - Disaster Recovery	NFWF Resilient Communities Program	USDA Community Facilities Direct Loan and Grant Program	USDA Conservation Innovation Grants	USDA Emergency Watershed Protection Program	USDA Tree Assistance Program	USDA Watershed Rehabilitation Program	USDA Watershed Protection and Flood Prevention (WFPO) Program	USDOT Better Utilizing Investments to Leverage Development Grant Program
Improve Building Stock Resiliency																											
3.1.1 Fortify regulatory floodplain building rules							✓																				
3.1.2 New and substantially improved critical facilities to be floodproofed														✓	✓		✓				✓						✓
Institutionalize Resilience																											
3.2.2 Complete watershed management planning necessary under National Flood Insurance Program Community Rating System Activity 452.b to obtain Class 2 certification										✓	✓	✓	✓						✓	✓	✓					✓	
3.2.7 Flood risk tracking tool and climate vulnerability assessments			✓				✓			✓	✓	✓	✓				✓		✓	✓	✓	✓					✓
3.2.5 Sediment/debris removal occurs when/where needed											✓	✓	✓										✓			✓	
3.2.6 Establish metrics for achieving community resilience		✓																		✓	✓						
3.2.3 Develop and adopt plans, policies, and routes for emergency access and egress in a flood	✓									✓								✓	✓		✓						
3.2.4 Develop a post-wildfire flood risk reduction program	✓		✓		✓				✓		✓	✓	✓		✓	✓	✓		✓					✓			
3.2.1 Develop procedures, capabilities, and Multi-Hazard Mitigation Plan recommendations to maximize infrastructure resilience funding from FEMA										✓	✓	✓	✓						✓	✓							
3.2.8 Increase awareness of resiliency matters among county staff and elected officials																											
Public Infrastructure Risk Reduction																											
3.3.1 Improve critical high-risk roads, bridges, and culverts											✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓		✓
3.3.3 Implement project prioritization processes that include resiliency																											

Top Action by Category	BLM Wildland-Urban Interface Community and Rural Fire Assistance	CDPHE Section 319/Nonpoint Source Program Grant Program	CSFS Forest Restoration & Wildfire Risk Mitigation Grant Program	CSFS Colorado Forest Legacy Program	CSFS Restoring Colorado's Forests Fund	DOLA Conservation Trust Fund	DOLA Energy and Mineral Impact Assistance Fund	DOLA Rural Economic Development Initiative	EDA Economic Development Administration Planning and Local Technical Assistance Programs	FEMA Emergency Management Performance Grants Program	FEMA Hazard Mitigation Assistance	FEMA Building Resilient Infrastructure and Communities	FEMA Flood Mitigation Assistance Program	FEMA Hazard Mitigation Funding Under Public Assistance, Section 406	FEMA Hazard Mitigation Grant Program	FHWA Emergency Relief Program and Resilience	FHWA Federal Lands Access Program	HUD Community Development Block Grant	HUD Community Development Block Grant - Disaster Recovery	NFWF Resilient Communities Program	USDA Community Facilities Direct Loan and Grant Program	USDA Conservation Innovation Grants	USDA Emergency Watershed Protection Program	USDA Tree Assistance Program	USDA Watershed Rehabilitation Program	USDA Watershed Protection and Flood Prevention (WFPO) Program	USDOT Better Utilizing Investments to Leverage Development Grant Program
3.3.4 Develop scour risk-based prioritization of bridge improvements																										✓	
3.3.5 Update infrastructure design standards and maintenance regimes to account for climate change							✓													✓							
3.3.6 Update design standard to favor bridges over multiple cell pipe culverts in critical locations																											
Increase Community Preparedness																											
3.4.1 Create high-risk building buyout program				✓		✓					✓	✓	✓	✓	✓			✓					✓				
3.4.3 Incentives for voluntarily raising freeboard											✓	✓	✓	✓	✓			✓		✓	✓						
3.4.4 Incentives for other voluntary flood protection measures											✓	✓	✓						✓	✓	✓						
3.4.2 Low- and moderate-income resiliency needs assessment: transportation systems							✓	✓										✓	✓	✓	✓						
3.4.7 Increase transit service in response to economic or natural disasters								✓									✓	✓									
3.4.5 Resiliency-focused engagement with the community		✓					✓											✓		✓							
3.4.6 Provide meaningful bilingual resiliency materials, engagement, and event-recovery support		✓					✓			✓								✓		✓							