Appendix 1. Public Survey Summary

Memorandum

To:	Boulder County Transportation Department
From:	Atkins North America, Inc.

Introduction

An online survey was created for the Floodplain Management and Transportation System Resiliency Study using an online survey tool. The survey was launched to help ensure that public input is collected uniformly and accurately and to enable people who could not attend in-person Community Conversations to have an equal voice in expressing their opinions as those who attended in-person.

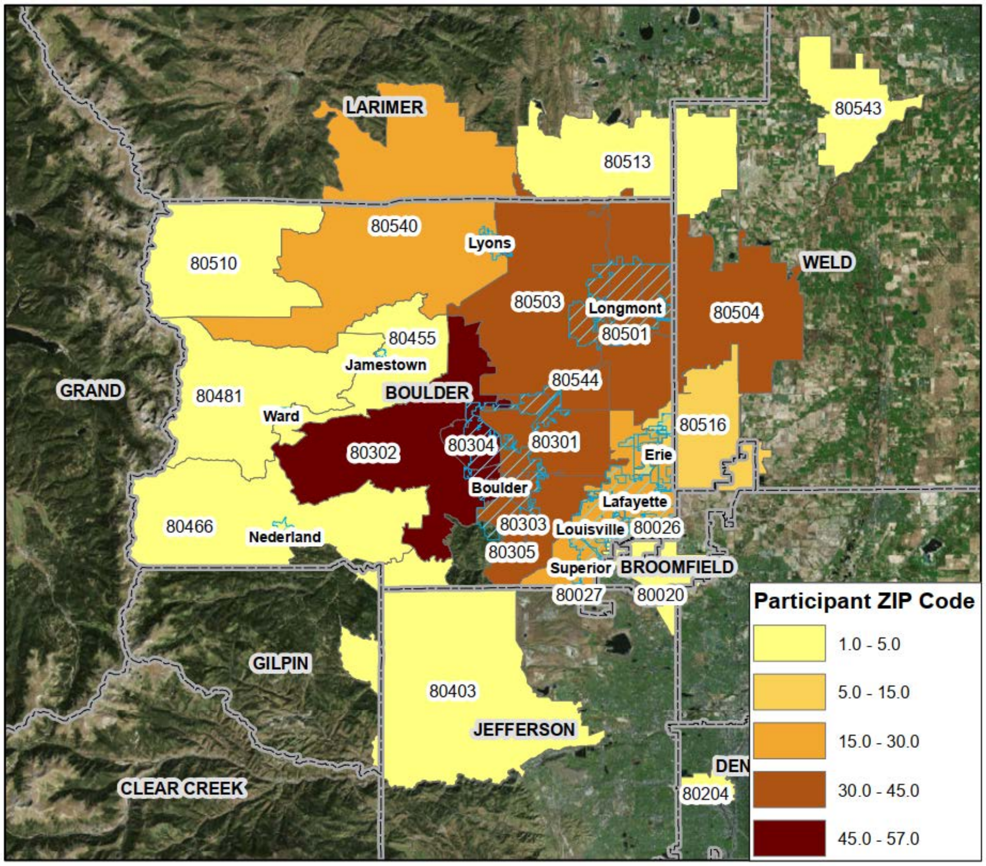
The survey was posted on the project website, http://www.bocoresiliencystudy.org/, and announced through press releases and on NextDoor, a neighborhood social network website, via Boulder County's agency profile.

Summary

The survey included 18 questions, three of which required an answer to determine what follow-up questions respondents were asked. Depending on participants' responses to those questions, with logic applied, they may have been presented with only 13 questions.

The survey went live on Friday, January 18, 2019, and was closed on Monday, February 4, 2019. A total of 413 responses were received to the survey, which had an 83-percent completion rate and took an average of six minutes to complete. The heatmap shown in Figure 1 displays the geographic distribution of survey respondents by ZIP code. Note that a small number of respondents are from outside Boulder County. Of the total respondents, 187 provided their email address, indicating that they wish to learn more about this study.

Figure 1. ZIP Code of Survey Respondents

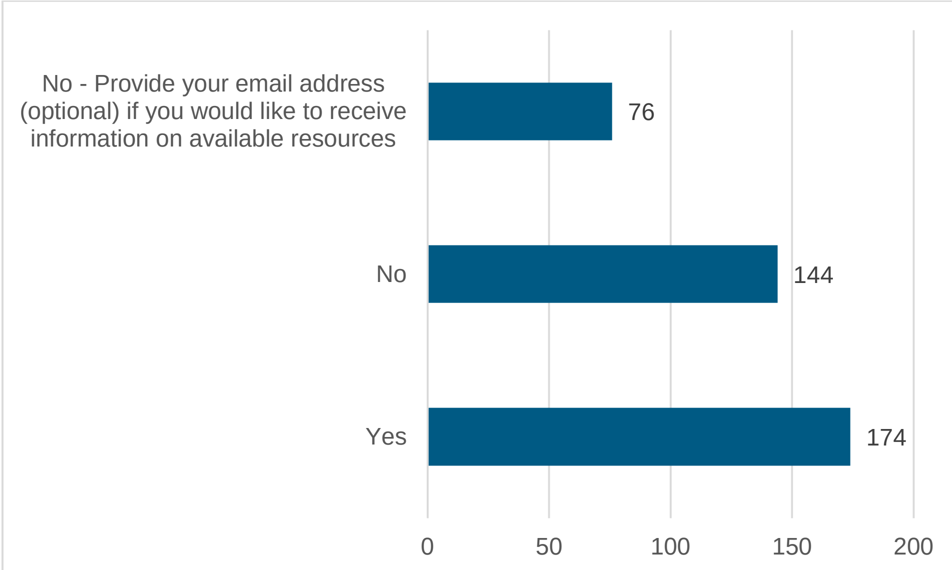


Results Snapshot

Results of the survey will be used to help inform and direct the Action Plan and associated weighting of actions and proposed infrastructure improvements. A snapshot of results to some of the questions is presented in the following pages.

Question 5 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 and want to receive information about resources via email." See Figure 2, below. It is reassuring that 44 percent of responders are aware of some resource available to them to help develop household emergency plans. Increased awareness could help to increase resilience and disaster preparedness across the county.

Figure 2. Question 5 Responses

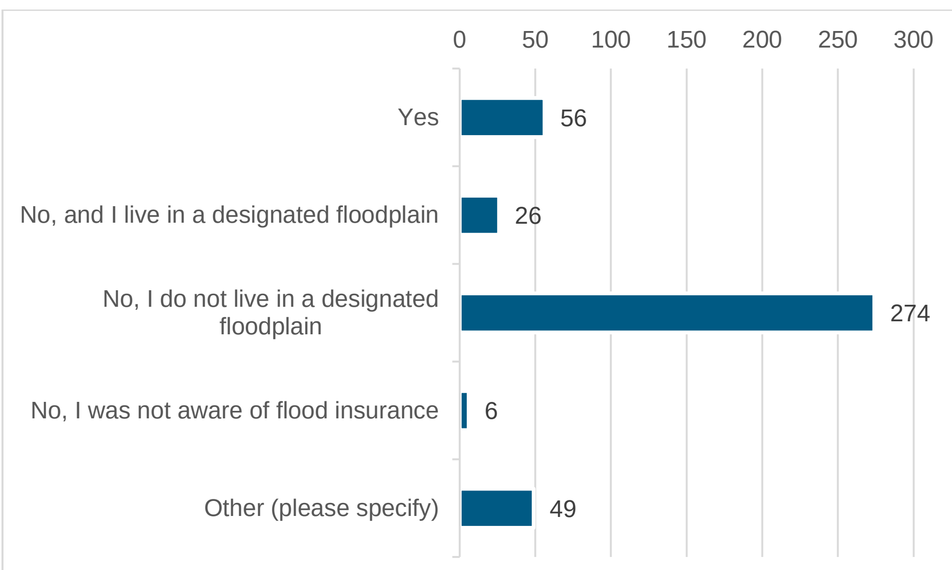


Question 6 asked: ***"Do you have flood insurance for your home? (Note that most homeowner insurance policies do not cover flooding. Specific flood insurance is often required for coverage)."*** Of the total responses received, 14 percent said "Yes," 69 percent said "No, I do not live in a designated floodplain" and 7 percent said "No, and I live in a designated floodplain,". See Figure 3, below.

It is reassuring that, of those who responded "No," only 2 percent of responders were unaware of flood insurance. Additionally, 12 percent of respondents selected "Other, please specify," and comments included, but were not limited to, the following:

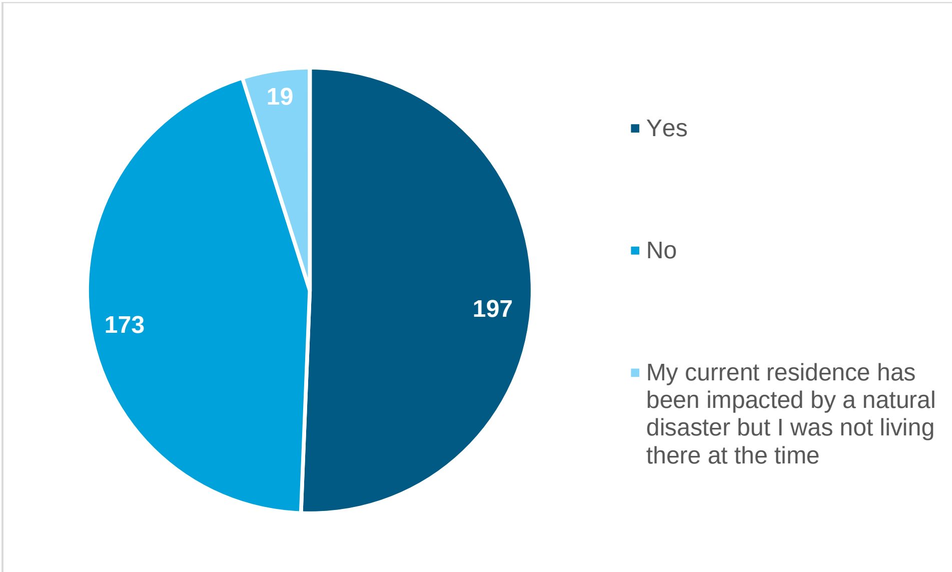
- Not sure if I live in a floodplain
- I do not live in a designated floodplain, but my home was damaged by floods
- I live on an upper floor

Figure 3. Question 6 Responses



Question 9 asked: ***"Have you been impacted by recent natural disasters such as the 2013 flood or recent wildfire events?"*** Of the total responses, 50 percent indicated they were impacted, 45 percent were not impacted, and 5 percent were not living in their current residence when it was impacted by a natural disaster. See Figure 4, below.

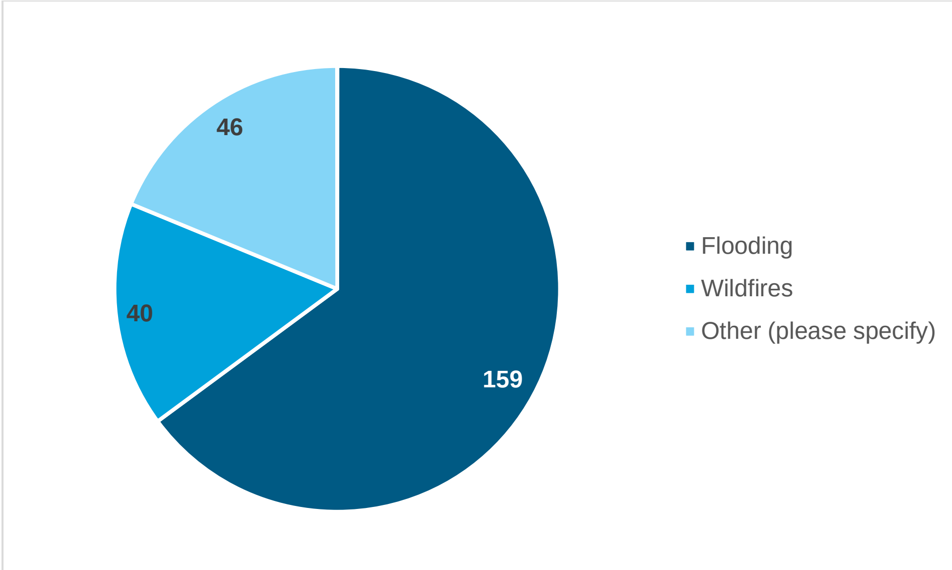
Figure 4. Question 9 Responses



Those who responded "Yes" to Question 9 then were asked Question 10: ***"How were you impacted?"*** Multiple options could be selected (see Figure 5, below). Of the total respondents, 80 percent were impacted by flooding, 20 percent by wildfires, and 23 percent by other natural disasters, including, but not limited to, the following:

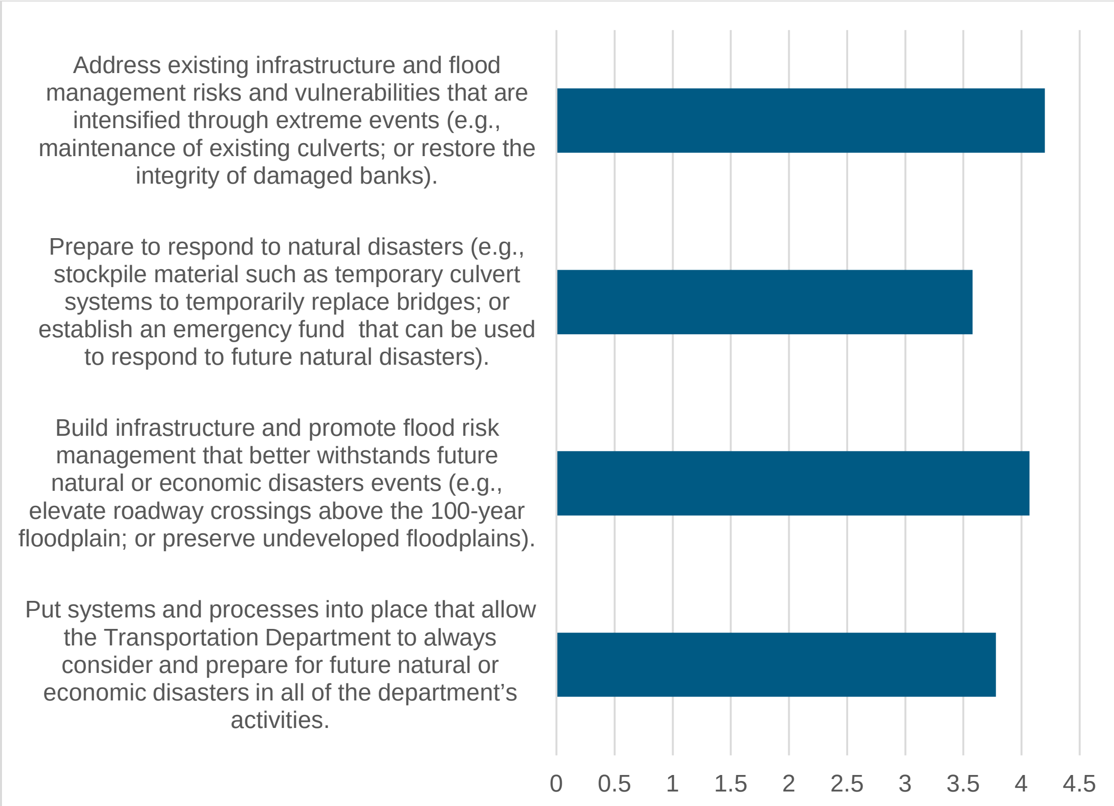
- Roadway closures and infrastructure/utility damage
- No home damage, but could not leave home for days
- No structural damage, but land was impacted
- No home damage, but was evacuated
- Could not access work
- Rain damage
- Mud damage
- Hail damage

Figure 5. Question 10 Responses



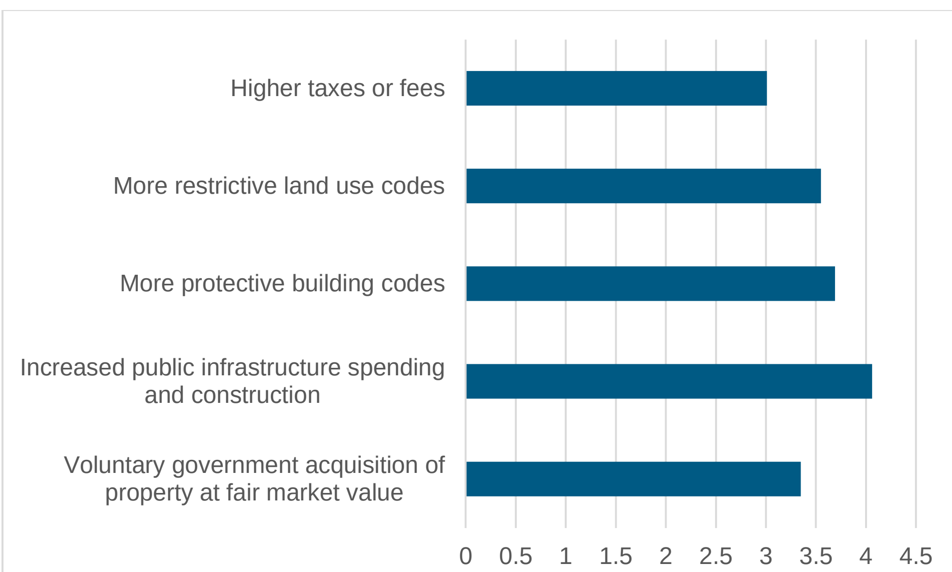
Question 14 attempted to determine which of the four goal areas was most important to respondents. The question was phrased: "***Boulder County needs to prioritize expenditure for future response to natural disasters and/or potential impacts of increased temperatures and variable weather on transportation maintenance activities. Which of the following statements would best ensure that the County's transportation system is able to function successfully, and floodplain management activities are appropriately chosen?"*** Figure 6, below, shows the weighted average response to the four goal areas. Note that the spread of responses is relatively even, with no single response standing out. This indicates that all goal areas are important to the survey respondents.

Figure 6. Question 14 Responses



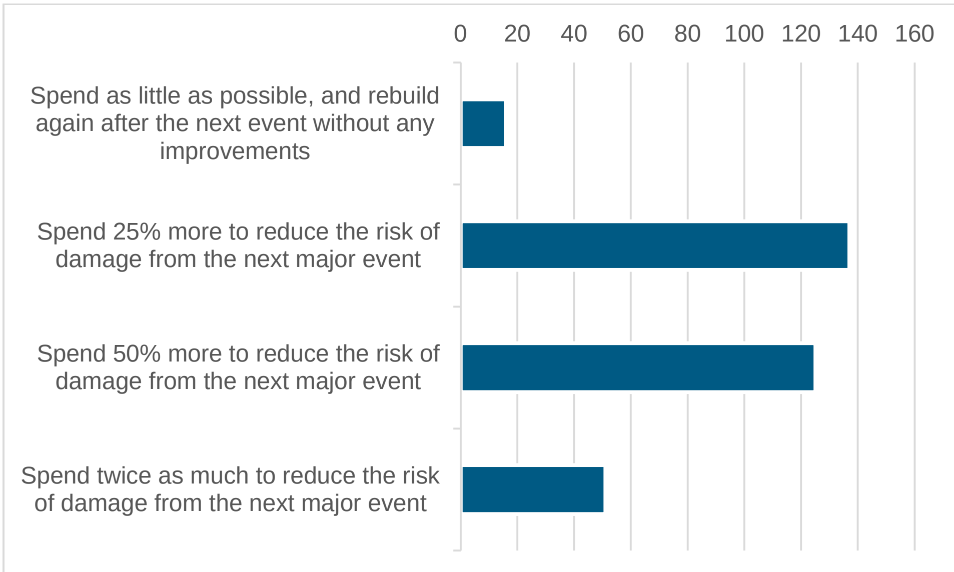
Question 15 aimed to gauge what tradeoffs would be acceptable to survey respondents to achieve greater resiliency, stating: ***"Which are acceptable tradeoffs for having greater resiliency when considering potential catastrophic disasters?"*** The spread of responses is relatively equal among the five options, as shown in Figure 7, below, with "Voluntary government acquisition of property at fair market value" and "Higher taxes or fees" slightly less preferable than the remaining, and "Increased public infrastructure spending and construction" slightly more preferable than the remaining.

Figure 7. Question 15 Responses



Question 16 aimed to gauge what level of increased spending on roads and bridges would respondents support, stating: ***"During re-construction and/or replacement of roads and bridges, the decision must be made on how much more should be spent to better prepare for the next major event. What level of increased spending on roads and bridges would you support?"*** Of the respondents, 42 percent indicated they would support a 25-percent increase in spending to reduce the risk of damage from the next major event, with 38 percent supporting a 50-percent increase in spending. These results indicate that the majority of the Boulder County public support some level of increased spending to improve the resiliency of County roads and bridges. See Figure 8, below.

Figure 8. Question 16 Responses



The final two questions on the survey were open-ended questions that aimed to elicit local information from respondents.

Question 17 stated: ***"Are there any conditions that make your home/neighborhood particularly vulnerable to flooding or vulnerable in the recovery from a flooding event?"*** This question received 271 responses ranging from concerns about proximity to creeks, to infrastructure concerns, to personal property concerns. These responses provide Boulder County with individual and localized concerns that can be analyzed in more detail and compared against study modeling efforts.

The final question read: ***"If you have any additional thoughts, please share below."*** This question received 131 responses that ranged from participants voicing their appreciation for the study, to individual and countywide frustrations and concerns.

Appendix 2. Literature Review Memorandum

Memorandum

	Boulder County Transportation Department		
From:	Atkins	Email:	Steve.Hoover@atkinsglobal.com
Date:	December 03, 2018	Phone:	720.475.7087
Ref:	None	cc:	
Subject:	Floodplain Management and Transportation System Resiliency Study and Action Plan – Literature Review Memorandum		

Introduction

This memorandum summarizes the initial findings of a literature review conducted as part of Boulder County's Floodplain Management and Transportation System Resiliency Study and Action Plan (Study). This literature review will be used as the foundation for developing resiliency strategies and recommendations that will be evaluated for the degree to which they advance resiliency goals and for their potential effort to implement (i.e., financial, public sentiment, level of effort, etc.). Materials reviewed consist of existing mobility and resiliency studies, comprehensive plans, master plans, and standards. A list of the materials reviewed is provide in Appendix B.

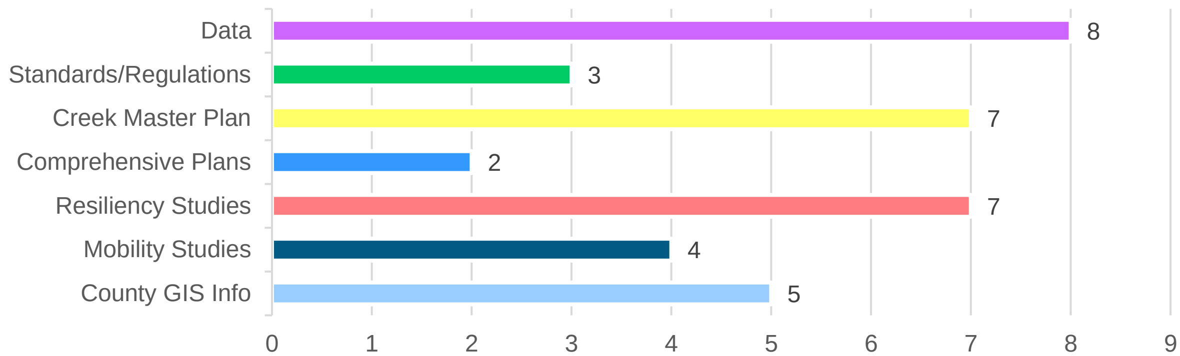
The resiliency goals for the Study, developed by the Project Management Team (PMT) and Steering Committee, serve as the basis for the literature review and are outlined below:

1. **Institutionalize resiliency:** Strengthen Boulder County Transportation Department and local governments' culture and prioritization of transportation system and flood risk resiliency.
2. **Withstand shocks:** Transportation systems and related flood risk management reduce long-term impact of shock events.
3. **Respond to shocks:** Transportation systems and flood risk management respond effectively to shock events.
4. **Address stresses:** Improve transportation system and flood risk management responsiveness to stresses.

Literature Review Composition

The literature review included 24 documents, as listed in Appendix B. Figure 1 outlines the various types of reports and data sets that were reviewed.

Figure 1. Document and Data Review: Number of Resources



These documents identify needs, solutions, and commitments (grouped together as potential resiliency action items) for floodplain management and transportation system resiliency. The literature review process is used to leverage the time and effort spent by Boulder County and other jurisdictions to determine the needs of individual communities by documenting known needs, solutions, and actions for use in the Study. This process avoids undercutting or duplicating the efforts previously undertaken by Boulder County and other agencies.

Process

The project team's approach to reviewing the large number of relevant local and countywide materials was to create a structured framework that allowed a focused review for topics relevant to the goals and objectives of the Study. The approach involved building a review matrix whereby all materials were analyzed using the same criteria. The framework poses 50 questions to the reviewer (see Appendix A) representing the Study's 4 goals and 20 objectives. Each question is designed to identify needs/gaps, proposed actions, or sufficiency in meeting goal/objective tenets. The use of a highly structured matrix ensured that all desired data—including needs, solutions, and commitments—were identified, noted, and tracked in one systematic and organized process.

The literature review resulted in the capture of 376 findings capable of becoming one or more potential resiliency actions. Findings may represent fully developed and implementable actions, procedures, requirements, or policies. They also may represent goals, recommendations, principles, or observations which are not yet implementable actions in and of themselves, but can become potential resiliency action items through further development by the Study's consultant team and PMT discipline tracks for: Floodplain Management, Infrastructure Design, and Transportation Planning. Each of the literature review findings was given a unique identifier and categorized under the following criteria. This ensures that any resiliency action resulting from a finding can be traced back to the document and rationale from which it originated. Categorization attributes also will be used during subsequent evaluation phases of the Study.

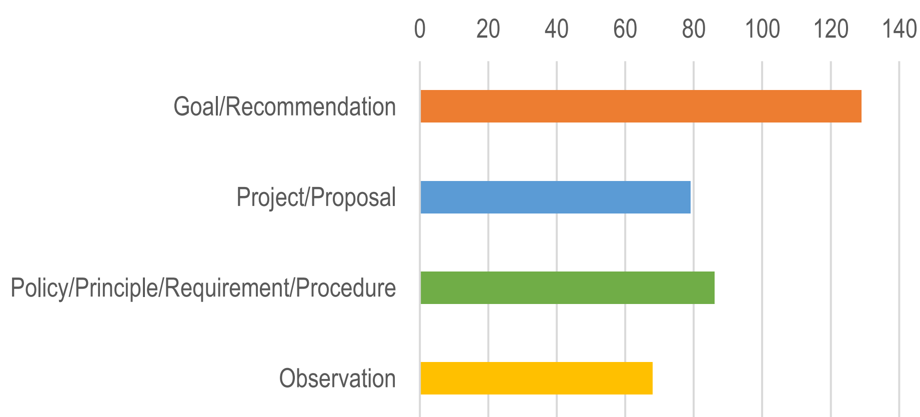
- Action item type
    - Goal/Recommendation
    - Project/Proposal

  - Policy/Principle/Requirement/Procedure
  - Observation
- Study Track
  - Infrastructure
  - Transportation Planning
  - Floodplain Management
- Relevant goal, objective, and framework question (see Appendix A)

Literature Review Findings

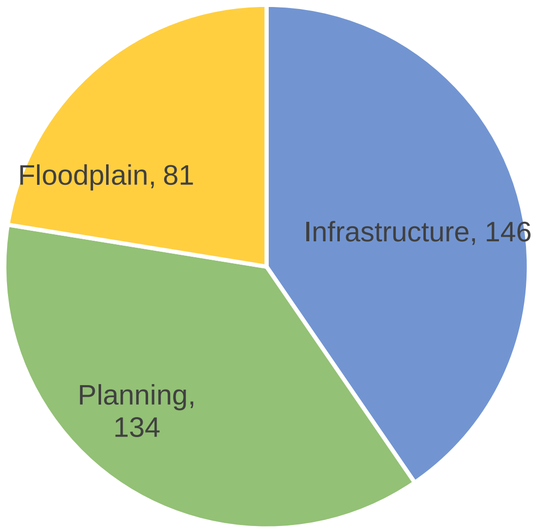
The 376 literature review findings were categorized to allow actions to be analyzed in logical groupings. Figure 2 outlines resiliency findings by type. Goals and recommendations make up the largest portion of the identified findings with a relatively even spread between the remaining findings. It should be noted that several individual findings represent multiple resiliency projects. For example, one finding from *Resilient Design Performance Standard for Infrastructure and Dependent Facilities* represents nine implementable projects. While these projects are noted in literature review documentation if further evaluation of these individual projects is necessary in subsequent phases of the Study, for now, they are noted as one finding in this literature review summary.

Figure 2. Finding Types



The Study is split into three distinct but interrelated tracks: Floodplain Management, Infrastructure Design, and Transportation Planning. Accordingly, the resiliency strategies and recommendations made as part of this study will be divided into these three tracks. Based on the initial literature review, Figure 3 illustrates that the distribution of literature review findings is relatively evenly split between the three tracks, with Floodplain Management having slightly less than the other two.

Figure 3. Literature Review Findings by Study Track



Findings identified through the literature review vary in terms of how mature potential resiliency actions are described. Whereas some findings describe broad needs, with no solutions offered, other findings represent solutions that are implementable projects and actions. To account for this variation, the literature review categorizes findings as solutions, needs, or commitments. Findings categorized as solutions typically are those where the respective plan outlined both an issue and suggested a solution. Needs typically are gaps between existing and desired conditions that have been identified in plans, but no solution is identified. Commitments are pledges documented in plans. These pledges may or may not be connected to implementable project-level or policy-level solutions.

As summarized in Figure 4, most of the initial literature review findings are solutions, with needs and commitments making up approximately one-third of findings.

Figure 4. Resiliency Type

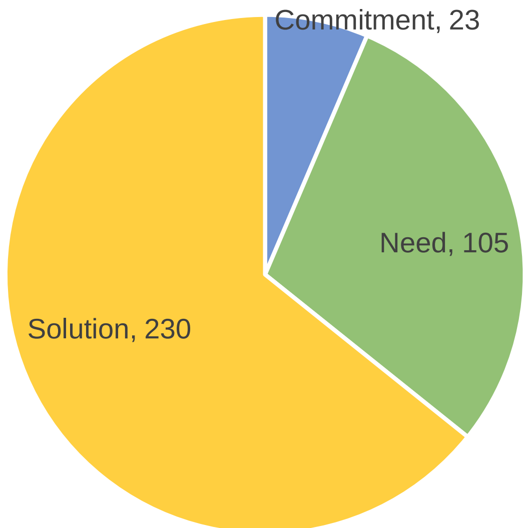
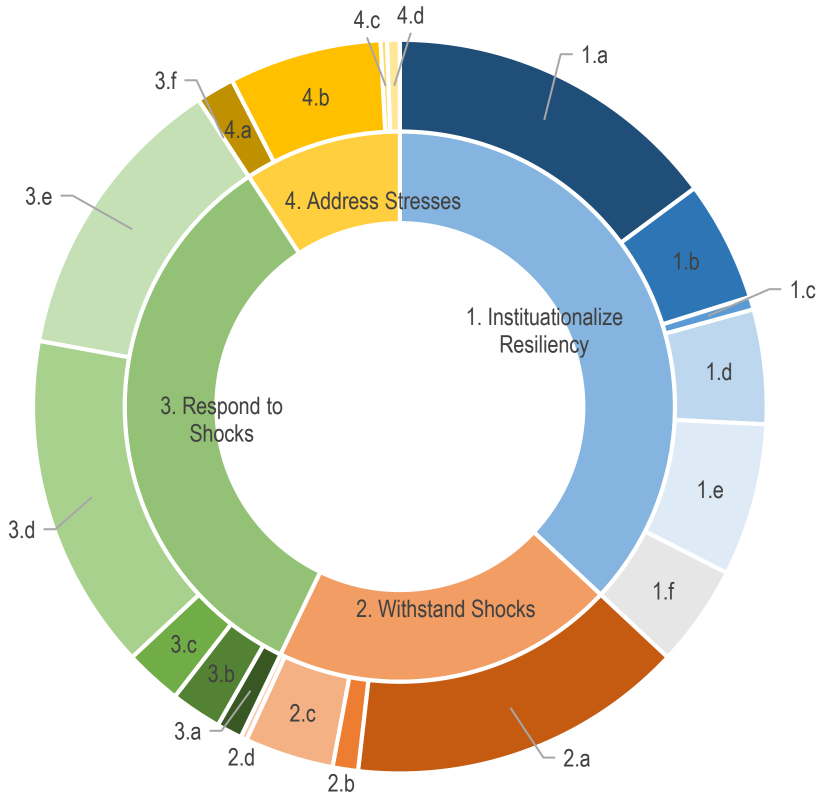


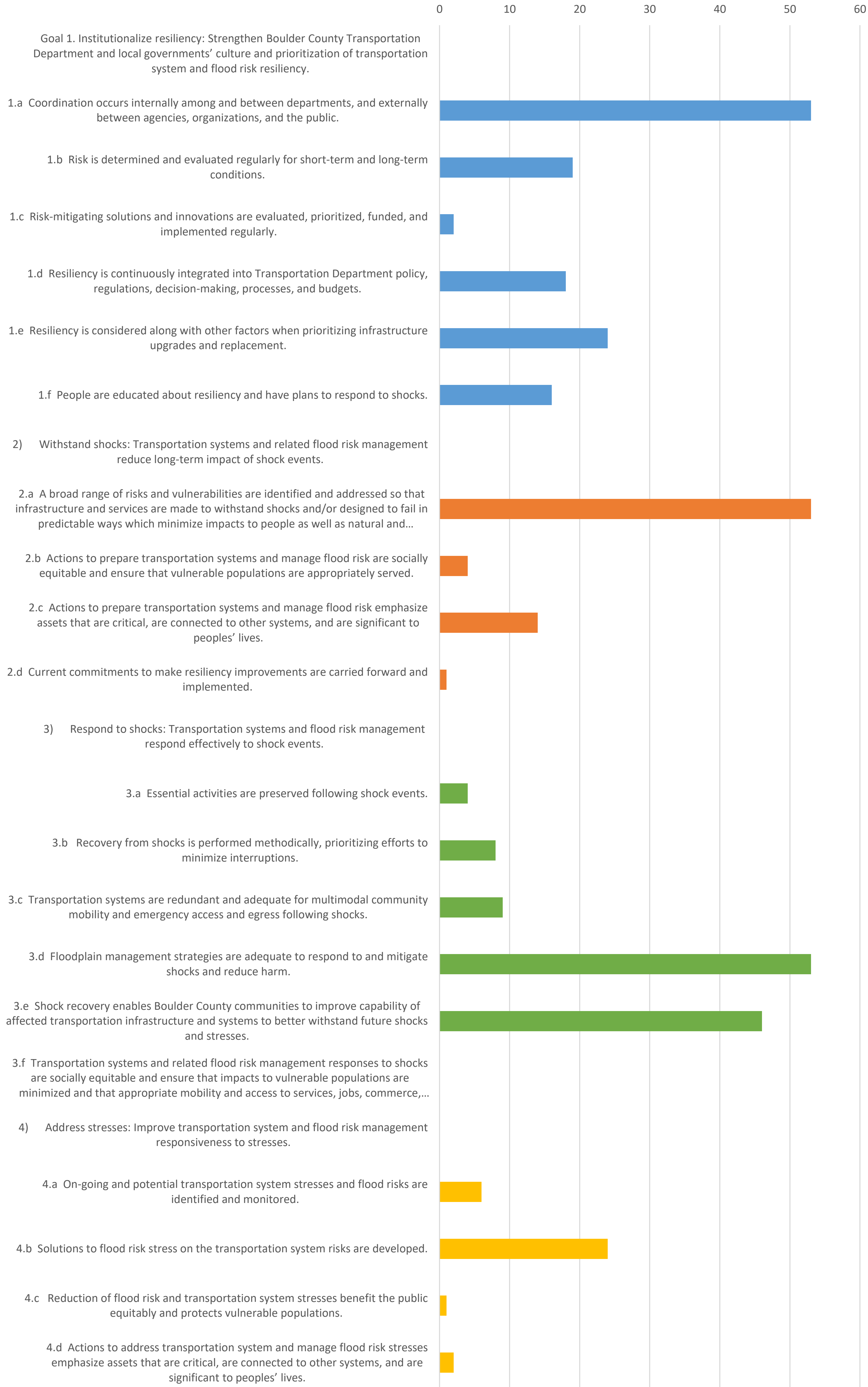
Figure 5 outlines the distribution of findings among Study goals and objectives. Note that Goal 1 (Institutionalize Resiliency), and Goal 3 (Respond to Shocks) are the most common goals identified from the action items. This is likely due to the large number of master plans and resiliency studies that were reviewed. Goal 4 (Address Stresses) is the least represented in the action items. Further refinement and analysis of findings in subsequent Study phases may alter the distribution of findings among the goals as resiliency actions are developed for needs and commitments (Figure 4) that are not yet adequately represented by projects. Figure 6 goes a step further than Figure 5 and outlines the orientating question associated with the goals and objectives for the identified findings. The full list of goals, objectives, and orientating questions can be found in Appendix A.

Figure 5. Findings by Goal and Objective



Note: Text descriptions of objectives 1.a through 4.d are noted below in Figure 6.

Figure 6. Literature Review Findings by Goal and Objective



Gaps

After completing the literature review, the areas that would benefit the Study most from further understanding or attention are:

- Most findings need to be developed further to be considered potential resiliency actions and should contain enough detail to be evaluated in subsequent phases of the Study.
- More consistent and countywide assessments of priority needs, assets facing risk, etc. would benefit the evaluation phase of the Study. For example, some of the master plans have a prioritized project lists, but others do not, nor are prioritization criteria consistent between all plans.
- Better understanding of transit use and needs would benefit the development of potential resiliency action ideas.
- Better understanding of travel needs of underserved populations would benefit the development of potential resiliency action ideas.
- There are a lot of recommendations to remove sediment and debris from structures. Better understanding of present-day inspection and removal frequency would be helpful.
- Understanding existing county-wide processes and procedures for identifying, developing, and prioritizing floodplain and transportation projects would benefit the development of potential resiliency actions in subsequent stages of this Study.
- To be determined*

*The bullets above highlight some of the initial gaps identified from the literature review process. As literature review findings are examined in greater detail through the next phase of the Study (i.e. developing potential resiliency actions), additional gaps will become more apparent and will be added to this bulleted list.

Next Steps

Results outlined in this memo summarize the findings of the initial analysis of the literature review. This review will be used as the foundation for developing resiliency actions, and ultimately strategies and recommendations for Boulder County's Floodplain Management and Transportation System Resiliency Study and Action Plan.

Appendix A—Goal, Objective, Orientating Question

Goal 1. Institutionalize resiliency: Strengthen Boulder County Transportation Department and local governments' culture and prioritization of transportation system and flood risk resiliency.	
1.a	Coordination occurs internally among and between departments, and externally between agencies, organizations, and the public.
1.a.i	What resiliency-related coordination needs/gaps are identified?
1.a.ii	What recommendations/solutions are offered to address coordination needs/gaps? (Reference these as **potential resiliency actions** [**Actions**])
1.a.iii	Describe depth of coordination gap being addressed by Action[s] (on-time, procedural, regular, programmatic, etc.)?
1.a.iv	What resiliency-related coordination is currently being done and who is participating?
1.b	Risk is determined and evaluated regularly for short-term and long-term conditions.
1.b.i	What activities are recommended to identify risks? (Reference these as Actions)
1.b.ii	What activities are being done to identify risks?
1.b.iii	What intervals are these activities occurring/needed?
1.b.iv	What time horizon(s) are being considered in risk determinations?
1.c	Risk-mitigating solutions and innovations are evaluated, prioritized, funded, and implemented regularly.
1.c.i	How is risk-mitigation factored in project development and selection processes?
1.c.ii	What recommendations are made for improving risk-mitigation representation in project development and prioritization processes? (Reference these as Actions)
1.c.iii	What risk types are the focus of recommendations?
1.d	Resiliency is continuously integrated into Transportation Department policy, regulations, decision-making, processes, and budgets.
1.d.i	What resiliency Transportation Department process, policy, regulation, decision-making, and/or budget needs/gaps are identified?
1.d.ii	What resiliency process, policy, regulation, decision-making, and/or budget solutions/recommendations are identified? (Reference these as Actions)
1.d.iii	What resiliency process, policy, regulation, decision-making, and/or budget solutions/recommendations are currently in place?
1.e	Resiliency is considered along with other factors when prioritizing infrastructure upgrades and replacement.
1.e.i	Is resiliency represented in infrastructure project prioritization/recommendation processes?
1.e.ii	Are recommendations made for improving representation of resiliency in infrastructure project prioritization? (Reference these as Actions)
1.f	People are educated about resiliency and have plans to respond to shocks.
1.f.i	What resiliency education and response planning needs/gaps are identified? (Reference these as Actions)
1.f.ii	What resiliency education recommendations are identified? (Reference these as Actions)
1.f.iii	What shock response planning recommendations are identified? (Reference these as Actions)
1.f.iv	What resiliency education and response planning activities are already in place?
2) Withstand shocks: Transportation systems and related flood risk management reduce long-term impact of shock events.	

2.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
2.a.i	What shock risks and vulnerabilities are already being identified and addressed?
2.a.ii	What shock risks and vulnerabilities have been identified, but not addressed?
2.a.iii	What shock solutions/recommendations are made for these unaddressed risks and vulnerabilities? (Reference these as Actions)
2.a.iv	What gaps in shock risks and vulnerabilities are identified?
2.a.v	What recommendations are made for identifying shock risks and vulnerabilities? (Reference these as Actions)
2.b	Actions to prepare transportation systems and manage flood risk are socially equitable and ensure that vulnerable populations are appropriately served.
2.b.i	What actions are currently being taken to manage flood risk and prepare transportation systems in socially equitable ways? (Reference these as Actions)
2.b.ii	What actions are recommended to manage flood risk and prepare transportation systems in socially equitable ways? (Reference these as Actions)
2.b.iii	What needs/gaps are identified in the provision of transportation system and flood shock prevention to vulnerable populations?
2.c	Actions to prepare transportation systems and manage flood risk emphasize assets that are critical, are connected to other systems, and are significant to peoples' lives.
2.c.i	Are assets that are critical, connected to other systems, and are significant to peoples' lives identified? What are they?
2.c.ii	How are assets that are critical, connected to other systems, and are significant to peoples' lives identified?
2.c.iii	Are actions recommended for assets that are critical, are connected to other systems, and are significant to peoples' lives? (Reference these as Actions)
2.d	Current commitments to make resiliency improvements are carried forward and implemented.
2.d.i	Which resiliency improvements have already been committed to? (Reference these as Actions)
3) <u>Respond to shocks</u>: Transportation systems and flood risk management respond effectively to shock events.	
3.a	Essential activities are preserved following shock events.
3.a.i	What shock response needs/gaps are identified?
3.a.ii	Are essential shock response activities defined? What are they?
3.a.iii	What actions are recommended for preserving essential activities after a shock? (Reference these as Actions)
3.a.iv	What have been previous impacts from shock events on essential activities?
3.b	Recovery from shocks is performed methodically, prioritizing efforts to minimize interruptions.
3.b.i	What shock recovery actions are high priority? Medium priority? Low priority?
3.b.ii	What needs/gaps in shock event response/prioritization have been identified?
3.b.iii	What actions have been identified to address recovery from shock events? What are their priorities?
3.c	Transportation systems are redundant and adequate for multimodal community mobility and emergency access and egress following shocks.
3.c.i	Which segments of the transportation system are redundant and can offer multimodal community mobility and emergency access and egress following shocks?
3.c.ii	If not, in what way are segments inadequate? What post-shock redundancy and multimodal community access needs/gaps have been identified?

3.c.iii	What post-shock transportation system redundancy and multimodal community/emergency access actions have been identified? (Reference these as Actions)
3.d	Floodplain management strategies are adequate to respond to and mitigate shocks and reduce harm.
3.d.i	What shock mitigating floodplain management needs/gaps are identified?
3.d.ii	What floodplain management strategies and actions for responding to and mitigating shocks have been identified? (Reference these as Actions)
3.d.iii	What minimum shock response and mitigation levels are identified?
3.d.iv	What shock mitigating floodplain management activities are currently being done?
3.e	Shock recovery enables Boulder County communities to improve capability of affected transportation infrastructure and systems to better withstand future shocks and stresses.
3.e.i	What needs/gaps have been identified in bouncing forward transportation infrastructure after shocks?
3.e.ii	What actions have been identified in bouncing forward transportation infrastructure after shocks? (Reference these as Actions)
3.e.iii	Have there been examples of affected transportation infrastructure being improved post-shocks?
3.f	Transportation systems and related 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.
3.f.i	What shock response needs/gaps are identified that focus on vulnerable populations?
3.f.ii	What shock response actions have been identified that focus on preserving connections of vulnerable populations with services, jobs, and community? (Reference these as Actions)
3.f.iii	How is socially equitability defined?
Goal 4. Address Stresses: Improve responsiveness of the transportation system and flood risk management to stresses.	
4.a	On-going and potential transportation system stresses and flood risks are identified and monitored.
4.a.i	What transportation system and flood risk stress needs/gaps have been identified?
4.a.ii	To what level are identified stresses documented/monitored?
4.a.iii	How often are stresses reviewed and/or updated?
4.b	Solutions to flood risk stress on the transportation system risks are developed.
4.b.i	What transportation system and flood risk stress actions have been identified? (Reference these as Actions)
4.c	Reduction of flood risk and transportation system stresses benefit the public equitably and protects vulnerable populations.
4.c.i	What stress reduction needs/gaps are identified that focus on vulnerable populations?
4.c.ii	What stress reduction actions have been identified that focus on preserving connections of vulnerable populations with services, jobs, and community? (Reference these as Actions)
4.d	Actions to address transportation system and manage flood risk stresses emphasize assets that are critical, are connected to other systems, and are significant to peoples' lives.
4.d.i	What priority has been placed on each transportation system and flood risk stress actions that have been identified?
4.d.ii	Which of these actions are connected to other systems, and are significant to peoples' lives?

Appendix B—Materials Reviewed

ID	Document Name	Source	Document Type	Year Published
1	Resiliency for All	BoCo Strong	Mobility Studies	2017
2	Boulder County Mobility for All Needs Assessment & Action Plan	Boulder County	Mobility Studies	2016
3	Resilient Design Performance Standard for Infrastructure and Dependent Facilities	Boulder County Collaborative	Mobility Studies	2016
4	Floods in Boulder: A Study of Resilience	ISET-International	Resiliency Studies	2014
5	The Impact of Climate Change: Projected Adaptation Costs for Boulder County, Colorado	Boulder County	Resiliency Studies	2018
6	Putting on a Resilience Lens: BOCO Strong Resilience Assessment for Boulder County	BoCo Strong	Resiliency Studies	2016
7	Boulder County Climate Change Preparedness Plan	Boulder County	Resiliency Studies	2012
8	Creating Room for the River	Boulder County	Resiliency Studies	2018
9	Boulder County Resiliency Coordination Plan	Boulder County	Resiliency Studies	
10	Colorado Resiliency Framework	Colorado Resiliency and Recovery Office	Resiliency Studies	2015
11	Boulder County Comprehensive Plan	Boulder County	Comprehensive Plans	2017
12	Boulder Valley Comprehensive Plan	Boulder County	Comprehensive Plans	2017
13	Boulder Creek Restoration Master Plan	Urban Drainage and Flood Control District	Creek Master Plan	2015
14	Coal Creek and Rock Creek Major Drainageway Plan	Urban Drainage and Flood Control District	Creek Master Plan	2014
15	Fourmile Creek Watershed Master Plan	Boulder County	Creek Master Plan	2014
16	Left Hand Creek Watershed Master Plan	Boulder County	Creek Master Plan	2014

ID	Document Name	Source	Document Type	Year Published
17	Little Thompson Watershed Restoration Master Plan	Little Thompson Watershed Restoration Coalition	Creek Master Plan	2014
18	St. Vrain Creek Watershed Master Plan	Boulder County	Creek Master Plan	2014
19	Upper Coal Creek Watershed Restoration Master Plan	The Environmental Group	Creek Master Plan	2014
20	Boulder County Multimodal Transportation Standards	Boulder County	Standards/Regulations	2012
21	Boulder County Storm Drainage Criteria Manual	Boulder County	Standards/Regulations	2015
22	Boulder County Land Use Code	Boulder County	Standards/Regulations	2017
23	2013 Flood losses experienced and avoided	FEMA	Data	2015
24	2013 Flood losses experienced and avoided	Boulder County and other local documentation of flooding extents, damages, losses (e.g. damage reports)	Data	2015

Appendix 3. City Simulator Calibration

Boulder County Resiliency Study

Atkins City Simulator: Calibration, Technical Notes, and Key Assumptions

Boulder County

August 18, 2019

Notice

Atkins' City Simulator ArcGIS Extension - Version 1.0

Table of contents

1 Document Purpose

This document is a set of notes on how City Simulator works and the options the user has in terms of modeling. The intent is to convey:

- the workflows used,
- the design of the City Simulator geodatabase, the tables within it and how they are related to each other,
- the methods for importing data into the geodatabase and the datasets that are available for use in a City Simulator application,
- the scenario paradigm and how scenarios can be compared,
- the algorithms used to run scenarios and the options users have to configure them.

The document is not intended to be a user manual for City Simulator, a detailed scientific explanation of the modeling algorithms, or a description of results and conclusions about any specific City Simulator application. That content is contained in separate documents and is authored and provided on a case by case basis when City Simulator applications are developed.

2 Notes on Boulder County's Application of City Simulator

City Simulator has many modeling choices. To define which choices and assumptions are made for a specific application, Atkins adds **text in blue** to this document in relevant sections to show which choices and assumptions were made for that application. By showing the choices in-line with an explanation of the workings of City Simulator, the intent is to convey the reasoning for the choices made. This document describes the application of City Simulator in Boulder County, CO.

3 Overview of City Simulator Algorithms

City Simulator simulates a target community evolving over time while being hit with climate change influenced events such as storms, heatwaves, and droughts. The simulation is multi-decadal, typically starting in the current year and ending in 2040, 2050, or 2060.

The model is agent-based, which means that a virtual population of “agents” lives within the community in the simulation. This population lives in residential buildings, works in commercial buildings, and commutes through the community infrastructure daily. City Simulator models this agent behavior to quantify the impact of disasters on city productivity over time.

The tool is an Esri ArcMap extension (v10.3 or higher). It works with a custom City Simulator geodatabase, which must be loaded using tools within the City Simulator extension.

The general workflow for using City Simulator is shown in figure 1. The remainder of this document will describe each of the steps in this process and outline the calculations that occur, and the assumptions made.

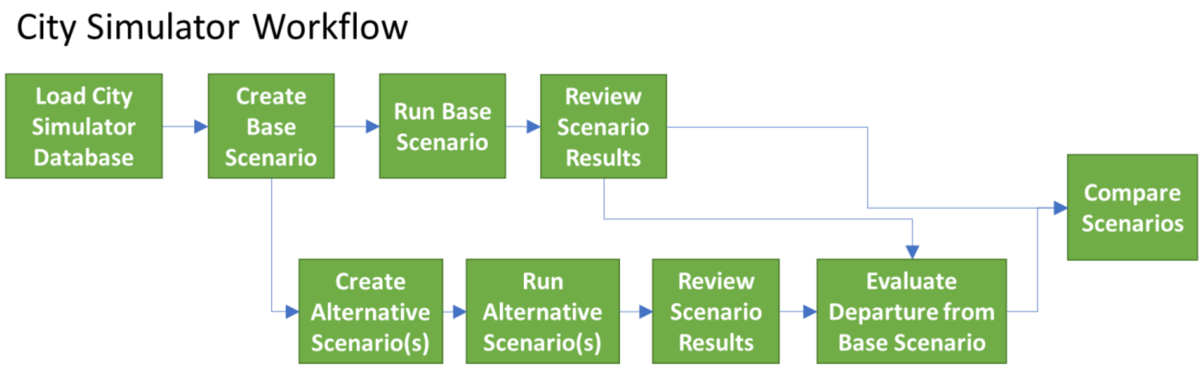


Figure 1: City Simulator Workflow

Boulder County: The Boulder County Simulator’s time horizon is 2019 – 2050. Atkins is providing Boulder County a “City Simulator as a Service” model, which means the Atkins team is:

- Building the model,
- Conducting the model runs, and
- Developing the results into reports and a deliverable City Simulator geodatabase.

4 Loading the City Simulator Database

The City Simulator geodatabase contains multiple feature classes and tables that collectively define a digital twin of the community in the base year, which is the start year of the simulation. The process of loading the database generally consists of preparing geospatial, time series, and statistical data on the community and loading it into the City Simulator geodatabase's tables. In many instances, there are tools built into the City Simulator extension that help with this process, either by tapping directly into a web- or map service, or by facilitating the process of data import.

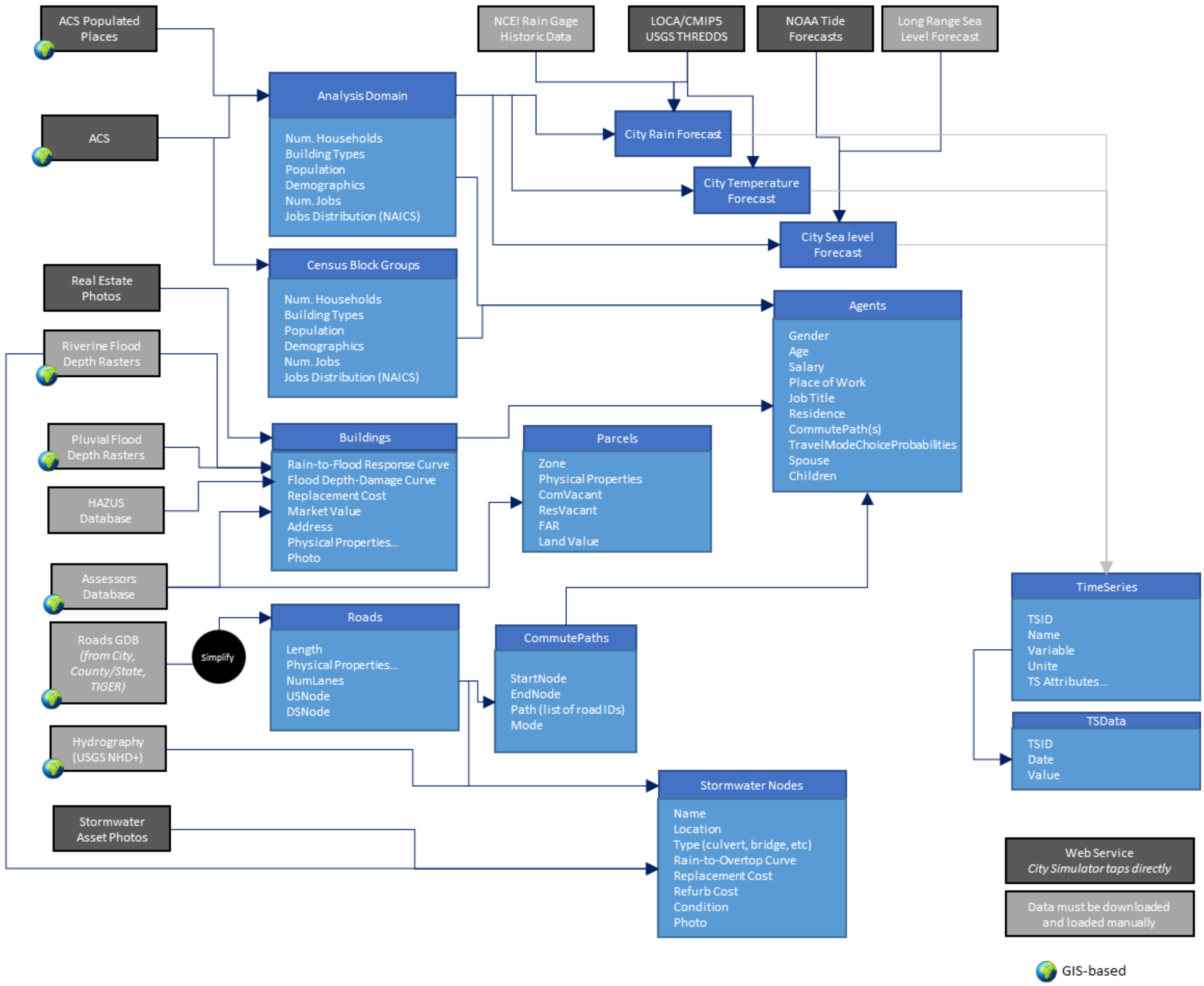


Figure 2: Loading the City Simulator Database

Figure 2 shows a diagram of the City Simulator geodatabase schema, the various data sources that typically feed into the geodatabase, and the tools/processes needed to import the data. The blue tables in the figure are the main feature classes and tables that make up the City Simulator geodatabase. The light and dark gray boxes show the data sources that typically provide the raw data that must be imported. Dark gray boxes represent on-line web services; City Simulator has multiple tools that tap into these web services to ease data import processes. Light gray boxes represent data that typically must be downloaded and prepared before importing. The globe icon next to some raw data boxes indicates that the data is geospatial in nature.

The following sections describe each of the datasets that can be imported into City Simulator.

4.1 Analysis Domain

The analysis domain is the geographic boundary of the City Simulator model. The boundary can be an incorporated area (city, town, etc.), a county that may contain incorporated areas, or a custom-defined area.

Often, if a target community is very large, it is beneficial to create multiple City Simulator models based on transportation corridors, watersheds, or some other logical division of the community landscape. These models can be “stitched” together by creating boundary nodes for transportation flows.

To make setting the domain as simple as possible, City Simulator comes with both a national counties map and a map of populated places (incorporated areas). The counties map is stored in a reference geodatabase that installs with City Simulator. The populated places map is pulled from the ACS Populated Places map service published by the US Census Bureau, which contains polygons of all incorporated areas in the US. Both map layers contain US-Census based estimates of population, number of households, and number of jobs, data needed by City Simulator for agent-based modeling.

By default, City Simulator calibrates the virtual agent population by distributing agents to buildings while ensuring that the total number of agents, jobs, and households within the analysis domain matches known values of those statistics. For example, if the US Census says that there are 100,000 people, 50,000 jobs, and 40,000 households in a community, City Simulator will ensure that the virtual population, number of jobs, and number of households match these “basic statistics.” Further, City Simulator will optionally ensure that secondary statistics like demographic distribution, distribution of salaries, education levels, and average commute times matches the census data.

Boulder County: For the Boulder County Simulator, the analysis domain is set as the county boundary and all land within it is being modeled including the incorporated areas such as City of Boulder and City of Longmont.

4.2 Secondary Statistics (Optional)

By default, City Simulator calibrates the population to the basic statistics while ensuring distributions of secondary statistics (age, gender, salary, job type, education level) follow national average distributions. Optionally, City Simulator can calibrate the virtual agent population to secondary statistics as well. To do this, fill in the Community/Statistics table, which is by default left empty. Each row contains a distribution statistic, such as “15.5% of the population in the analysis domain is age 0-4”, defined by the following attributes:

- **Area** – this string field specifies the area to which the distribution applies. If the field value is “Analysis Domain,” then City Simulator knows the statistic is for the whole modeling domain. The area can also be a Census block group (see the section below on Census block groups).
- **Statistic** – this string field specifies the statistic of the data entry being provided. It can be age, gender, education, job type, or salary.

- **Bin** – this string field specifies the part of the distribution for which the data point contains a percentage. For example, age can be “0-4”, “5-9”, and so on.

- **Percentage** – this double precision number field specifies the percentage of the distribution in the bin. It can range between 0 and 1. Note that over all bins for a given statistic, the percentages should add to 1.0.

Boulder County: The secondary statistics were not matched during population virtualization; City Simulator default distributions of gender, age, salary, education, and job type were used.

4.3 Census Block Groups (Optional)

Optionally, City Simulator can calibrate the virtual agent population more accurately by using Census block group level estimates of population, households, and jobs. Census block groups are polygonal areas that contain between 600 and 3,000 people. They are the smallest geographic area for which the US Census Bureau publishes sample data.

The City Simulator geodatabase holds a Census Block Group feature class, which can be populated using the Census Explorer tool that comes with the City Simulator extension. This tool taps into the US Census Bureau’s on-line databases and allows users to extract data for a collection of selected census block groups.

Note that in addition to population, number of jobs, and number of households, users can also download distribution data for secondary statistics like age, gender, education level, job type, and salary at the Census block group level, and store these in the community statistics table described above. If distribution data is utilized, City Simulator will allocate virtual agents within Census Block Groups such that they match the statistics you download.

Boulder County: For the Boulder County Simulator, the Census Block Group approach is being used to virtualize the agent population. The Census Block Group data is being pulled from the US Census Bureau’s online database. The calibration is being conducted in each census block group for basic statistics (population, number of jobs, number of households). This was done because intra-county travel is of interest in the model and therefore the accurate placement of the population and jobs within the county is required.

4.4 Buildings

Buildings are a required layer within the City Simulator geodatabase. They are contained as a polygonal layer of building footprints with multiple attributes related to address, physical properties, and economic value.

4.4.1 Building Footprint Polygons

The building polygons shapes can come from multiple sources:

- **The Community** – many communities actively maintain a GIS database of building footprints in conjunction with their other GIS layers like parcels, and roads. The databases also often contain physical attributes of the buildings, such as if the building has a basement, number of stories, heated square feet, etc. Often, this represents the best available data in terms of accuracy of the shapes of the buildings. This is therefore the preferred source for building footprint polygons.

- **Microsoft’s national building footprint database** - a secondary source for building footprint polygons is the Microsoft building footprint layer, which was published in 2018. This open source and freely available dataset contains building footprints for the entire contiguous United States. Derived through automated algorithms from aerial imagery, the building footprints are of lower quality than is typically seen with community-developed data. Further, physical attributes like number of floors are not available, and therefore must be imported from another source, or estimated by City Simulator.

- **Digitizing using City Simulator Tools** – for communities where no building footprint information is available, City Simulator provides a set of tools for digitizing buildings. By adding an aerial imagery base map such as Google Maps, the user can click a dot at each building location and the tools will generate polygons and add them to the City Simulator database. The tools contain a variety of functions that allow for controlling the shape, zoning, and other attributes as digitizing occurs. Further, the tools provide a way to add multiple buildings in a single action by adding them along a line or within a polygon that is drawn by the user. Because of the prevalence of building footprint data in the US, this tool is not often needed for US-based cities. However, in international cities, it is often a very helpful way to quickly populate the database with building footprints.

Boulder County: For the Boulder County Simulator, the building footprints were derived from Boulder County's GIS archive.

4.4.2 Building Attributes

City Simulator needs the following building attributes for modeling:

- **Type** – Type can be residential, commercial, or other, and is typically derived from the parcel layer's zone attribute – i.e. the municipal zoning designation attached to a parcel and building. See the Parcels section below for more information.

  Boulder County: Building Type was defined as residential or commercial to align with the City Simulator classification scheme. The type was inferred from the Building Class description in the Boulder County tax assessor database, which provides the building class assigned to each parcel. The building footprints were then joined to the parcels by a spatial join process and the buildings were allocated the residential or commercial classification from the underlying parcel.

  The parcels were assigned residential or commercial based on the following mapping:

  - Residential – BLDGCLASSDSCR =
    - Condos-Improvements
    - Single Fam Res Improvements
    - Dup/Triplex Improvements
    - Farm/Ranch Residential Improvements
    - Manufactured Housing Improvements
    - Multi-Units (X-Y) Improvements (All Classes)
    - No Value Residential Improvements
    - Ex Charitable Residential Improvements
    - Ex Church Residential Improvements
    - Ex Federal Residential Improvements
  - Commercial – Bldgclassdscr =
    - Airport
    - All Other Ag Imps
    - Auto Dealer
    - Banks
    - Child Care Cen – Char
    - Commercial Condominium
    - Contracting/Service Improvements
    - Earth/Stone Prod-Improvements
    - Electrical Co Real
    - Elem/Secondary

    - Ex All Other Improvements
    - Ex Charitable Non-Residential Improvements
    - Ex Church Non-Residential Improvements
    - Ex County Non-Residential Improvements
    - Ex Federal Non-Residential Improvements
    - Ex Political Sub Non-Residential Improvements
    - Ex Prv Schol Non-Residential Improvements
    - Ex State Non-Res Imps
    - Garage Auto Repair
    - Industrial Condominiums

  Note that there were parcels within the tax assessor database that had null building class descriptions, and therefore the buildings in the parcels received null classifications as well. This amounted to 3.2% of the buildings across the county; 1.6% in Unincorporated Boulder County. As a thorough review of each building was not supported within the scope of this study, the City Simulator model was set to assume these buildings are commercial during the simulation. It is recommended that a separate building database development project be undertaken in the future to increase the accuracy of the dataset for future resilience analyses.

- **SubType** – Subtype is used to further differentiate buildings beyond their Type classification. Examples of commercial SubType are Business, Mercantile, Educational, Factory, High Hazard, Agricultural/Fishing, and Assembly Space. Examples of residential SubType are single family, multi-family, high-rise, and informal settlement. These categorizations are loosely based on the international building code system. Completing the subtype field is optional. By default, the City Simulator model assumes a distribution of commercial building sub-types and uses the number of units attribute (see below) to differentiate between single- and multi-family residential buildings. If sub-type is filled in in the database, then City Simulator will use the specified sub-type in modeling.
- **Building Quality** – this is defined as low, med, or high. It impacts the length of recover of a building as described in the section on flooding modeling in the simulation and forecasting chapter below.

  Boulder County: The building-to-parcel database join was also used to assign building class to the buildings. A 3-class building quality estimate (low, med, high) was derived based on the building quality code in the database.
- **Number of Floors** – this is used to derive the height of buildings, which is used in 3D visualizations of the community. It is also used to help classify the building, which determines which HAZUS depth-damage curve is used to estimate flood-related damage.

  Boulder County: The Stories attribute was used to define the NumStories field in the City Simulator Database. Where the Stories attribute was null, one story was assumed.

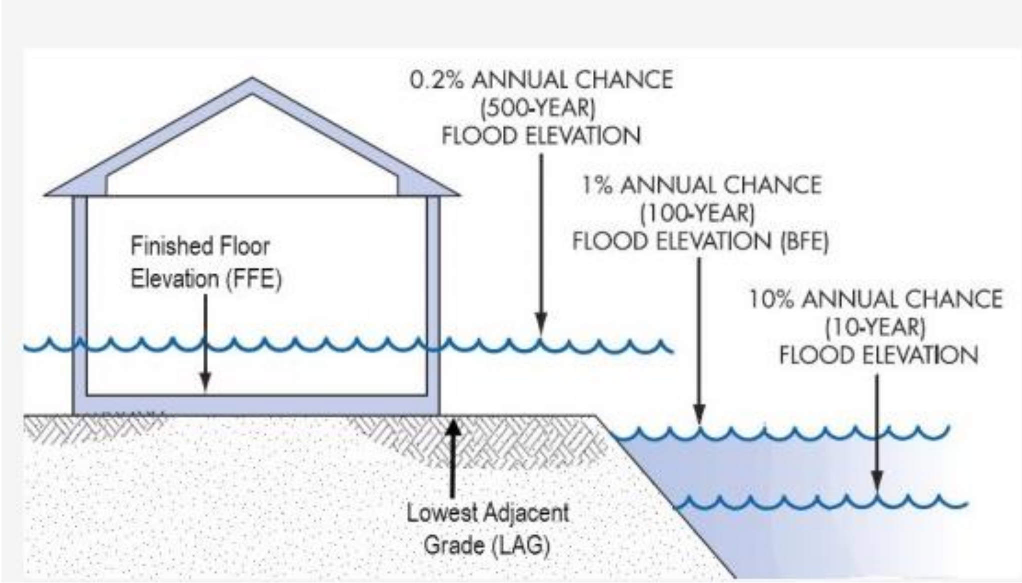
- **Market Value** – this is used to estimate the real estate value of the community, as well as the related tax revenues. Often, this data is available within the community's tax assessor database, or through commercial sites like Zillow.
- **Replacement Value** – this is used to estimate damage from disasters. Often it is used in conjunction with curves that map the disaster impact to the direct damage. For example, the HAZUS depth-damage curves map depth of flooding to percentage of replacement value. Using this attribute, the total dollar damage can be calculated.

  Boulder County: Land, replacement, and total values (market value assumed to be total value, which is the sum of land and replacement values) were imported from the Boulder County GIS Archive and tax assessor database by way of linking the buildings GIS data to the parcel GIS database as described in the building type section above. See the parcels section below for more detail. These values are used in the city simulator model run as described in the simulation and forecasting section of this document.

- **Number of Units** – this can be applicable to multi-family residential or multi-unit commercial buildings. As the City Simulator models households – as opposed to buildings – in the daily simulation, the number of units is an important attribute.

  Boulder County: The UnitCount attribute was used to define the NumUnits field in the City Simulator Database. Where the UnitCount was null, one unit was assumed.

- **Finished Floor Elevation (FFE)**



  FFE is used to estimate the depth of flooding in each building when storms occur. There are several methods for getting this data:

  - **Community-provided**: Some communities maintain a dataset of FFE for their buildings, which is the preferred data source. The data can be imported directly when the buildings layer data is imported.
  - **City Simulator Elevation Range Method**: Many times, communities don't have FFE estimates. City Simulator provides a tool that will estimate FFE as the lowest adjacent ground elevation plus a randomly selected elevation that ranges from a lower height (say, 0.5 feet) to higher height (for example, 3 feet, or in some coastal communities where houses are on stilts, 10 feet). Often, this random pattern exists in communities, and therefore using the tool can produce reasonably accurate flood damage estimates at the community scale. For individual buildings, the accuracy is unreliable due to the random estimate of elevation at each structure.
  - **HAZUS Method:** City Simulator also provides a method that is similar to the method used in FEMA losses avoided studies that use the HAZUS catastrophe model. This method assigns FFE based on building type and properties like foundation type and if the building has a basement.

Boulder County: Building type and basement status have been imported for buildings in the Boulder County Simulator. FFE was estimated by building type following the methods in the recent FEMA LAS (losses avoided study). The FFEs were then raised/lowered to ensure the percentage of FEMA

SFHA homes damaged matched the LAS estimate. See the section on calibration later in this document for more detail.

- **LMIPct_HUD** – This field gives the percentage of households that are considered low-to-moderate income in the census block group in which the building lies. The field is used to determine the impacts to low-to-moderate income populations, as opposed to other more economically advantaged populations. A national database of this metric is available from the U.S. Housing and Urban Development department. There is some discrepancy between the labeling of categories between the US Section 8 Housing Assistance Payment program and the Community Development Block Grant program (see the link below). Both define their categorization based on the percentage of the area median income (AMI). If that percentage is less than 50% of the AMI, then Section 8 refers to a household as Very Low Income, while the CDBG system refers to it as Low Income. If the percentage is between 50% and 80% of the AMI, then the category label is Low Income and Moderate Income for Section 8 and CDBH respectively.

  https://www.hud.gov/program_offices/comm_planning/communitydevelopment/rulesandregs/memoranda/lmidef84

  Boulder County: In this study, the LMIPct_HUD data follows the CDBG classification; i.e.. the data in this field in the City Simulator Geodatabase give the percentage of households that have income lower than 80% of the AMI for Boulder County for the census block group in which the buildings reside.

4.4.3 Building Attributes Derived by the City Simulator Tool

The Building layer also stores attributes used in the simulation to model damage. These attributes are calculated by the City Simulator tool using other data that has been imported to the database, and auxiliary datasets provided by the user. The attributes include:

- **Rain-to-flood response curve** – this is a set of numbers stored as a string that describes the level of flooding that will occur in a building in response to a rain event of a certain depth. The numbers are stored as triplets separated by semi-colons, which contain return period, rain depth (inches), and flooding depth (feet) above the ground elevation. See Figure 3 for an example of how the curve is converted to a text string.

  Each building can have two rain-to-flood curves, related to riverine and pluvial flooding. See the chapter on forecasting and simulation later in this document for details on how these attributes are used.

  - **Riverine Rain-to-Flood Curve** – describes the flood response in the building when flooded by nearby river sources.
  - **Pluvial Rain-to-Flood Curve** – describes the flood response in the building when flooded directly by ponding rain.

Return Period (yr)	Rainfall (in)	Flood Level (ft)
2	3.4	0
5	5.3	0
10	7.2	0
25	8.6	0
50	10.2	0.5
100	12.4	1.2
500	15.5	4.6

2,3.4,0; 5,5.3,0; 10,7.2,0; 25,8.6,0; 50,10.2,0.5; 100, 12.4; 500, 15.5, 4.6

Figure 3: Storing Rain-to-flood curves in the City Simulator Geodatabase.

The rain-to-flood curves are generated for each building by the City Simulator tool. Input data required is:

- **Building Footprints.**
- **Depth rasters for each of the major return period storms.** These rasters are gridded GIS products that give the depth of flooding at each grid cell for each return-period storm. They are typically one of the outputs of a hydraulic model. They can be obtained in the following ways:
  - **From the Community:** Many communities maintain their own hydraulic models and have access to the rasters from that modeling effort. These rasters can be used directly by City Simulator.
  - **FEMA's NFIP Program:** A good source for the rasters is FEMA's NFIP (National Flood Insurance Program), which uses hydraulic model results to create the national set of flood maps that FEMA maintains. If published recently, the model usually includes the rasters as non-regulatory products, which can be used directly by City Simulator as it produces the rain-to-flood curves. If the model does not contain depth rasters, it often will contain GIS-based polygonal maps of the floodplain with cross-section lines of water surface elevation called BFEs (base flood elevations). Using these features, a GIS analyst can generate a water surface, from which a digital elevation model (DEM) can then be subtracted to produce a depth raster. Often, the latter method will produce less accurate results than if the rasters have been generated from the original modeling effort, due to differences in the DEM used for modeling and the one available currently. However, for the purposes of City Simulator modeling, the inaccuracies are often acceptable, as they produced minimal differences in the overall result metrics.

Boulder County: Boulder County provided riverine depth rasters for 2, 5, 10, 25, 50, 100, and 500-year storms from the 2017 CHAMP study and other flood models. This was used to extract depths of riverine flooding from ground level at each of the buildings in the database. These depths were matched with the corresponding rainfall for the same return period storm to create a "rain-to-flood" curve for each building. See the chapter on simulating floods, which describes how this curve is used in flood forecasting.

Atkins provided the pluvial depth rasters for 10, 100, and 1000-year storms, which were outputs from Atkins Telemac 2D pluvial flood model – extracted for Boulder from the full-state depth rasters. The same process was used as with the riverine rain-to-flood curves to create a curve for each building. See the below section on simulating floods for more detail.

- **Rain depths for equivalent return period storms.** City Simulator drives flood simulation by using a daily rain forecast that is created by blending global climate model rain projections for the community with historical daily rainfall in the community. To translate a rain storm to flooding in buildings, the return periods that define each flood raster must be translated to depths of rainfall.

  Assuming a flood of a specific probability (return period) occurs because of a rain storm of approximately the same probability, City Simulator requires rain depths for each of the return periods used to create the flood rasters.

  The rain depths can be looked up in NOAAs Atlas 14 web tool, which provides rainfall statistics for locations across the nation (https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=pa). The figure below shows an example of a look-up table generated by Atlas 14. In this case, the table applies to Boulder, CO. City Simulator requires the rainfall depths for the 24-hour duration storm, for each of the return period for which there is a flood raster. See the highlighted yellow row in the table for the 24-hour term rainfall depths.

PF tabular | PF graphical | Supplementary information | Print page

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**0.200** (0.161-0.249)	**0.249** (0.201-0.310)	**0.339** (0.272-0.424)	**0.423** (0.337-0.531)	**0.551** (0.428-0.735)	**0.661** (0.496-0.889)	**0.780** (0.562-1.08)	**0.910** (0.624-1.29)	**1.10** (0.719-1.60)	**1.25** (0.790-1.83)
10-min	**0.292** (0.236-0.364)	**0.364** (0.294-0.454)	**0.496** (0.398-0.620)	**0.619** (0.493-0.777)	**0.807** (0.626-1.08)	**0.968** (0.727-1.30)	**1.14** (0.823-1.58)	**1.33** (0.914-1.89)	**1.61** (1.05-2.34)	**1.83** (1.16-2.68)
15-min	**0.357** (0.288-0.444)	**0.445** (0.358-0.554)	**0.605** (0.486-0.757)	**0.755** (0.602-0.948)	**0.985** (0.764-1.31)	**1.18** (0.887-1.59)	**1.39** (1.00-1.92)	**1.63** (1.12-2.31)	**1.96** (1.28-2.86)	**2.23** (1.41-3.27)
30-min	**0.480** (0.387-0.597)	**0.598** (0.481-0.745)	**0.813** (0.653-1.02)	**1.01** (0.808-1.27)	**1.32** (1.02-1.76)	**1.58** (1.19-2.13)	**1.87** (1.35-2.58)	**2.18** (1.50-3.09)	**2.62** (1.72-3.83)	**2.99** (1.89-4.38)
60-min	**0.600** (0.484-0.746)	**0.739** (0.595-0.921)	**0.996** (0.799-1.25)	**1.24** (0.986-1.55)	**1.61** (1.25-2.15)	**1.93** (1.45-2.60)	**2.28** (1.64-3.15)	**2.66** (1.83-3.78)	**3.21** (2.10-4.68)	**3.66** (2.31-5.37)
2-hr	**0.719** (0.584-0.889)	**0.881** (0.714-1.09)	**1.18** (0.953-1.46)	**1.46** (1.17-1.82)	**1.90** (1.49-2.52)	**2.28** (1.73-3.04)	**2.69** (1.96-3.68)	**3.14** (2.18-4.43)	**3.79** (2.51-5.50)	**4.33** (2.77-6.31)
3-hr	**0.807** (0.658-0.992)	**0.975** (0.794-1.20)	**1.29** (1.05-1.59)	**1.59** (1.28-1.97)	**2.06** (1.62-2.72)	**2.47** (1.88-3.29)	**2.91** (2.13-3.98)	**3.41** (2.38-4.79)	**4.12** (2.75-5.95)	**4.71** (3.03-6.83)
6-hr	**1.02** (0.835-1.24)	**1.20** (0.984-1.47)	**1.55** (1.27-1.90)	**1.89** (1.54-2.33)	**2.43** (1.93-3.19)	**2.90** (2.23-3.84)	**3.43** (2.53-4.65)	**4.00** (2.83-5.59)	**4.85** (3.27-6.95)	**5.55** (3.61-7.99)
12-hr	**1.31** (1.08-1.59)	**1.53** (1.26-1.85)	**1.94** (1.60-2.36)	**2.34** (1.92-2.86)	**2.98** (2.39-3.88)	**3.55** (2.75-4.65)	**4.17** (3.11-5.61)	**4.86** (3.46-6.72)	**5.86** (4.00-8.34)	**6.70** (4.41-9.57)
24-hr	1.61 (1.34-1.93)	1.90 (1.58-2.29)	2.44 (2.02-2.94)	2.95 (2.43-3.57)	3.73 (3.00-4.78)	4.40 (3.44-5.70)	5.13 (3.86-6.82)	5.93 (4.26-8.12)	7.08 (4.88-9.97)	8.02 (5.34-11.4)
2-day	**1.87** (1.57-2.23)	**2.26** (1.89-2.69)	**2.96** (2.46-3.53)	**3.58** (2.97-4.30)	**4.51** (3.64-5.71)	**5.29** (4.16-6.77)	**6.13** (4.63-8.05)	**7.02** (5.08-9.49)	**8.28** (5.75-11.5)	**9.30** (6.26-13.1)
3-day	**2.07** (1.74-2.45)	**2.46** (2.06-2.91)	**3.15** (2.64-3.75)	**3.79** (3.16-4.53)	**4.76** (3.87-6.01)	**5.59** (4.41-7.13)	**6.47** (4.93-8.48)	**7.44** (5.42-10.0)	**8.81** (6.17-12.2)	**9.92** (6.73-13.9)
4-day	**2.24** (1.89-2.64)	**2.62** (2.20-3.09)	**3.31** (2.78-3.92)	**3.95** (3.30-4.70)	**4.94** (4.03-6.22)	**5.78** (4.59-7.36)	**6.70** (5.13-8.75)	**7.70** (5.64-10.4)	**9.13** (6.43-12.6)	**10.3** (7.02-14.4)
7-day	**2.63** (2.23-3.08)	**3.05** (2.59-3.58)	**3.81** (3.22-4.49)	**4.50** (3.78-5.32)	**5.54** (4.54-6.89)	**6.41** (5.11-8.07)	**7.34** (5.65-9.50)	**8.35** (6.16-11.1)	**9.78** (6.93-13.4)	**10.9** (7.52-15.2)
10-day	**2.97** (2.53-3.47)	**3.44** (2.93-4.02)	**4.26** (3.61-4.99)	**4.99** (4.21-5.87)	**6.06** (4.97-7.46)	**6.94** (5.55-8.67)	**7.86** (6.07-10.1)	**8.85** (6.56-11.7)	**10.2** (7.29-14.0)	**11.3** (7.84-15.7)
20-day	**3.98** (3.41-4.61)	**4.53** (3.88-5.25)	**5.46** (4.66-6.34)	**6.25** (5.31-7.30)	**7.38** (6.08-8.95)	**8.28** (6.66-10.2)	**9.20** (7.16-11.7)	**10.2** (7.60-13.3)	**11.5** (8.26-15.5)	**12.5** (8.76-17.1)
30-day	**4.82** (4.15-5.55)	**5.46** (4.69-6.29)	**6.51** (5.58-7.52)	**7.39** (6.30-8.59)	**8.62** (7.12-10.4)	**9.58** (7.74-11.7)	**10.5** (8.24-13.3)	**11.5** (8.67-15.0)	**12.9** (9.31-17.2)	**13.9** (9.79-18.9)
45-day	**5.86** (5.07-6.71)	**6.66** (5.75-7.64)	**7.95** (6.85-9.15)	**9.01** (7.72-10.4)	**10.4** (8.65-12.5)	**11.5** (9.35-14.0)	**12.6** (9.90-15.7)	**13.7** (10.3-17.6)	**15.1** (11.0-20.1)	**16.1** (11.5-21.9)
60-day	**6.73** (5.84-7.68)	**7.71** (6.68-8.81)	**9.28** (8.01-10.6)	**10.5** (9.05-12.1)	**12.2** (10.1-14.5)	**13.5** (10.9-16.2)	**14.7** (11.5-18.2)	**15.8** (12.0-20.3)	**17.3** (12.6-22.9)	**18.4** (13.1-24.9)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

Estimates from the table in CSV format: Precipitation frequency estimates Submit

Figure 4: A NOAA Atlas 14 web site table showing rainfall depths for multiple return periods and storm durations.

Boulder County: Rain depths for the City of Boulder from NOAA Atlas 14 were used in developing the rain-to-depth and overtopping curves. The rainfall depths are shown below.

Return Period (years)	Rainfall (inches)

2	2.08
5	2.71
10	3.27
25	4.11
50	4.80
100	5.54
500	7.42

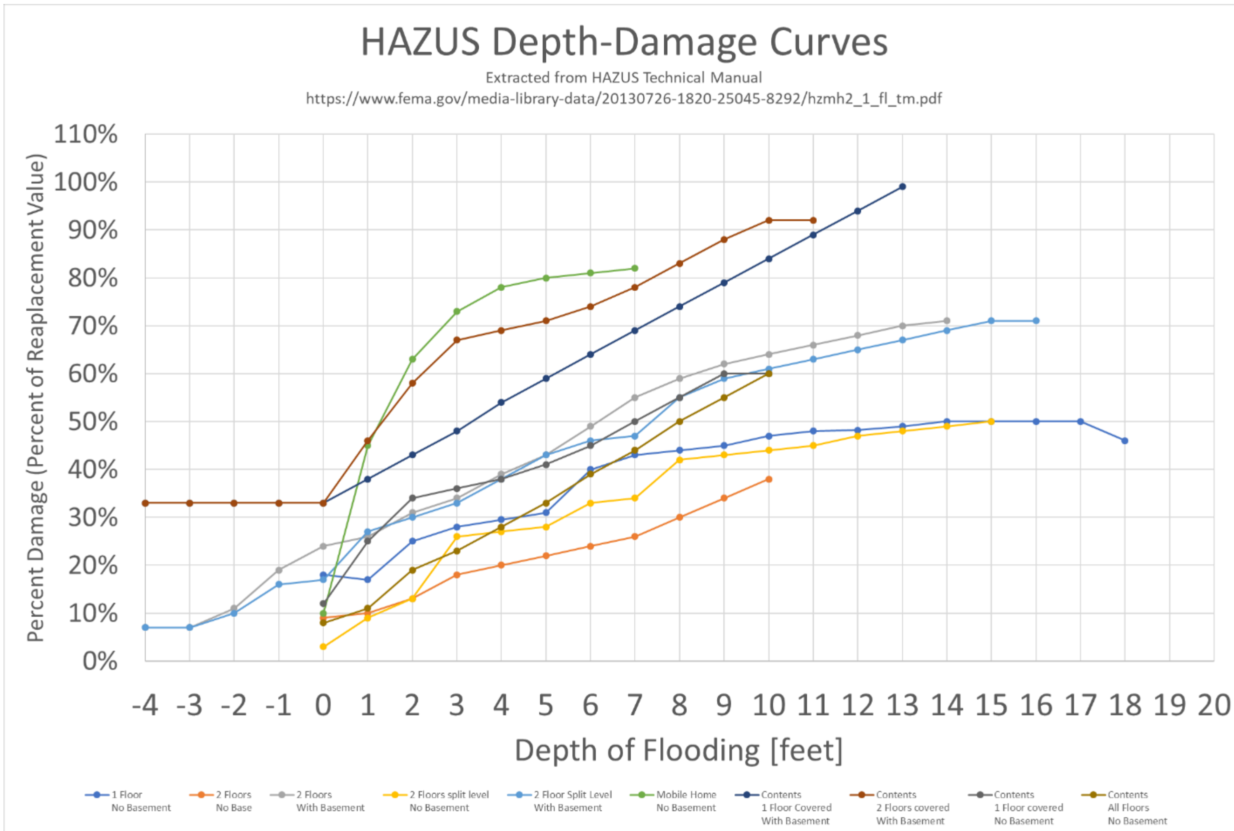
- **Depth-Damage Curve** – To convert flooding at a building to dollar damage, each building also requires a depth damage curve. By default, this curve is selected from a library at the time of simulation based on properties of the buildings (number of stories, if basement exists, construction materials, etc.). Optionally, a Depth-Damage Curve attribute can be added to the Building layer that allows users to apply a specific depth-damage curve to each building. This curve is stored as a text string in the same way the Rain-to-Flood curves are stored, with flood depth and percent damage as the data values in each data double.

  Boulder County: HAZUS depth-damage curves are used for estimating direct- and contents damage to structures. The curves were extracted from the HAZUS technical manual, which can be found at this link:

  https://www.fema.gov/media-library-data/20130726-1820-25045-8292/hzmh2_1_fl_tm.pdf

  The curves give the percentage of damage (percentage of the replacement cost of the building) as a function of the depth of flooding that occurs. The curves include negative flooding depths for when buildings have basements and the flood level does not overtop the finished floor.

  Developed primarily by the US Army Corps of Engineers, the curves began as an estimate of damage response to flooding derived from mathematical formulas that were calibrated from relatively small database of post-flood insurance claims. Over the decades the curves have been in use, more data points have been added to the calibration dataset as more storm events have occurred, progressively making the curves more accurate estimators of damage levels.



this study, four curves were used for direct-damage estimation. They included:

- **Mobile Homes** – this curve assumes the home has no basement, which is most often the case with mobile/manufactured homes.
- **Buildings with Basement** – this curve is based on a two-story home with basement. As no single story with basement curve was available within the technical manual, it was assumed within this study that any building with a basement would follow this curve.
- **Building with no basement and 1-story** – as the building and tax assessor database contained information on the number of stories and if the building had a basement, this class of building was parse-able relative to other buildings and this curve was used for this set of buildings accordingly.
- **Buildings with no basement and 2-story or more** – as with the 1-story buildings with no basement, this class of building was parse-able from the dataset and this curve was used for these buildings.

These curves were used for both residential and commercial buildings, as the two families of curves are close in magnitude across building types.

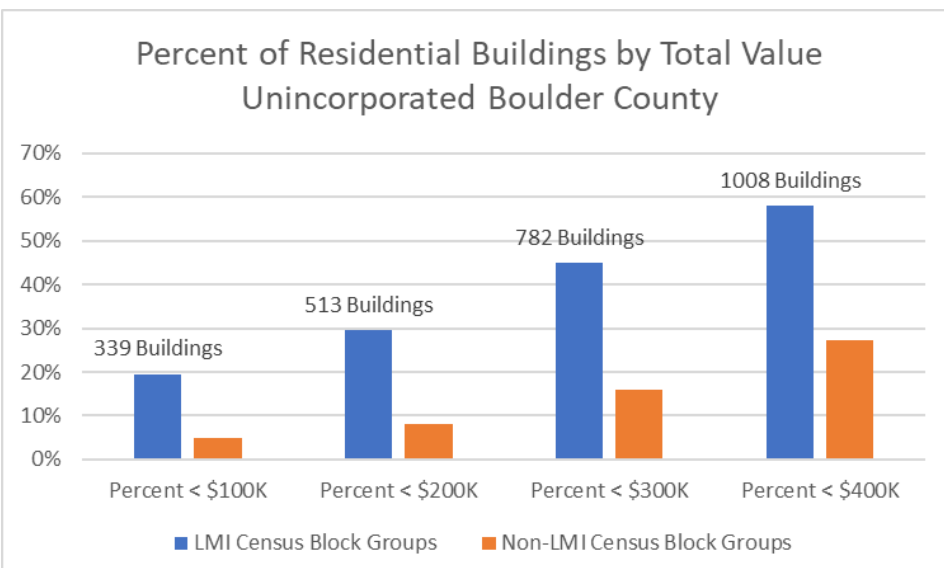
As flood damage is largely confined to the basement and first floor of impacted buildings, the replacement value for the building was replaced by a Flood_Replacement value for multi-story buildings. This was calculated as the replacement value divided by the number of floors.

- **Buildings Occupied by Low-to-Moderate Income Populations** – In order to estimate impacts on LMI populations from flood and related disruption, buildings in which these populations live must be identified. The census block group level is too coarse; often one census block group can contain a wide variety of buildings occupied by populations that cover the range from Very Low to Very High income levels. If all buildings within the census block are used, then an very high income populations may be included in what is supposed to be the low to moderate income population group.   If the income level of the residents within each building is known, then this information should be used to identify the specific buildings. If it isn't available, which is common, then a system should be used to estimate which buildings are low-to-moderate income.

Boulder County: All assessments of disadvantaged populations in the Boulder County resiliency study define residential buildings as being disadvantaged when two conditions are met:

- **The LMIPct_HUD value for the census block group in which they lie is less than 50%.** (see previous section on buildings and parcels in the base year discussion earlier in this document for more detail).
- **The per unit total value of the residential structure is below $200,000.** The census block group scale is relatively coarse in Unincorporated Boulder County. There can be a wide range of building values within a single census block group. The median number of residential building units per census block group where LMIPct_HUD is greater than 50% is 158, with a maximum of 715. The average value per residential unit ranges from $282,000 to $18,294,025. The lowest value for any building is $28,200 while the highest is $63,768,500. Classifying these buildings as low-to-moderate households would therefore likely be in error. A threshold was therefore introduced that requires the per unit value of the building to be less than $200,000 in order to be classified as a low-to-moderate income building. Per unit value is defined as the total value (land value + replacement value) of the building divided by the number of units.

  The chart below shows an assessment of the percent of buildings that have total values below a series of thresholds ($100K, $200K, $300K, $400K) in the LMI > 0.5 and LMI < 0.5 (Non-LMI) census block groups in Unincorporated Boulder County. The chart clearly shows that LMI census block groups have higher percentages of lower total value buildings than non-LMI census block groups. For example, 5% of the homes in non-LMI census block groups are below $100K, while 20% of the homes in the LMI census block groups are under $100K. In other words, people who live in these census block groups are four times as likely to live in home worth less than $100K than those people who live in non-LMI areas.



  This assessment was used to select the $200,000 threshold. The selection was based on maximizing the percentage difference between the LMI and Non-LMI census block group values, while ensuring there were enough buildings in the LMI census block groups that statistically significant conclusions could be made from analysis involving them. While the $100K threshold had the largest difference in percent of homes (4.07 times as likely to be in a low-value home), it would imply that only 339 buildings in all of Unincorporated Boulder County (about 1.0%) are low-value homes. This is likely too restrictive, and likely inaccurate.

As the total home value thresholds increases, the difference between the LMI and Non-LMI percentages starts to converge. At $400K, a person in an LMI area is 2.13 times as likely to be in a low-value home as compared to the Non-LMI person.

Taking these factors into consideration, the $200K threshold for per unit value was selected. This meant that 513 building in Unincorporated Boulder County would be considered low-value in the study.

4.5 Parcels

Parcels are a required layer within the City Simulator geodatabase. They are contained as a polygonal layer with multiple attributes. Many communities maintain parcel databases as part of their tax assessor database, and this data can be used to load the City Simulator parcel layer. The specific data required is:

- **Parcel Polygon** – Many communities will store their parcel database either as a geodatabase, or as a series of data files related to a geospatial file of the parcel shapes. This geospatial data can be imported as the parcel polygons within City Simulator.
- **SQFT (Square feet)** – this attribute provides the total square feet of the parcel. It is often part of the parcel geodatabase used to derive the parcel polygons.

  Boulder County: Loaded from the tax assessor parcel database.
- **TaxVal (Taxable Value)** – this attribute can be extracted from the assessor database, which most communities maintain.

  Boulder County: Loaded from the tax assessor parcel database.
- **LandVal (Land Value)** – this attribute can be extracted from the assessor database, which most communities maintain.

  Boulder County: Loaded from the tax assessor parcel database
- **BldgVal (Building Value)** – this attribute cab be extracted from the assessor database, which most communities maintain. It is equivalent to the replacement value in the Buildings map layer.

  Boulder County: Loaded from the tax assessor parcel database
- **Zone** – City Simulator uses a very simple zoning classification of Commercial, Residential, or Other. Many communities have more complex zoning systems. These should be translated into commercial, residential, or other to conform to the City Simulator default system. This can be done using standard ArcMap attribute editing tools. Alternatively, City Simulator can be adjusted to work with the more complex systems. This requires adjustment to the underlying code. Please consult with Atkins if this is desired.

  City Simulator can optionally schedule zoning changes at future dates. Using a table called ZoneSchedule, users can specify which parcels will change zone and at which dates. The simulation will then take this into account as it allocates new growth across the landscape over the planning time horizon.

- **Address** - this includes the street number and name, city, state, zip code. This is an optional attribute and is not currently used by City Simulator.

  Boulder County: No address data was loaded as it was not relevant to the study

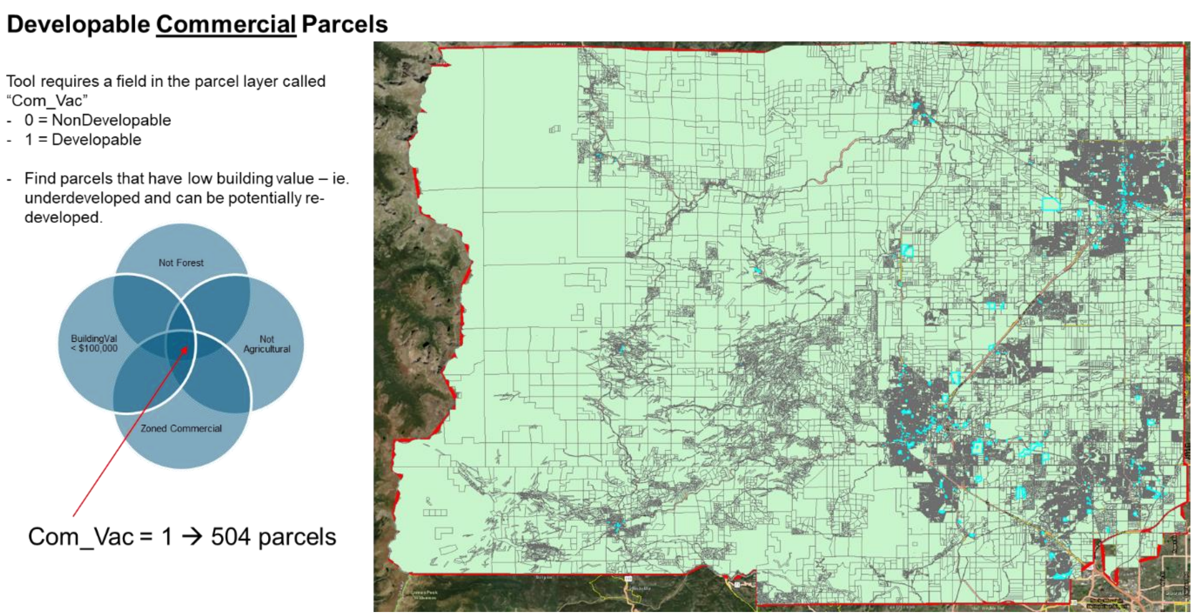
- **YearBuilt** – this is the four-digit year in which the buildings on the parcel were built. This data can be used by City Simulator to model condition of the buildings over time, allowing for more accurate forecasts of damage when disasters hit, and for modeling maintenance events and costs at the building scale. This asset-based forecasting is optional within City Simulator.

  Boulder County: Loaded from the tax assessor parcel database

- **Com_Vac (Vacant Commercial)** – this is a true/false variable which indicates if the parcel is vacant and commercial. It is used by the City Simulator to determine where new buildings can be built across the landscape. It must be populated manually using ArcMap GIS attribute tools, and is usually assigned as 1 when zone is equal to commercial and one of the following is also true: heated square feet = 0, replacement value = 0, there is no building in the parcel, or some other indicator that the parcel it is undeveloped. These attributes are typically part of a community tax assessor database. Note that there is a re-development switch in City Simulator, which allows for new buildings to be built in non-vacant parcels if those parcels have a low floor area ratio (FAR). The assumption is that re-development will happen to parcels with relatively few developed square feet relative to the total square feet of the parcel. By default, the re-development switch is turned off in City Simulator.

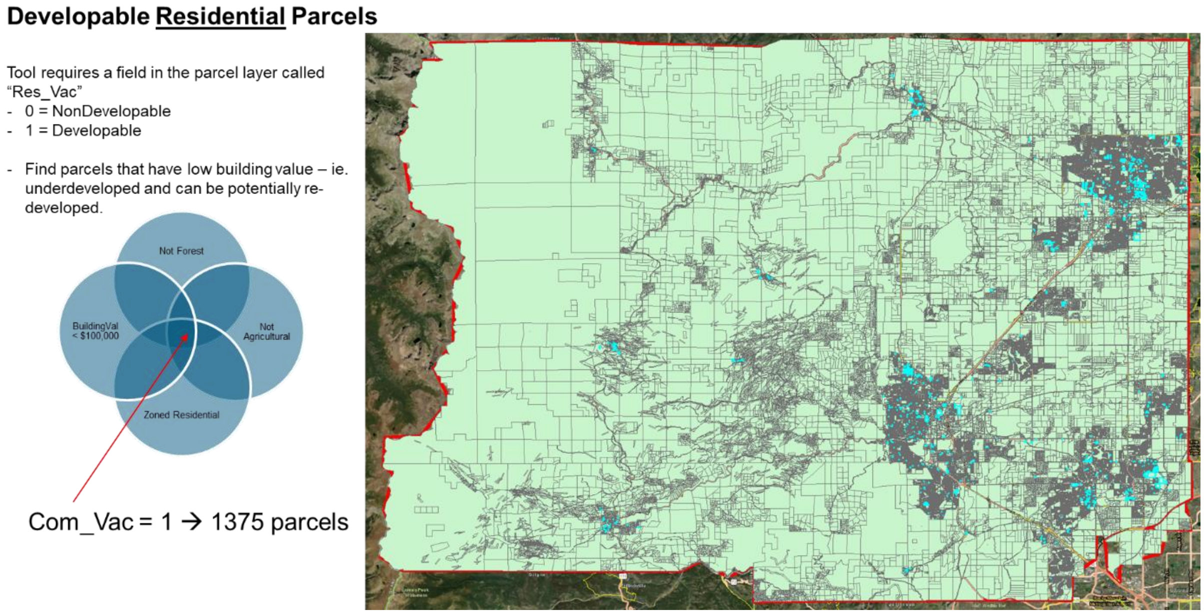
- **Res_Vac (Vacant Residential)** – this is a true/false variable like the Com_Vac variable, but for residential parcels.

The Com_Vac and Res_Vac fields were populated by assuming parcels that were not forest, not agricultural, have a building value less than $100K and were zoned commercial were developable. The figure below shows the parcels.



Res_Com was done with the same process except the parcels needed to be zoned residential. The figure below shows the parcels.

The process resulted in 512 developable residential acres and 56 developable commercial acres in the base year. Discussion with county stakeholders revealed that relatively few acres are developable and so there was general agreement with this result.



Boulder County: Increasing Developable Land: A recommendation from county stakeholders to increase developable land in future runs, was that current zoning allows for development of one building per 35 acres of agricultural and forestry lands. This strictly means one building in each 35-acre lot, not a density over a large area. Though sparse, this would increase the available developable land considerably, given the large areas of agricultural and forestry zoned lands in the county. In future simulations, these areas should be partitioned into 35 acres parcels where their total acreage is over 70 acres, and a single development within each parcel with no development should be simulated. This was not implemented in the current study.

4.6 Roads

Roads are a required layer within the City Simulator geodatabase. They are stored in Transportation_Links polyline feature class in the database. The sources for road segments are typically:

- **The Community** – Many communities maintain their own highly detailed and up-to-date transportation geodatabases. This is the preferred data source for road data. This data must be manually downloaded and then imported to the City Simulator using the import tools in the City Simulator ArcMap extension.
- **State DOT** – Another good source is state DOT organizations, who often have a mandate to create and maintain state-wide transportation geodatabases, with focus on state-maintained roads. Often, a good way to approach building the City Simulator database of roads is to blend the community's road data with the state data. This data must be manually downloaded and then imported to the City Simulator using the import tools in the City Simulator ArcMap extension.
- **US Census Bureau TIGER Roads** – a good backup if no other data is available is the US Census Bureau's TIGER roads database, which is available from the US Census Bureau's website and has national coverage. Often, the detail of the road segments in this data set is limited, with local roads often missing altogether. This will impact the accuracy of the City Simulator runs, particularly when evaluating road-based flooding and its impact on commerce of buildings on the streets being flooded. This data must be manually downloaded and then imported to the City Simulator using the import tools in the City Simulator ArcMap extension.

  Boulder County: For Boulder County's application, the roads are sourced from the CDOT roads database and the County GIS roads layer.

The attributes that must be loaded manually to the roads layer are:

- **Name** – this must include the name and suffix, which can be processed using standard ArcMap tools.
- **NumLanes** – this is a long integer field that gives the number of lanes in the road segment in one direction.
- **RoadClass** – this is a string field that informs City Simulator of which road segments to use in commute modeling. The values can be "Primary" or "Other". See the discussion on Commute Paths below for more information on how to fill in this attribute.

Most fields that are in a fully developed City Simulator roads layer are generated by tools within the City Simulator Extension. They are listed below by the tool that generates them:

4.6.1 Network Attributes

These attributes include from- and to-node attributes for each road segment. They are used to load the road network including links and nodes into the City Simulator at run time. Note that the nodes are not stored in the Transportation_Nodes layer; rather the City Simulator creates virtual nodes at run-time based on the data in the road segments and their geography. This tends to reduce errors that arise from loss of fidelity between links and nodes layers.

There is a tool within City Simulator that generates each of the attributes listed below automatically. A requirement is that the road segments each touch another segment on both ends (except for segments that end at the analysis domain boundary). The tool adds these fields to the Transportation_Links table; the fields do not exist until the tool is run.

- **SmallID** – this is a long integer unique ID that numbers the road segments from 1 to N, where N is the number of road segments with RoadClass = “Primary”. Using the smallest possible ID integers ensures fast run time for City Simulator tools.
- **From_Node** – this is a long integer field that contains the SmallID of the node that the road segment starts with.
- **To_Node** – this is a long integer field that contains the SmallID of the node that the road segment ends with.
- **FNODE_X** – this is double precision number field that contains the X coordinate of the From_Node.
- **FNODE_Y** – this is double precision number field that contains the Y coordinate of the From_Node.
- **TNODE_X** – this is double precision number field that contains the X coordinate of the To_Node.
- **TNODE_Y** – this is double precision number field that contains the X coordinate of the To_Node.

4.6.2 Elevation Attributes

To assess sea level rise, pluvial rainfall events, and other flood-related impacts, City Simulator requires knowledge on the elevation of road segments. Utilizing the USGS NED (National Elevation Dataset) web service, City Simulator provides a tool that queries the elevation of the road segments to find the points of minimum and maximum elevation along each road segment.

The tool partitions each road segment into ten foot increments and queries the web service for the elevation at the end of each segment. The tool stores the x and y coordinates and the elevation of the maximum elevation point and the minimum elevation point. These attributes are stored as:

- **MinElev** – this is a double precision number field that contains the elevation of the lowest point along the road segment.
- **MaxElev** – this is a double precision number field that contains the elevation of the highest point along the road segment.
- **LowPointX** – this is a double precision number field that contains the X coordinate of the lowest point along the road segment.
- **LowPointY** – this is a double precision number field that contains the Y coordinate of the lowest point along the road segment.
- **HighPointX** – this is a double precision number field that contains the X coordinate of the lowest point along the road segment.
- **HighPointY** – this is a double precision number field that contains the Y coordinate of the lowest point along the road segment.

Boulder County: For Boulder County’s application, the elevation search was run as part of the pluvial flooding analysis.

4.6.3 Model Result Attributes

As the simulation runs, it creates multiple fields within the roads layer to store results. These are used primarily for animation of the results during the run and turning the results into maps, graphs, tables, and other displays at the end of the run. The fields are:

- **NumTrips** – this long integer field contains the number of trips that are taken on a road segment per year in the last year the simulation was run.
- **Congestion** – this double precision integer field gives the number of trips per lane per hour estimated by the City Simulator Travel Model divided by the maximum level of service flow rate expected for a single lane as published by the Florida DOT. If the number is 1.0, this means the

road is carrying the highest level of service. If above 1, the road is congested. The higher the number gets, the more congested the road segment is at rush hour.

- **TripsDisrupted** – this long integer field contains the number of trips disrupted in the last year of the simulation. Disruption can be due to multiple disasters (flood, heat wave, etc), and will depend on the disasters being modeled in the simulation.

4.7 Commute Paths

City Simulator uses the roads layer to simulate commutes from work to home and back for each of the working agents in the model. This requires that each worker in the community have a commute path, which is by default the shortest route on the road network from their workplace to residence, or to multiple way points if journey trip modeling is being used.

To get these shortest routes, City Simulator provides a tool that applies the well-known Dykstra algorithm to the road system. This algorithm finds the shortest path from every node in the transportation system to every other node. Before you can use the tool, and because the algorithm is computationally expensive, the number of nodes, and therefore links, in the road network must be minimized. Typically, a total number of road segments of under 2,000 is required.

Often, GIS databases of transportation networks contain thousands of road segments, where the same road network can be simplified down to hundreds, even tens, of road segments. If the number of road segments in a system is more than 2,000, the system must be simplified. To do this, multiple strategies may be utilized. The principle strategies are described below. They can be done with a combination of ArcGIS tools and tools available in the City Simulator Extension. The objective for both is to bring the road network to the fewest number of road segments while still ensuring that each commuter in the community has a path from their place of work to residence.

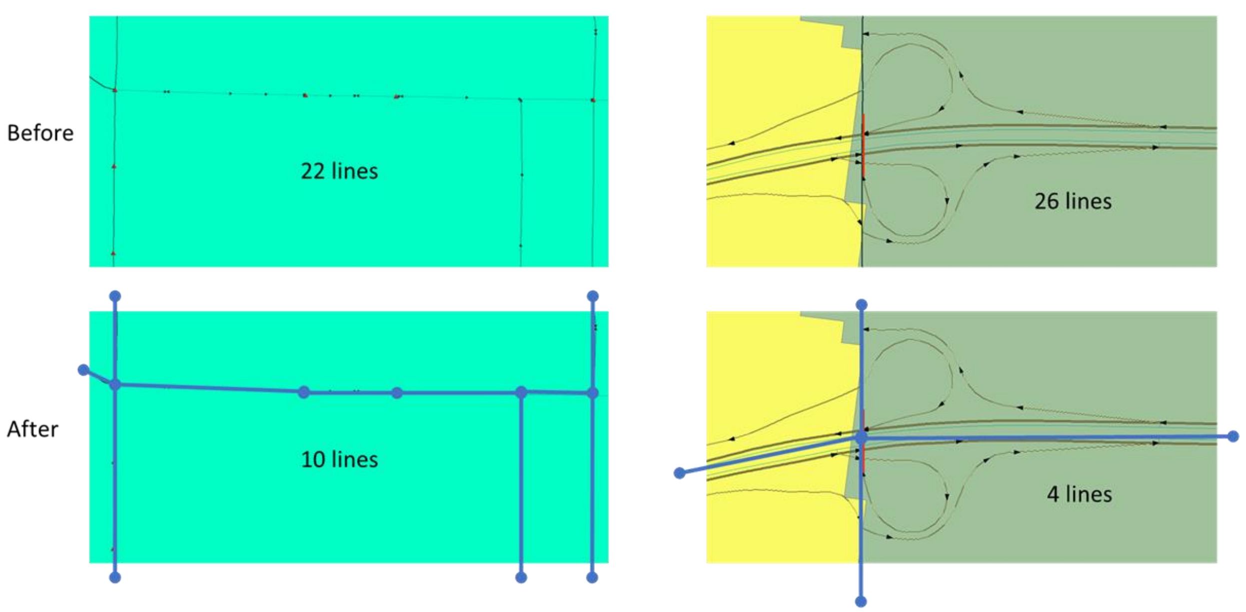
Simplifying the Road Network

Road networks can be simplified in many ways. City Simulator has tools for applying three methods, the first two of which are shown in the figure below:

- **Merge roads segments that only are connected to each other**
- **Convert divided highways and interchanges into single road segments with simplified topology**
- **Remove dangling roads – roads shorter than a threshold with no connection on one side.**

When applied together, the methods typically reduce the number of road segments by an order of magnitude.

Road Network Simplification



Once the road network is simplified, it can be loaded into the Transportation_Links feature class in the City Simulator geodatabase using the import tools in the City Simulator extension.

Note that City Simulator can hold both the highly complex road network and the simplified road network in the same Transportation_Links feature class. This is useful if for modeling disasters that impact both commuting and local-street flooding – sea level rise and hurricane flooding for example. To store both road networks, import the simplified roads and set their RoadClass to “Primary,” and then import the complex road network and set their RoadClass to “Other.” See the discussion on RoadClass above for more information.

Boulder County: For Boulder County’s application, all three of the methods mentioned above were applied, while ensuring that all road segments that over-lie a bridge or culvert are retained. This process reduced the road segment count from 22,000 to approximately 1,000.

The roads are stored in the transportation_links layer in the Boulder County Simulator geodatabase. The nodes are stored in the transportation_nodes layer.

The commute paths were derived from the simplified transportation network and stored in the CommutePaths table in the Boulder County Simulator geodatabase.

4.8 Stormwater Network

The stormwater network within City Simulator consists of the Stormwater_Nodes and Stormwater_Links feature classes in the City Simulator geodatabase. Stormwater_Nodes is a required layer, while Stormwater_Links is optional, and may be used if modeling stormwater features like open channels and pipes that reduce flooding by conveying flooding stormwater to other locations in the stormwater system is desired.

Overtopping Curves

The Stormwater_Nodes layer is used to store stormwater assets like culverts and bridges, as well as manholes and other connectors of the stormwater link-node system. The layer can be used to store overtopping curves for each intersection of the hydrologic and transportation systems (culverts, bridges). Overtopping curves are used by City Simulator to model the impact of flooding on commutes. They match the depth of rain of storms to the depth of overtopping above the road at the culvert or bridge in question. They are stored in a similar manner to Rain-To-Flood curves described above in the buildings section, as a string that contains the return period (years), depth of rain (inches), and overtopping depth (feet).

Sources of Data

The sources for stormwater data are typically:

- **The Community -** Many communities maintain their own highly detailed and up-to-date stormwater system geodatabases. This is the preferred data source for stormwater data. This data must be manually downloaded and then imported to the City Simulator using the import tools in the City Simulator ArcMap extension.
- **State DOT -** Another good source is state DOT organizations, who often maintain state-wide stormwater geodatabases, with focus on stormwater features in and around state-maintained roads. This data must be manually downloaded and then imported to the City Simulator using the import tools in the City Simulator ArcMap extension.
- **Virtualization** – When no stormwater asset data is available, or only a general idea of the impacts of climate change related to the stormwater system is desired, stormwater data does not need to be loaded into the database. Tools within the City Simulator ArcMap extension are capable of virtualizing the stormwater system. There are two tools available:
    - **Intersections between the hydrography and the transportation system –** this tool finds intersections between the stream network and the road system. As input, it requires road segments to be loaded into the geodatabase and that a polyline stream layer is added into ArcMap. It finds all intersections between these two polyline map layers and adds each point as a stormwater node to the Stormwater_Nodes feature class. By default, each point is defined as a culvert, though the type can be changed after the tool has been run.
    - **Full stormwater system virtualization –** this tool creates a representative stormwater system including pipes and manholes. It is based on the road segments layer, assuming that each road has a storm sewer buried under it and that there are manholes at the intersections of the sewers. The tool requires as input:
        - **Road Segments –** these are the road segments you loaded in to the Transportation_Links layer. Note that the tool uses all road segments, not just those with RoadClass = "Primary". One can specify exactly which road segments to use by adding a small integer field to the Transporation_Links map layer called "UseInSW" and assigning 1 to each road segment that should have a sewer and zero to all other road segments.
        - **Outlets –** this is a point map layer that specifies the ultimate outlets for the stormwater system. The tool will use the points in this layer to create a sewer network for each

outlet. It also uses the elevation at these points to determine the elevations of the virtualized manholes and slopes of sewer lines.

Note that the stormwater system virtualizing algorithm in the tool determines a mostly likely sewer network for each outlet point based on the connectivity of the roads, and a combination of elevations and proximity of road segments to the outlet. While reasonably accurate, the algorithm can get the stormwater networks wrong in terms of their connectivity. To force sewers under certain roads to flow to certain outlets, add a field to the roads network called "OutletID" and set its value to the ObjectID (see field description below) of the outlet in your input Outlets layer.

- **Non-Road Sewers** – you can add this polyline layer optionally to specify sewers that do not fall under road segments, but that you know exist. The tool will treat these lines as road segments while in the process of virtualizing.
- **Digital Elevation Model (DEM)** – by default, the tool uses the USGS National Elevation Dataset (NED) web service to estimate the elevations of each point in the system. As such, no DEM needs to be provided. But, a DEM can be used instead of NED.

After running, the tool fills the Stormwater_Node and Stormwater_Link layers in the geodatabase with the virtualized links and nodes, along with network attributes like the road system network attributes (FromNode, ToNode, etc). It also virtualizes the variables like type, replacement cost, date installed (see the attributes below for a complete list) to create a representative stormwater network that can be used in modeling.

Boulder County: Boulder County provided the locations of all culverts and bridges in the county, along with overtopping curves based on the results of CHAMP and other studies. No manholes or storm sewers were imported to the model.

The culvert/bridge locations were imported to the Stormwater_Node layer in the City Simulator geodatabase. They were classified as either a major or minor structure according to the Boulder County classification system. Major structures were understood to be bridges, while minor structures were assumed to culverts. Each culvert/bridge was associated with the road segment that ran over it, to facilitate modeling of disrupted traffic during the simulation.

Overtopping curves give the depth of water flowing over the road deck for varying storm sizes (2, 5, 10, 25, 50, 100, and 500-year storms). These were imported to the City Simulator geodatabase as an attribute in the stormwater_nodes layer. They are used to forecast if a road becomes impassable during a storm and if the level of damage the road sustains.

A full stormwater system (pipes, canals, manholes, etc) was not imported nor virtualized, as this level of modeling is not being undertaken.

For this study, asset decay was not modeled, and so no asset decay related attributes were loaded into the database. Photos of all culverts and bridges were also provided and loaded.

A third class of stormwater node was also incorporated into the analysis. These were road segments with frequently flooding sections. These were identified using a GIS analysis, where each road segment in the county was sampled for flood depth along every 10m along the section that was covered by the 500-year floodplain, if there was one. Where the deepest flood depth occurred in the segment, a stormwater node was created and an overtopping curve created from the depth rasters for the 2, 5, 10, 25, 50, 100, and 500-year storms. When storms were simulated, if the storms are big enough, they would flood this segment of road, causing the road to be impassable, and possibly damaged if the flowing was deep enough. See the section on Flood Simulation for more detail.

The specific attributes in the Stormwater_Nodes layer are:

- **SWID** – This is a long integer unique ID field. The City Simulator ArcMap extension incrementally assigns IDs to the stormwater nodes as they are imported.

- **Type** – this is a string field that specifies the type of stormwater node. It can be Culvert, Bridge, Manhole, or Pump.
- **Replacement Cost** – this is a double precision number field that specifies the cost of replacing the asset at the node. The replacement cost should be stated in dollars relevant to the start year of the City Simulator scenarios. Filling in this field is optional.
- **Date Installed** – this is a date field that specifies the date at which the stormwater asset was installed. Filling in this field is optional.
- **Description** – this is an optional string field for describing a stormwater asset. Filling in this field is optional.
- **Decay Parameters** – this is a string field that stores parameters of a decay model for the stormwater asset. This decay model specifies the rate at which the asset's condition decays over time. Optionally, City Simulator can be used to forecast asset decay and trigger replacement and refurbishment of assets when threshold conditions are reached. The parameters held in this string are used as the coefficients of the decay model for the asset. Filling in this field is optional.
- **SourceID** – this is a string field that contains the ID of the stormwater asset in the source database. It is set as a string so that it can store numeric or string-based IDs. Filling in this field is optional.
- **Overtop Curve –** this is a string field that allows for the storage of the overtopping curve for a stormwater asset that lies beneath a road. As described above, the overtopping curves consists of number triplets (return period, rain depth, overtopping depth) and are stored like rain-to-flood curves for buildings. Filling in this field is optional.
- **PhotoURL** – this is a string field that specifies an URL or local computer path where a photo of the asset is stored. If filled in, the City Simulator stormwater asset viewer will load the photo as you review stormwater nodes in the geodatabase in ArcMap. Filling in this field is optional.

Boulder County: For Boulder County's application, Atkins did not model asset decay, and so no asset decay related attributes were loaded into the database. Overtopping curves were loaded as they were provided by the county. Photos of all culverts and bridges were also provided and loaded.

4.9 Agents

Agents are a required dataset to do a City Simulator run. They are stored as a table with multiple attributes within the City Simulator geodatabase. Much of the data within the agents table is derived by tools within the City Simulator extension; tools that create virtual agents to match the real population of the city statistically.

To generate agents, the following data must be imported into the geodatabase:

- Analysis Domain and basic community statistics (population, number of households, number of jobs). Note that one can optionally import secondary statistics (age, gender, education, job type, salary) and statistics at the Census Block Group scale (see sections on the Community Statistics section above).
- Buildings with type and number of unit attributes.
- Simplified road network and commute paths – note the roads need to have network attributes.

The agents table has the following attributes:

- **PlaceOfWork** – this is a long integer field that species the ID of the building in which the agent works. The ID is the objectID of the building from the building feature class. This field is filled in automatically when agents are virtualized.

- **Residence** – this is a long integer field that species the ID of the building in which the agent lives. The ID is the objectID of the building from the building feature class. This field is filled in automatically when agents are virtualized.
- **Salary** – this is a double precision number field that specifies the salary of the agent in dollars relevant to the start year of the simulation. This field is filled in automatically when agents are virtualized.
- **Occupation** – this is a text field that specifies the job title of the agent. This field is filled in automatically when agents are virtualized.
- **DOB** – this is a date field that specifies the date of birth of the agent. This field is filled in automatically when agents are virtualized.
- **EducationLevel** – this is a string field that specifies the highest level of education attained by the agent. This field is filled in automatically when agents are virtualized. The higher the education level, the more random the commute path.
- **Gender** – this is a string field that specifies the gender of the agent. This field is filled in automatically when agents are virtualized.
- **CommuteDistance** – this is a double precision field that specifies the commute distance of the agent. This field is filled in automatically when agents are virtualized. Note that it requires that the commute paths have been calculated ahead of virtualizing the agents.
- **CommutePath(s)** – this is a string field that specifies the commute path for the agent. There can be up to 5 commute paths for each agent. The first represents the shortest home-to-work commute. This commute path must be filled in to do a City Simulator run. The remaining four commute paths represent "journey" paths that include stops along the way from home-to-work. Using the paths from the CommutePaths table (see the section on roads), City Simulator will automatically generate routes for each agent when agents are virtualized. If the City Simulator run is set to use journey commuting in the travel model, then these routes will be selected at random as the route the agent takes in any given day. See the travel modeling section in the Running the Base Scenario section below for more detail on journey commuting.

Boulder County: The Boulder County's City Simulator model run contains a virtual population of "agents" that matches the real population in the start year of the simulation as closely as possible. This includes matching the total population, the number of working people, and the distribution of those people across the county. The calibration data used is the census block group dataset provided by the US Census – the American Community Survey (ACS). There are 203 census block groups in the county. The ACS dataset contains population, number of jobs, and number of households in each. It also contains information on commute times to work for multiple modes from each census block group, which is used in step 2 below. City Simulator's loading tools were used to create a population such that:

- **Population matched:** the total population in each census block group matched the ACS's estimate of population as close as possible.
- **Jobs matched:** the commercial buildings were stocked with businesses and jobs such that the total number of jobs in each census block group matched the ACS number of jobs.
- **Households matched:** the number of occupied homes in each census block group was governed by the number of households reported in the ACS. In several census blocks groups, this meant leaving residential buildings unoccupied. Many of these census block groups were on the west side of the county, and the unoccupied buildings were assumed to be vacation homes.
- The algorithm used to allocate the population took the following steps:
    1. For each census block group, allocate the number of jobs to the commercial buildings.

2. For each worker in each building, assign a home such that the average commute time across the census block group matches that reported by the ACS
3. Assigning Working Population Commute Paths by finding the shortest commute path between the transportation nodes closest to the workers place of work and home.

4.10 Driver Forecasts

The City Simulator geodatabase also holds driver forecasts, which are forecasts of weather, sea level rise, and economics for the city over the course of the simulation. These are known as exogenous variables, because they are determined outside the city system. They are called driver forecasts because they tend to drive city evolution over time. For example, as sea level increases, it will influence where/if new development occurs at the coast and determine when/if mitigation projects will happen.

The City Simulator extension contains a weather and a sea level forecaster. Using these tools, you can pull data from sources such as NOAA and USGS to create the forecasts for your target city. Once created, the forecasts are stored in the geodatabase in the Timeseries table couplet (see section below on Timeseries). See the section on Driver Forecasts below for details on creating and saving them.

Boulder County: The forecasts were developed using the methods described in section 6. They were not stored in the time series tables described below, but were rather stored as text files as described in section 6.1.3.

4.11 Timeseries

Timeseries are stored in the Timeseries table couplet in the geodatabase. This couplet includes two tables, TimeSeries and TSData. The TimeSeries table contains a single row for each timeseries stored.

Any feature within the database can be associated to a time series by way of the FeatureType and FeatureID fields, which specify the type and unique ID of the feature respectively. Typically, the TimeSeries tables are used to store results from the City Simulator model, which apply to the analysis domain of the model – i.e.. they are community-wide metrics. However, multiple routines within the model do create time series results that apply to buildings, parcels, road segments and other features. This will be discussed in the Simulation section later in this document.

For the most part, this data is populated by the City Simulator ArcMap extension automatically through the process of running City Simulator.

The fields in the table are:

- **TSID** – this is a string field that contains the unique ID of the time series.
- **Variable** – this is a string field that contains the name of the variable the time series is measuring.
- **StartDate** – this is a date field that contains the date of the first datapoint in the time series.
- **EndDate** – this is a date field that contains the date of the last datapoint in the time series.
- **Unit** – this is the unit of the variable being measured in the time series.
- **FeatureType** – this is a string that states the type of feature in the geodatabase for which the time series is related. The values can be the name of any feature class in the City Simulator geodatabase (eg. Transportation_Link, Stormwater_Node, AnalysisDomain, etc.)
- **FeatureID** – this is a long integer field that stores the objectID of the feature that the time series is related to.

- **SourceURL** – this is a string field that stores an URL or local hard drive path that provides a reference to the source of the data for the time series. This field can be filled in optionally.

The TSData table contains a single row for each data point in the time series. It is related to the TimeSeries table by way of the TSID. Its fields include:

- **TSID** – this is a string field that contains the unique ID of the time series.
- **TSDateTime** – this is a date field that contains the date/time for the datapoint.
- **TSValue** – this is a double precision number field that contains the value of the time series.

5 Creating Driver Forecasts

As mentioned in the section on loading the City Simulator database, simulations of community evolution are driven by forecasts of economic growth and climate-change influenced weather and sea-level rise.

As these “driver” forecasts are uncertain, the general modeling concept within City Simulator is to create an ensemble of many plausible forecasts and run the simulation using all of them. This means that for each metric the City Simulator estimates, a distribution of values is calculated. This is helpful, as it provides a median value of the metric as well as the best- and worst-case values, which are often more valuable for decision-making.

An important note is that driver forecasts are created separately from scenarios. The general workflow is to create a library of driver ensemble forecasts and then assign one to each scenario when running them. This way, multiple scenarios can run with the same ensemble forecasts, which facilitates comparisons between scenarios in the same future climate.

Driver forecasts are created with multiple tools within the City Simulator ArcMap extension including a weather, sea level, and economic forecaster. They are accessed through the tool’s Driver Forecasts tab.

5.1 Weather Forecast

The City Simulators provides a weather forecaster tool to create forecasts of rainfall and maximum and minimum temperature for your target community.

These forecasts are spatially and temporally downscaled projections of these variables from the family of global climate models (GCMs) that are being run by research centers around the world.

Each GCM runs multiple scenarios that reflect different approaches to controlling greenhouse gas (GHG). The scenarios are set by the United Nations Intergovernmental Panel on Climate Change (UN IPCC). Known as representative concentration pathways (RCP), the scenarios are named RCP2.6, RCP4.5, RCP6, and RCP8.5, where the numeric part of the name is the amount of radiative forcing in W/m^2 at the year 2100. Radiative forcing is the difference between incoming solar radiation absorbed by the earth and energy radiated back into space. As GHG concentrations get higher, the radiative forcing increases. In plain words, the RCP8.5 scenario is the worst case in terms of global warming, while the RCP2.6 is the best case.

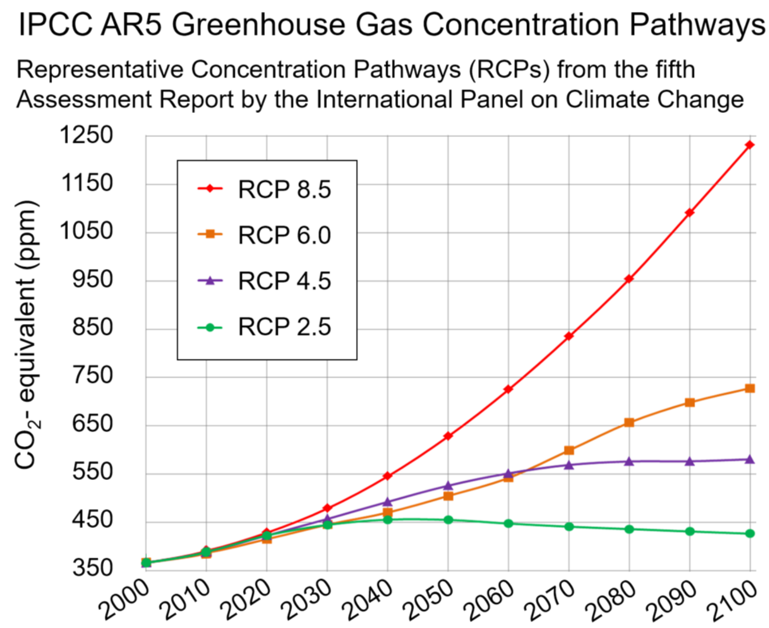


Figure 5: RCP scenarios from UNIPCC.

Downscaling refers to the process of localizing the data to a region of interest. The GCMs have grid cells that range from 2-3 degrees latitude and longitude. In the US, that equates to roughly 200-300 km, which is usually much larger than the target community. Moreover, due to approximations in the GCMs, modeling error, and multiple other reasons, the projections are often biased, significantly over- or under-estimating weather variables in a given grid cell. While run at hourly time steps, it is often necessary to average the results to longer times steps (e.g. monthly) to get some reliability in the projections. The result is that the GCM projection cannot be used directly as a weather forecast, where daily forecasts (or even sub-daily) are needed with realistic extremes.

To solve the problem, downscaling introduces historic data recorded in the location of interest as an example of the real weather experienced in the target community. The climate science community has developed multiple algorithms that blend the monthly GCM projections with daily (and sub-daily) historic data to produce useful forecasts for tools like City Simulator.

The weather forecaster tool uses the following algorithms and data:

5.1.1 Rainfall:

Atkins has developed an algorithm called StormCaster, which is used to create daily rainfall forecasts for City Simulator runs. The general steps of the algorithm are:

1. **Localize the GCM data** –The localization process consists of the following steps. Refer to Figure 6 for an illustration of the process.

    1.1. Select a historical rainfall gage within or close to the target community. The historical gage must have a record with at least thirty years of recorded rainfall.

    1.2. Build a rainfall climatology from the historical data at the rain gage selected. This climatology gives the average rainfall in January, February, March, and so on.

    1.3. Build a base local climate forecast from this climatology, essentially repeating the climatology year after year from 2010-2100.

1.4. For each GCM-Scenario precipitation projection, create a monthly time series of departures from pre-industrial revolution control. This means subtracting the GCM rainfall projection time series from a “control” time series of precipitation, where the GCM was run as if the industrial revolution – and its attendant increases in GHG – did not happen. These time series are called “delta” time series.

1.5. Add the delta time series to the base local climate forecast to produce a monthly localize forecast.

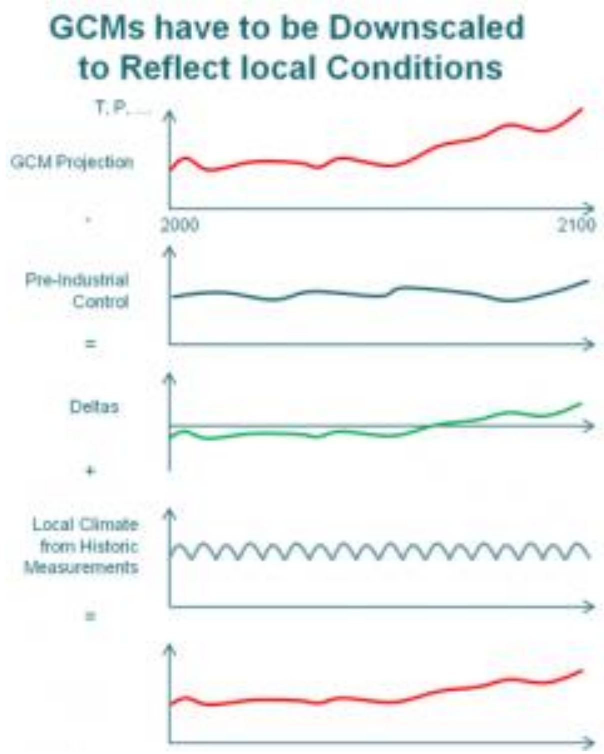


Figure 6: Stormcaster GCM Localization Process

2. **Synthesize the short time-step forecast** – Once the localized monthly GCM projection has been created, the next step is to create a short-time step forecast that equates to the total rainfall forecasted in a month to the monthly projection from the GCM run. The steps are:

2.1. Build a library of historic storms from the historic record for each month of the year. These storms should be at daily or sub-daily time step.

2.2. Evaluate the probability that it will rain on any given day from the historic record (known as Markov probabilities).

2.3. For each day from the start of the forecast time horizon to the end, use a random number generator and the Markov probabilities to determine if it rains. If it does, then extract a storm from the appropriate library.

2.4. Create a scaling factor for the storm by comparing the projected rainfall for the current month to the range of rainfall for that month from the historical record. The scaling factor is defined as:

- If Projected rain > Max rain, Scaling Factor = Projected Rain / Max Rain
- If Max rain > Projected rain > Min rain, Scaling Factor = 1.0
- If Projected rain < Min rain, Scaling Factor = Projected Rain / Min Rain

2.5. Multiply the rainfall in the historic storm at each time step by the scaling factor.

2.6. Add the storm to the forecast.

2.7. Repeat steps 2.3-2.6 for every day in the forecast.

The sources of data for the rainfall forecast development are:

- **GCM projections** – The weather forecaster taps into the THREDDS web service, which is run by USGS. This service provides multiple climate related datasets and allows the user of the service to extract time series from them for a specific location and time horizon. The specific dataset used is the CMIP5 BCSD, which contains monthly projections of rainfall for all GCMs and GHG scenarios, a total of 120 projections. The process of downloading the projections is easy for the user, as the weather forecaster provides a download all option that will find the grid cell for a user's target community – the grid cell that overlaps the geographic centroid of the community - and automatically download all 120 projections.
- **Historical Rainfall Gage** – The weather forecaster also allows the user to select a historical gage for use in the downscaling process. It works by finding the latitude of the geographic centroid of the community and finding a list of five gages with at least 30 years of record closest to it. For the Study, City of Boulder NCEI Gage (USC00050848) was used.

5.1.2 Max and Min Temperature:

The weather forecaster uses a pre-downscaled dataset for temperature forecasts. The dataset is called LOCA, which stands for Localized Constructed Analogs. Developed by Scripps Institute at the University of California, San Diego, the LOCA data is widely used for climate impact assessment. It uses a statistical process to downscale GCM data from monthly and at 2-3 deg grid cells to daily and 1/16th degree grid cells.

Like the rainfall forecast, the weather forecaster finds the LOCA grid cell closest to the geographic centroid of the target community and downloads 120 GCM projections of maximum and minimum daily temperature, which are used in the ensemble forecast.

Why not use LOCA for Rainfall forecasts?

The algorithm used to create the LOCA dataset differs from the Atkins Stormcaster algorithm described above, but the general concept of using historical data blended with GCM projections is similar.

In terms of rainfall, Atkins researchers have found that the extremes in LOCA forecasts are much lower than in Stormcaster forecasts. Moreover, the extreme rainfall forecasts in LOCA often do not exceed the historic extremes for nearby gages. This "damping" of extremes is a common problem in spatially downscaled data, where the process is essentially averaging rainfall from multiple gages.

Atkins researchers have compared the LOCA rainfall extremes and Stormcaster rainfall extremes to rainfall in recent years (2010-2018), both from the perspective of magnitude and frequency. They found that Stormcaster extremes are much closer to observed storms, with LOCA heavily underestimating. We expect this is due to the scaling factors the Stormcaster algorithm uses as well as the fact that the Stormcaster algorithm does not average rainfall spatially. Because of this assessment, we recommend using Stormcaster in City Simulator.

Our assessment also compared temperature forecasts from LOCA to actual temperature forecasts. In this case, we found that LOCA forecasts were relatively similar to actual temperatures that have occurred in recent years. We therefore recommend using LOCA for temperature forecasts and have set the weather forecaster to pull the LOCA_Future from the USGS THREDDS web service.

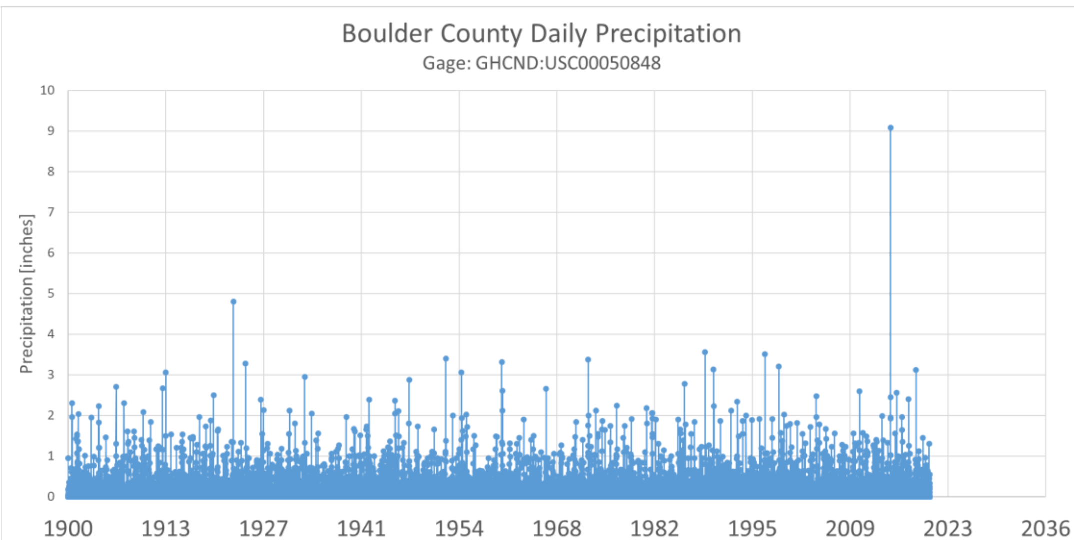
Boulder County:

- **Rain:** An ensemble of 630 GCM/Scenario forecasts of rainfall was created using the Atkins Stormcaster method and a rain gage based in the City of Boulder (NCEI Gage USC00050848). The GCM data was gathered from the USGS THREDDS site from the CMIP5_BCSD dataset. The RCP 8.5 (High GHG) scenarios were used because they represent a worst-case condition and have been shown in the last two decades to be closest to the actual GHG levels that are present in the global atmosphere. A chart of the available historical daily rain data is shown below.

  The CMIP5_BCSD dataset contained 63 model realizations of monthly rainfall for Boulder County. Using the Atkins Stormcaster algorithm, which is a Monte Carlo approach for downscaling the monthly GCM rainfall projection time series to daily time series using libraries of historical daily rainfall data, 10 realizations per GCM realization were produced, resulting in 630 daily rainfall projections for the county.

  A severity score was then calculated for each realization, where the severity score was defined as the sum of the cubed rain amounts across the time series. Cubing the rainfall amounts emphasized those realizations with larger storms in terms of severity. The 630 severity scores where then ranked, and 0^{th}, 5^{th}, 25^{th}, 50^{th}, 75^{th}, 95^{th}, and 100^{th} percentile realizations were selected. The Boulder County Simulator base scenario was run with each of these percentile realizations to show the range of possibly values the key metrics in the simulation would take.

  Based on the analysis, the 75^{th} percentile realization was used as the design forecast, as it resulted in values for the key metrics that were closest to the 50% mark on the range of each of the key metrics.



- **Temperature:** No temperature data forecasts was used in this study as the study's scope was not focused on temperature or factors influenced by temperature. An initial conceptualization of an aridity forecasting model was considered, to estimate the increase flood damage risk when storm events occur soon after wild-fires in the upstream sections of Boulder County watersheds. This model would have required temperature forecasts, as it relies on a simple water balance calculation. The model was not included in this study in the end because it was judged too high a level of effort to develop within the budget and time allowed. It is recommended that such a model be incorporated into the Boulder County City Simulator model in the future.

5.1.3 Creating and saving Forecasts in the Weather Forecaster

Creating and Saving weather forecasts is simple in the weather forecaster tool. Just create a forecast using the "+" button. Name the forecast at the prompt. Then, go to the rainfall and hit the download all button to download the CMIP-5 data for the target community. Select the historic rain gage and then hit the create ensemble forecast to generate the forecast using the Stormcaster algorithm. When the forecast is complete, the tool within the weather forecaster can be used to review the forecast, look at trends, and the spread of the rainfall estimates. Then, save the forecast to the database for use in scenarios created moving forward.

To create a temperature forecast, go to the temperature tab in the weather forecaster and hit download all. Then hit the create ensemble forecast button. When complete, the forecast can be perused like the rainfall ensemble. Hit save to store the forecast.

Note that the rainfall and temperature forecasts are part of the same ensemble forecast. As City Simulator needs both forecasts to run, they are stored together as a joint ensemble. Further note that City Simulator uses rainfall and temperature from the same GCM/Scenario pairing when it does a run. This ensures that the weather being used came from the same model run and that interdependencies between the variables are preserved.

Boulder County: The forecasts were created in the weather forecaster tool and stored as text files – one per precipitation severity percentile – that are used by the City Simulator during simulation. Only rainfall forecasts were created, not temperature, as mentioned above.

5.2 Sea Level Forecast

The City Simulator provides a sea level forecaster tool that blends forecasted mean sea level and forecasted diurnal tide levels to produce an hourly forecast of tides over the forecast time horizon. This is used to drive forecasts of sunny day flooding, as well as adjust storm surge floodplain height and extent during hurricanes.

Boulder County: Given Boulder County is not coastal, the sea level rise forecaster was not used in the Boulder study.

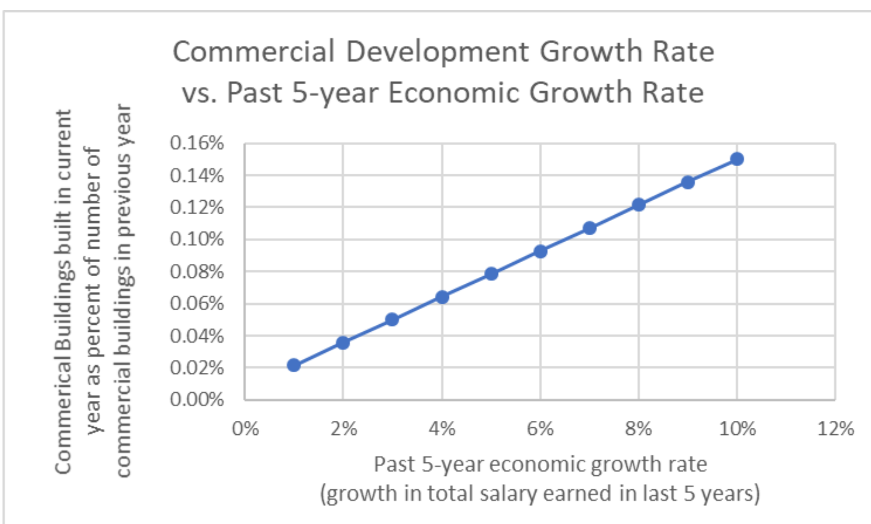
6 Simulation and Forecasting

Simulation within City Simulator is accomplished with a nested loop process. The outer loop simulates urbanization and is run on an annual basis. The inner loop simulates travel, commerce, education, and disasters and how they impact these activities.

6.1 Urbanization Forecasting

- **Yearly Urbanization Algorithm:** Urbanization is modeled at the beginning of each year according to the following algorithm:
  1. Forecast the number of new commercial buildings to be developed in the coming year
  2. Place the commercial buildings in the most likely locations
  3. Populate each building with businesses and workers
  4. Assign the closest transportation node to each worker.
  5. Assign housing for each worker:
     - 5.1. If there is empty housing, then assign the workers to it
     - 5.2. Create new housing units to provide a unit for each of the remaining workers. Place the units in the most likely locations.
     - 5.3. For each new building, assign the closest transportation node
     - 5.4. Populate the housing with non-working spouse and children

- **Economic Growth Rate vs Number of Commercial Buildings Developed per year:** It is assumed that the number of new commercial buildings built in a year is dependent on the average economic growth of the previous five years, where economic growth is measured by the growth in total salary earned across the community in a year. The chart below provides a typical relationship used in a City Simulator simulation. For the initial year, the economic growth rate is derived from information from the US Census Bureau.



Allocating New Structures by Likelihood of Development: New structures are distributed across the county according to likelihood of development. The developable land is ranked according to likelihood through a GIS process similar to suitability analysis. A grid that covers the analysis domain is created with cells approximately equal to area of an average land parcel. Each grid cell is assigned a likelihood of development for its landuse class (residential or commercial). The likelihood is a weighted sum of factors related to density of development and proximity to desirable features for the landuse type. When new growth allocation is done each year, the highest likelihood locations are allocated first, then the next highest and so on.

Below is an example of factors and weights that can be assigned to assess likelihood of development in a community.

- **Commercial:**
  - Proximity to Major Roads: 40%
  - Density of existing commercial buildings: 60%
- **Residential:**
  - Proximity to Major Roads: 5%
  - Density of existing residential buildings: 95%

- **Accommodating Build-out:** Many communities will reach build-out over the course of the simulation, where all developable land is used. In this situation, the modeling choices within City Simulator are:
  - **Adjust growth and density parameters such that build out occurs in the final year of the simulation:** The parameters that can be adjusted include:
    - Number of jobs per commercial building
    - Number of Units in each Multi-Family Building
    - Size of average single family lot
    - Percentage of residential buildings that are multi-family vs single family
    - Economic Growth Rate vs Commercial Building Count per year.
  - **Allow build-out to occur and assume any new jobs that are created when no housing is available are staffed by workers from outside the community:**
  - **Allow for re-development**

Boulder County

Likelihood of Development: The grid cells size used was set at 65 meters, which produces grid cells approximately one acre in size. The factors and weights used were:

- **Commercial:**
  - Proximity to Major Roads: 40%
  - Density of existing commercial buildings: 60%
- **Residential:**
  - Proximity to Major Roads: 5%
  - Density of existing residential buildings: 95%

Accommodating Build-out: As mentioned previously, due to its zoning rules, Boulder has relatively little developable land. Assessment of the tax assessor parcel database showed 512 residential acres and 56 commercial acres were available across the entire county. As such, the simulation is likely to hit a state of build-out by the end of the simulation (2050). It is possible that zoning may change as build-out condition approaches, or redevelopment may occur, allowing for additional jobs and residences in already developed parcels. However, as there is considerable uncertainty in when and if this will happen, and to what degree, it was assumed that new development is constrained to the vacant developable land. **To ensure the build out condition occurred at 2050, multiple parameters were adjusted.** In situations where build-out is not likely to occur the simulation timeline, these parameters are set to estimates of their value in the base year. Base scenario runs showed that this resulted in build-out occurring long before the 2050 end year. The parameters included:

- **Number of Jobs per commercial building:** The average number of jobs per new commercial building was set at 25. See the section on business type in the New Commercial Buildings section below for detail on how these employee's – or agents – are defined. As each new agent is assigned a residence, the number of jobs per building has a strong influence on the number of residential buildings constructed each year.
- **Number of Units in each Multi-Family building**: As multi-family buildings can contain many households; the number of units has a strong influence on the area required to house the growing population. In this study, the number of units was set at 50.
- **Percentage of Residential Buildings that Are Multi-Family vs Single Family:** As this percentage increases, the total number of housing units in the remaining developable land increases. In this study, the percentage was set at approximately 10%. This resulted in a higher percentage of multi-family dwellings than single-family as compared to the base year, but this increasing percentage was judged likely given the need to accommodate new population in an ultimate build-out situation.
- **Economic Growth Rate vs Commercial :** With the number of jobs per commercial building, number of units in each multi-family building, and percentage of residential buildings that are multi-family set as described above, the number of commercial buildings vs economic growth rate formula was adjusted (see the chart above) iteratively until the base scenario showed land development reaching build-out right at 2050. The resulting relationship is illustrated in the chart and was used in the forecasting process.

6.1.1 Adding New Commercial Buildings

When a new commercial building is added to the landscape, the quality level, subtype, if the building has a basement, the related transportation node, and business type and agent distribution are set. By default, the following methods are used to set these attributes.

- **Quality:** The building's quality is assigned using a uniform distribution random number generator as follows:
    - Low – 10% probability
    - Medium – 50% probability
    - High – 40% probability
- **Subtype:** The building's subtype is assigned using a uniform distribution random number generator as follows:
    - General Business – 40% probability
    - Mercantile/Retail – 20% probability
    - Assembly Space/Restaurant – 30% probability
    - Educational – 8% probability
    - HealthCare – 2% probability

Business Type and Agent Distribution: Depending on sub-type, the building will be allocated businesses and agents with a set distribution of job types, salaries, gender, education levels, and NAICS category. For example, if the subtype is general business, then the business type can be legal, financial, info/telecom, or other. If it's a legal business, then the following distribution of job types is used by default. Note that the salary and age have a random number generated “delta” added/subtracted to achieve a distribution in ages and salaries.

Num Jobs	Title	Salary	Avg Age	Pct. Female	Education Level	NAICS Category
Attorney	4	$100,000	50	0.3	Advanced	Professional, Scientific, and Technical Services
Paralegal	6	$65,000	40	0.6	Tertiary	Professional, Scientific, and Technical Services
Assistant	10	$45,000	30	0.75	Secondary	Professional, Scientific, and Technical Services

- **Basement:** A uniformly distributed random number generator is used to assign if the new building has a basement or not. The probability that a new building will have a basement is set at 1% to align with percentage of county-wide commercial buildings in the base year that have basements (91 of 10,135).
- **Other Building Attributes:** New commercial buildings are assumed to have the same distribution of size, cost, and number of floors as base year commercial buildings. The parameters are estimated from the base year commercial building attributes.
- **Transportation System:** When a new building is added, the closest node in the transportation system is found and associated with the building. This relationship allows the tool to create commute and journey paths for the workers when they are created and given homes. Note that the journey paths are derived from the commute paths created when creating the base year model.

Boulder County: The default values were used in the Boulder County City Simulator simulation with the exception of the number of workers per commercial building to account for build-out. A description of the settings used for the build-out modeling is included in the previous section.

6.1.2 Adding New Residential Buildings

When a new residential building is added to the landscape, the quality level, subtype (single or multi-family), number of units, if the building has a basement, and the related transportation node are set. By default, the following methods are used to set these attributes.

- **Multi- vs Single-family:** If the community is not forecast to reach build out (when all developable land is used), the percentage of single family vs. multi-family is matched to the base year percentage, which is derived from the building footprint and parcel database provided by the county. If the community will reach build-out, then multiple parameters related to density including percentage of multi- vs single-family homes are set to manage growth. See the section on accommodating build-out above for more detail.
- **Number of Units:** The number of units per multi-family buildings is typically set to match the base year average. If build-out is likely to occur, then this number may be increased to accommodate new population.
- **Number of Residents per household:** As the simulation proceeds, households are occupied by new workers, who are added to new commercial buildings each year. The remaining residents of the household are then allocated as follows:
    - **Two-Worker and One-worker Households**: The US Census data will give the total number of jobs and households in the community. Use the ration of the number of jobs to the number of houses to find the total number of two-worker homes. For example, if there are 150 jobs and 100 homes, then there are 1.5 workers per home. This means that for every two households

allocated, one should have two workers in it. City Simulator evaluates this ratio automatically based on the census data loaded at the census block group level and allocates new residential buildings such that the future percentage of two-worker homes is matched to the base year percentage.

  - **Children:** 0 to 5 children are added to each household using a gaussian distributed number generator with a mean set to the base year average number of children for the community, as reported in the US Census. The age of the first child is assigned with a random number generator ranging from 0 to 18. Siblings are then assigned age using the age of the first sibling and subtracting years using a long-tail distribution that peaks at 2 years and extends to 18 years with progressively lower probability, keeping the minimum age at zero.

- **Building Attributes:** New residential buildings are assumed to have the same distribution of size, cost, number of floors, basement, and in the case of multi-family, number of units that the base year residences do. The parameters are estimated from the base year residential building attributes.
- **Transportation System:** When a new building is added, the closest node in the transportation system is found and associated with the building. This relationship allows the tool to create commute and journey paths for the workers when they are assigned the residence. Note that the journey paths are derived from the commute paths created when creating the base year model.

Boulder County: Zoning rules resulted in little developable land (512 residential acres and 56 commercial acres), which meant that build-out is likely. As mentioned in the previous section on urbanization forecasting, the model was configured to reach build-out at 2050 by adjusting the following parameters:

Multi-vs Single Family: Set to 10%, which is significantly higher than the base year value.

Number of units per Multi-family Building: Set to 50, which is significantly higher than the base year average.

Two-worker vs. one-worker households: Base on the US Census data, there are 1.56 jobs per household in Boulder County. In this study, it was assumed that this means that 56% of new residential buildings are two-worker. In each year, as new workers in commercial new buildings are assigned homes, 56 of every 100 workers is assigned to an existing home with one worker assigned already assigned to. For remaining 44 workers out of 100, the household is assumed to be single-worker and a new spouse agent is generated with no workplace.

6.2 Flood Simulation

6.2.1 Riverine Flooding

In City Simulator, riverine flooding of buildings is simulated when the driver rain forecast for a given day has a non-zero rain amount. When this happens, every structure in the community is evaluated to see if it is flooded using the structure's rain-to-flood curve. The curve is used to estimate the level of flooding and then recovery time is estimated as a function of the flood depth. If flooded, a structure is considered non-operational and being repaired for the duration of the recovery time.

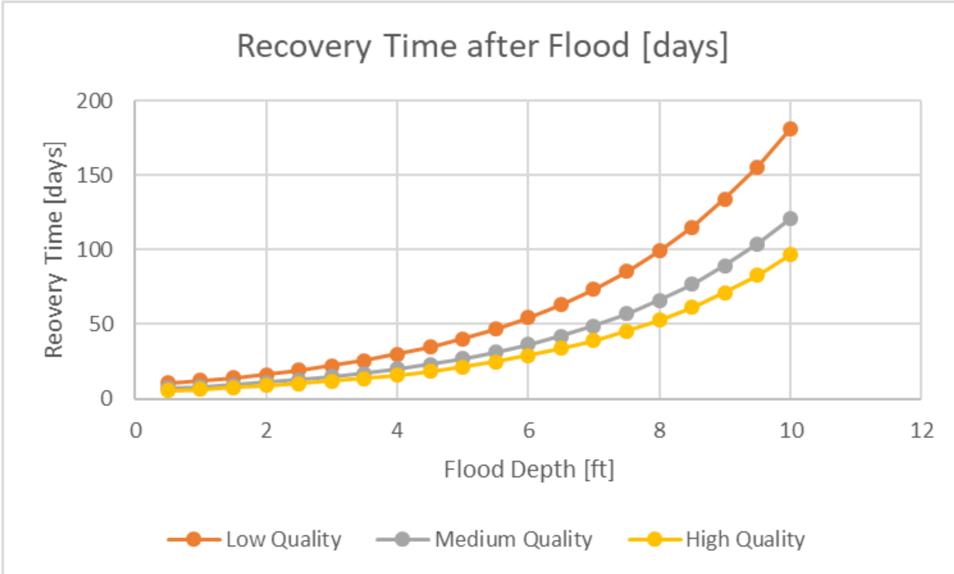
- The Rain-to-flood curve is derived based on the location of the new building and flood depth rasters.

Boulder County: The flood depth rasters were produced by the County based on the recent CHAMP study. Depth rasters in the City of Boulder were produced from existing studies and merged with the CHAMP study rasters to make a county-wide product (see Base Year, Buildings and Parcels section).

- FFE is estimated for existing buildings using the methods described above. For new buildings, FFE is estimated using a random number generator that places FFE between 1 and 9 feet above ground. This is based on the range of FFE values used in typical FEMA losses avoided study mentioned previously.
- Storms at or below the 10-year storm depth are assumed to have no impact on commercial buildings.

Boulder County: In Boulder County this depth is 3.27".

- When a 10" rain depth or higher occurs, depth of flooding in the structure is estimated as depth of flood above ground from rain-to-flood curve minus FFE.
- If the structure has a basement, then the depth of flooding is estimated relative to the FFE. The depth, even if negative, is used with the HAZUS depth-damage curve to estimate damage level. See the section on depth-damage curves above.
- Direct and Contents Damage is estimated using the depth-damage curves mentioned in the section above.
- Recovery Time is estimated using the following assumptions. The chart below shows the recovery time as function of depth of flooding for the different quality classes for buildings.
    - Recovery Time = BuildQualityFactor * 6.0 * e ^ 0.3 * FloodDepth [ft]
    - Building Quality factor is:
        - Low: 1.5
        - Medium 1.0
        - High: 0.8



Boulder County: The recovery time for buildings model described above was use in the Boulder County City Simulator model simulation.

6.2.2 Pluvial Flooding

Pluvial flooding of buildings is forecasted in the same way riverine flooding is forecasted, with the exception that the rain-to-flood curves are derived using a 2D hydraulic overland flow rainfall model. This model estimates the depth of ponded rainfall that will occur at each building given a rain event occurs. In riverine flooding, rainfall runs off to rivers, forcing river levels to rise until high enough to flood buildings. Pluvial flooding can occur if the rain rate is fast enough that the ground around a building is not able to drain the ponding water quickly enough. Given this can occur anywhere in the county – not just in the riverine floodplains – pluvial flooding can represent a high risk county-wide.

- By default, City Simulator uses pluvial rain-to-flood curves for each building that are derived from depth rasters that are outputs from a 2D hydraulic model produced with the Telemac modeling tool. The default storm events used included the 10-, 100-, and 100-year. Atkins typically provides these model results from a state level model run. The model works on a 2D mesh with variable spacing of around 1-meter. It is designed to match the detail in the USGS National elevation dataset, which is the DEM used in the modeling and has a 1-meter horizontal resolution throughout the country. At each location node in the mesh, the rain event used is a derived from the historical rainfall statistics for the closest rain gages, provide through NOAA's rainfall data APIs – the same data that NOAA's ATLAS 14 site uses (see above for discussion on using NOAA's ATLAS 14 data to derive the rain depths for varying storm sizes).
- **Riverine or Pluvial Flood:** When the model is simulating floods, the depth of flooding is calculated for both the riverine and pluvial flood curves, should both exist for the building. The deeper flooding estimate is used to derive damage estimates.
- **Other Modeling Parameters**: The remaining modeling choices described in the riverine flood simulation section above were used for pluvial flood simulation as well.

Boulder County: The Telemac model for Colorado was used to clip out the Boulder County rain-based floodplains. In the Boulder County study, it was assumed that less than 0.5 ft of rainfall was received at a building, it did not flood, even if it had a basement. Had a zero threshold been used, thousand of homes across the county would flood with as little as a 10-year storm event, a reality that is not seen today. The 0.5' threshold was selected by completing a sensitivity analysis (Figure 7) and the force that 0.5' would place on basement walls. Water piled up against a basement wall as a result of rain will cause a force that increases with the square of the depth of the water. The formula for the force is $F = \frac{1}{2} Y0 * h^2$, where Y0 is the unit weight of water (62.4 lbs / ft^3). At 0.5 ft, the force is 7.8 lbs/ft^2. Given weaknesses in basement perimeters like egress points (windows, doors), we assumed that this force would be sufficient to cause a breach in the basement during the pluvial flood. Note that at 0.25 ft depth, the resulting force would be one quarter of the force at 0.5 ft, or 1.95 lbs / ft^2, a force that we assumed would likely not cause breach over the course of the transient pluvial flood.

Further, if the 0.5 feet of water caused a breach in, a 3' wide egress window, then the resulting broad-crested weir flow, Q, would flow at $Q = 2.65 * \text{Width of Flow} * \text{Height of Flow}^{1.5}$, or $2.65 * 3\text{ ft} * 0.5\text{ ft}^{1.5} = 2.8$ cubic feet per second. At this flow rate, it would take approximately six minutes to fill a 1,000 square foot basement to 1-foot depth. As this would be a highly damaging flood and would take a short enough time that even a transient rain-driven flood would likely not abate within the six minutes, we assumed that 0.5ft would be a sufficient depth to cause damaging floods.

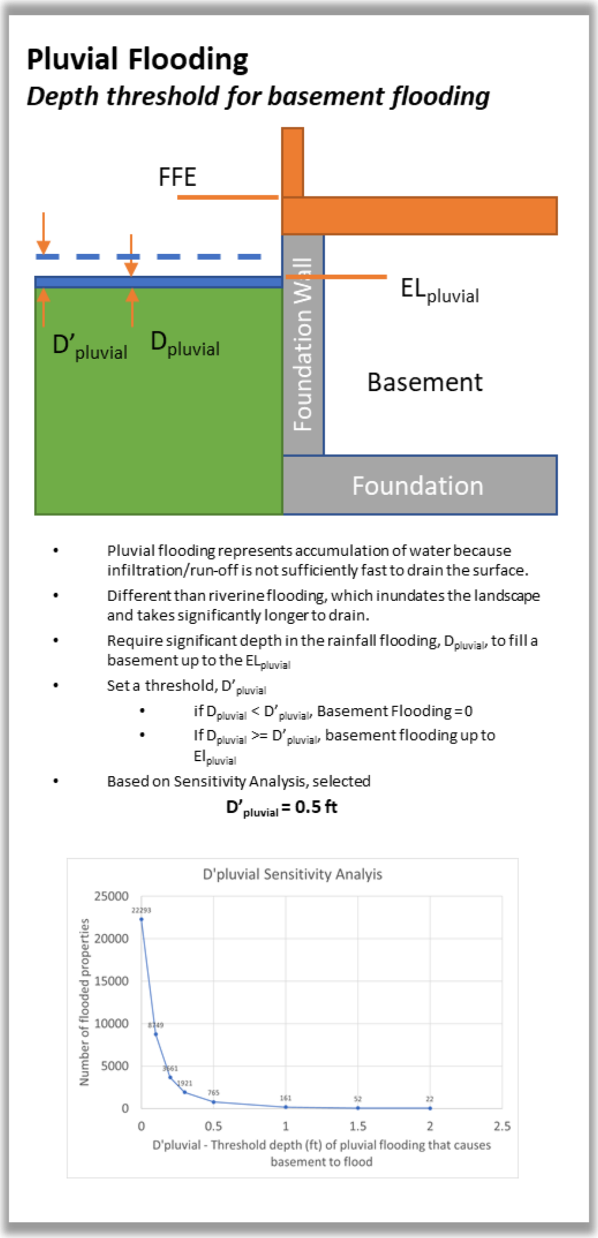


Figure 7. Pluvial Flooding: Depth threshold basement flooding

6.2.3 Key Flood Modeling Assumptions:

Several key assumptions are made in the riverine flooding process:

- **Uniform rainfall covers the whole county in a rain event:** By leveraging existing flood models, City Simulator is able to simulate building-by-building flooding for a large number of buildings at relatively low cost. The most typical source of these flood models is FEMA's flood study models, the models that are used to create NFIP flood zones. These models are typically built with the US Army Corps HEC RAS software as a steady state model that assumes a uniform rainfall amount for the watershed in question. As such, City Simulator flood modeling is necessarily following the same assumptions.

In the planning-level analysis that city simulator provides, the interest is more in the relative levels of damage and disruption – ie. comparing one culvert to another or comparing the average home in the SFHA the average home outside the floodplain – than to estimating absolute measures of these metrics. As such, this level of accuracy is not actually needed to make informed decisions on planning level actions. Further, as the level of effort and cost of executing this kind of modeling is several times higher than a planning study will normally fund, and as the 2013 event is unique in nature, and probably won't be seen again exactly as it occurred, the traditional flood modeling approach of assuming uniform rainfall across the county is typically judged reasonable for resiliency studies.

- **Riverine flooding occurs with the same probability as rain events:** A key assumption in the city simulator model is that a rainfall event of a certain probability will cause a flood of the same probability. In situations where antecedent soil moisture condition is at saturation, this is a reasonable assumption, because there is no reservoir for incoming rain to fill in the soil column. If the soil is not at saturation, then a portion of it will be absorbed, reducing the total flood volume and delaying the resulting stream hydrographs and reducing their peaks. In many situations, the assumption of saturation is reasonable. In the 2013 event in Boulder Colorado, for example, there was 3.5" of rain the day before the very large storm event occurred. This would have saturated the soil column and made the assumption reasonable. Still, the assumption is purposely conservative and certainly over-estimates the flooding that would occur during real storms.

6.3 Travel Simulation

6.3.1 Daily Commuting

On a daily basis, city simulator simulates agents moving from home to work and back home. The agents are assigned their place of work and residence during the base year population virtualization routine (see the base year section above) and when new agents are added each year as a result of jobs being created in new commercial buildings. The agents' commute paths are defined using the set of shortest node-to-node commute paths created during base year model creation. The shortest path from the transportation node associated with the agents place of work to the transportation node associated with the agent's residence is looked up in the CommutePath table. This path defines the set of road segments that the agent travels on their commute. At the beginning of the simulation, the total number of trips taken on each road segment in the network is evaluated by summing the agents that have that road segment as part of their commute. The count is multiplied by two because it is assumed the agents travels to and from work on the same path. As long as a disaster hasn't occurred and disrupted agents, all trips for the road segment are counted each day.

Boulder County: Boulder County had a total of 883 transportation links in the simplified road network. The mean number of trips taken per day was 3,674.

6.3.2 Disruption

If floods occurred in the simulation, they can disable homes, work places, and road segments, as described earlier in this section and the stormwater impacts section (section 4.8). When a bridge, culvert, or frequently flooding road segment are impacted by a storm, all agents that use the overlying road segment are disrupted. The recovery period depends on the type of structure and the level of overtopping that occurred.

By default in city simulator, if a structure is overtopped by less than 1 foot, the structure is rendered impassable for the day, and no damage is assumed. If the overtopping level is over a foot, the structure is assumed to be damaged, and repair work is required before the road can re-open. Default repair durations are 30 days for culverts and 180 days for bridges.

The level of disruption a damaged culvert, bridge, or low road cause is dependent on how remote the structure is. Using the remoteness Index tool in City Simulator, each structure is assigned a remoteness index that describes how sparse the road network is around the structure. If the index is 1, then the road network is highly dense, and travelers can likely easily find another path to commute. If the index is 10, the road is likely the travelers only option, and they are assumed to not be able to make it to work until the road is repaired.   By default, City Simulator assumes a linear relationship between remoteness of a damaged asset and fraction of the 8-hour work day the agent misses 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 remoted index is 1, then the agent misses 30 minutes of work.
- If the remoteness index is between 2 and 7, then:
    - Agent Missed Work Time = 8 * (1 – (remoteness index of damaged asset – 1) /6)

Regardless of remoteness index City Simulator records each time an agent can't get to work through their normal commute path as a disruption. The remoteness of damaged assets does, however, impact the lost production key metric. This metric is the sum of all salary not earned during disasters. During a storm recovery period, the hours not worked by employees are multiplied by the employees assumed salary and the total dollar amount is reported as the community-wide lost production. If the majority of assets damaged are in dense areas, therefore, the lost production is reduced, because the travelers can find detours fairly easily. If the damaged assets are remote, this can have a large impact on lost production. Remoteness, however is inversely proportional to the number of trips being made on the overlying road. That is, remote assets often underlie roads that have little traffic. As such, even if they are damaged for extended periods of time, they often impact relatively few agents.

When buildings are disrupted, they follow the recovery model described in section 6.2.2. During the time the building is damaged, the agents that live or work in the building are assumed to not be able to go to work, and therefore their daily commutes are disrupted for each day the structures are not recovered and their lost production is a full 8 hours salary each day of the disruption.

City Simulator tracks the cause of agent commute disruption as either road flood, work flood, or home flood. By default, the road flood is counted first. So, even if an agent has all three situations on the same day (work is flooded, home is flooded, and commute path is flooded), the cause for the disruption will be recorded as road flood.

Boulder County: In Boulder County, the default models described above were used with the exception of the recovery time for major structures (bridges), which were assumed to require 356 days for recovery.

7 Calibration

The City Simulator model is calibrated against multiple datasets related to flood damages, traffic flow, demographics, and economics. The demographics and economics data is derived from the ACS census database and is used in virtualizing the population as described in section 5.3 above. The flood damage calibration is typically done using a FEMA losses avoided study, which contains a FEMA HAZUS-based estimate of number of structures impacted by the 100-year riverine flood and the damages associated with that event. The traffic flow calibration is carried out using measured traffic flow rates on major roads in the community in the base year.

7.1 Calibrating Flood Damage in the 100-year Storm Event.

Given a FEMA losses avoided study (LAS) is available, the City Simulator model can be calibrated by adjusting the FFE (first floor elevations) of all the buildings in the analysis domain such that the percentage of buildings damages in the FEMA special flood hazard area (SFHA) matches the percentage estimated in the Las study. The first-floor elevation (FFE) has a large impact on the level of damage a single building can incur in a storm. In a community-wide study, FFE therefore becomes an important variable, as it is the single-most influential parameter on the level of damage and the fraction of buildings that are damaged.

With City Simulator, calibration is done using the following steps:

1. Start by assigning FFE based on the process used in the LAS. The table below shows the FFE levels used in a typical LAS. For each building use the available attributes to select the appropriate FFE from the Default FFE column Pre-FIRM or post-FIRM column depending on if a FIRM exists for the are the building is in. The FFE is the height above the ground at the location of the building.
2. Create a scenario that matches the 100-year storm and run the simulation with the FFEs set in step 1. To match the 100 year storm, use the City Simulator weather forecaster to create a forecast that is two years in duration (present year to present year + 1) and insert one event in the first month of the forecast that has equivalent depth to the 100-year rain event.
3. When the run is complete, compare the percentage of damaged homes in the SFHA for the same area as was computed in the LAS to the percentage of damaged SFHA buildings in the LAS. Repeat the following steps (3.1 – 3.3) until the difference between the percentage of damaged homes estimated by Boulder County's City Simulator model run is less than 1%.

   3.1. If higher (i.e. more damage than expected), then adjust the FFE up by 1' for 5% of the buildings selected at random. If repeating this step, then increase the percentage of buildings by 5%.

   3.2. If lower (i.e. less damage than expected), then adjust the FFE down by 1' for 5% of the buildings selected at random as long as the resulting FFE > 0.5'. If repeating this step, then increase the percentage of buildings by 5%.

   3.3. Re-run the scenario.

Note that the LAS study will also provide an estimate of total dollar damages experienced by the community. City Simulator evaluate direct and contents damage. If these estimates are stated as separate amounts in the LAS, then it is valuable to also compare these metrics. However, often the LAS combines these estimates with estimates such as inconvenience costs and social anxiety avoided, making it difficult to make a direct comparison. Further differences in the time at which the studies are being calculated may mean that the building stock has changed or increased in market value, also making comparing the damage estimates a challenge.

Occupancy Class	Foundation	Default FFE (feet)	Adjustment factors (feet)		Adjusted FFE (feet)	
		Pre-FIRM	Post-FIRM adjustment	Basement adjustment	Pre-FIRM	Post-FIRM
Single family home	Pier	5	1	0	5	6
	Solid Wall	7	1	0	7	8
	Crawlspace	3	1	0	3	4
	Fill	2	0	0	2	2
	Slab	1	0	0	1	1
	Unfinished Enclosed Basement	4	0	0	4	4
	Finished Enclosed Basement	4	0	-8	-4	-4
	Unfinished Walkout Basement	4	0	-8	-4	-4
	Finished Walkout Basement	4	0	-8	-4	-4
Mobile home	Pier	3	1	0	3	4
	Crawlspace	3	1	0	3	4
Multi-family	Unfinished Enclosed Basement	4	0	0	4	4
	Pier	5	1	0	5	6
	Crawlspace	3	1	0	3	4
Other residential	Slab (Assume slab for all foundation types)	1	0	0	1	1
Non-residential	Slab (Assume slab for all foundation types)	1	0	0	1	1

Boulder County

There is currently no structure-by-structure estimate of FFE for Unincorporated Boulder County. As such, an estimate of FFE is required at each structure. As foundation type was not available in the County tax assessor database, the LAS FFE estimation table (shown above) was used to estimate FFE with the following modifications:

1. If the building is residential,
   1.1. If the building is not a manufactured home, then
      1.1.1. If the building has a basement, FFE = 4' above ground level
      1.1.2. If the building doesn't have a basement, FFE = 1' above ground level (slab assumed)
   1.2. If the building is a manufactured home, then FFE = 3' above ground level
2. Otherwise, FFE = 1' above ground (slab assumed).

The LAS showed that the percentage of buildings in the SFHA that sustained damage was 31%. The calibration algorithm was run setting the FFE iteratively until there was a close match in percentage of buildings in SFHA damaged.

As the community = all | income class all table from the 100-year storm scenario shows (see the next section), there are 1454 damaged buildings in the SFHA, which has a total of 4661 buildings county-wide. This equates to 31.1% of the buildings and was considered a sufficient match to the LAS study.

75% of the buildings, chosen at random across the County had their FFE adjusted up by 1 foot to reach this match.

The FEMA LAS study estimated that 31% of homes in the SFHA would be damaged in a 100-year storm. The Boulder County's City Simulator model was calibrated to this statistic by adjusting the FFEs until the resulting number of damaged structures in Boulder County's City Simulator model run for a 100-year storm event was 31%.

100-year Storm Scenario Results

The following nine pages were extracted from the City Simulator Scenarios Results Report for the 100-year storm event that was used for calibration. They show:

- the scenario parameters,
- key metrics for the run,
- metrics related to equity,
- a map of the buildings that have a rain-to-flood curve either for riverine flooding, pluvial flooding, or both, and
- Three tables that provide statistics for the whole county run – as this was the focus of the LAS study. The tables include:
  - Community = All | Income Class = All
    - All communities including unincorported county and all cities
    - LMI and nonLMI communities
  - Community = All | Income = LMI
    - LMI implies the building is residential and in a census block group with greater than 50% low-to-moderate income households according to the HUD LMI dataset, and with a total value less than $200K per household.
  - Community = All | Income = nonLMI
    - nonLMI implies the building is residential and does not meet the LMI criteria described above.

Note that the LAS study also provided an estimate of dollar damage and benefits resulting from using actions such as freeboard and other more stringent regulations. This study did not attempt to match these dollar figures because the LAS study did not provide a single direct building damage estimate for the whole county; rather the estimates provided in the LAS were for cumulative benefits including items not calculated in this study, such as social anxiety avoided. As the building damage alone could not be parsed from these totals, the percentage of damaged structures was used as the sole calibration parameter.

Scenario Results Report

for Assessment of Boulder

Scenario: 100-year Storm

A report generated by:

city simulator

ATKINS

Scenario Parameters

Name: 1/1/2019

Community of Interest: Unincorporated Boulder County

Start Date: 1/1/2019

End Date: 12/31/2020

Measures

Prevent Building in Floodplain

Map Layer Defining Restricted Area: Floodway

Prevent Building All: True

Prevent Building Critical Facilities: False

Prevent Building At-risk population facilities: False

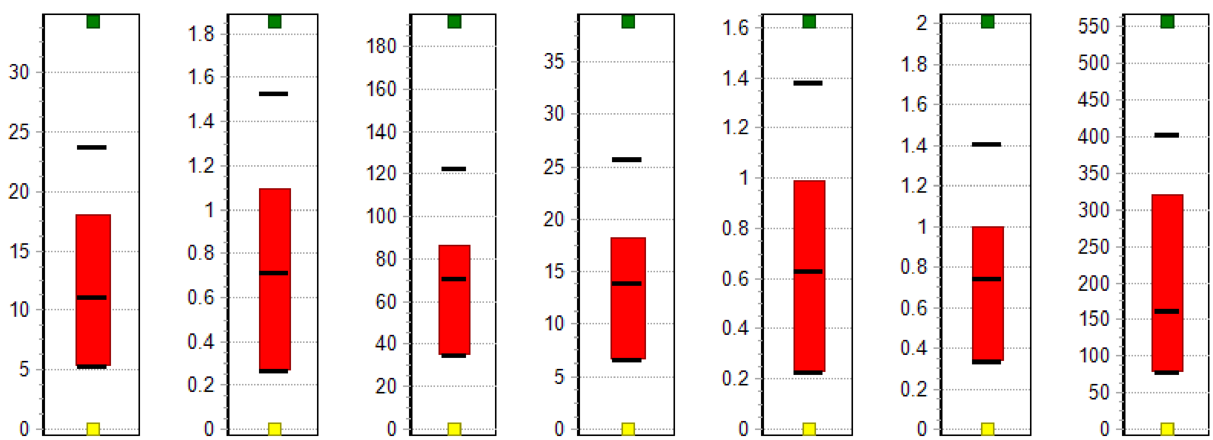
Prevent Building Basements: False

Prevent Building in 500year Fringe: False

Prevent Building in SFHA: False

Key Metrics

Building-Recovery Days	Disrupted Trips	Work Flood	Home Flood	Road Flood	Lost Production	Flood Damage
115 K	18.9 M	841 K	159 K	17.9 M	410 M	573 M



Other Metrics (Unincorporated Boulder County)

Substantially Protected Homes per year	**14**
Substantially Protected Homes in SFHA per year	**14**
Substantially Protected Homes in 500year fringe per year	**0**
Substantially Protected Homes outside 500year floodplain per year	**0**
Total Number of New Buildings Built in SFHA	**55**
Total Number of New Buildings Built in 500-year fringe	**0**
Total Number of new critical or at-risk population facilities built in SFHA	**0**
Total Number of new critical or at-risk population facilities built in 500-year fringe	**0**

Equity Metrics (Unincorporated Boulder County)

SPH_LMI: 0

SPH_NonLMI: 28

Damage_LMI: 0

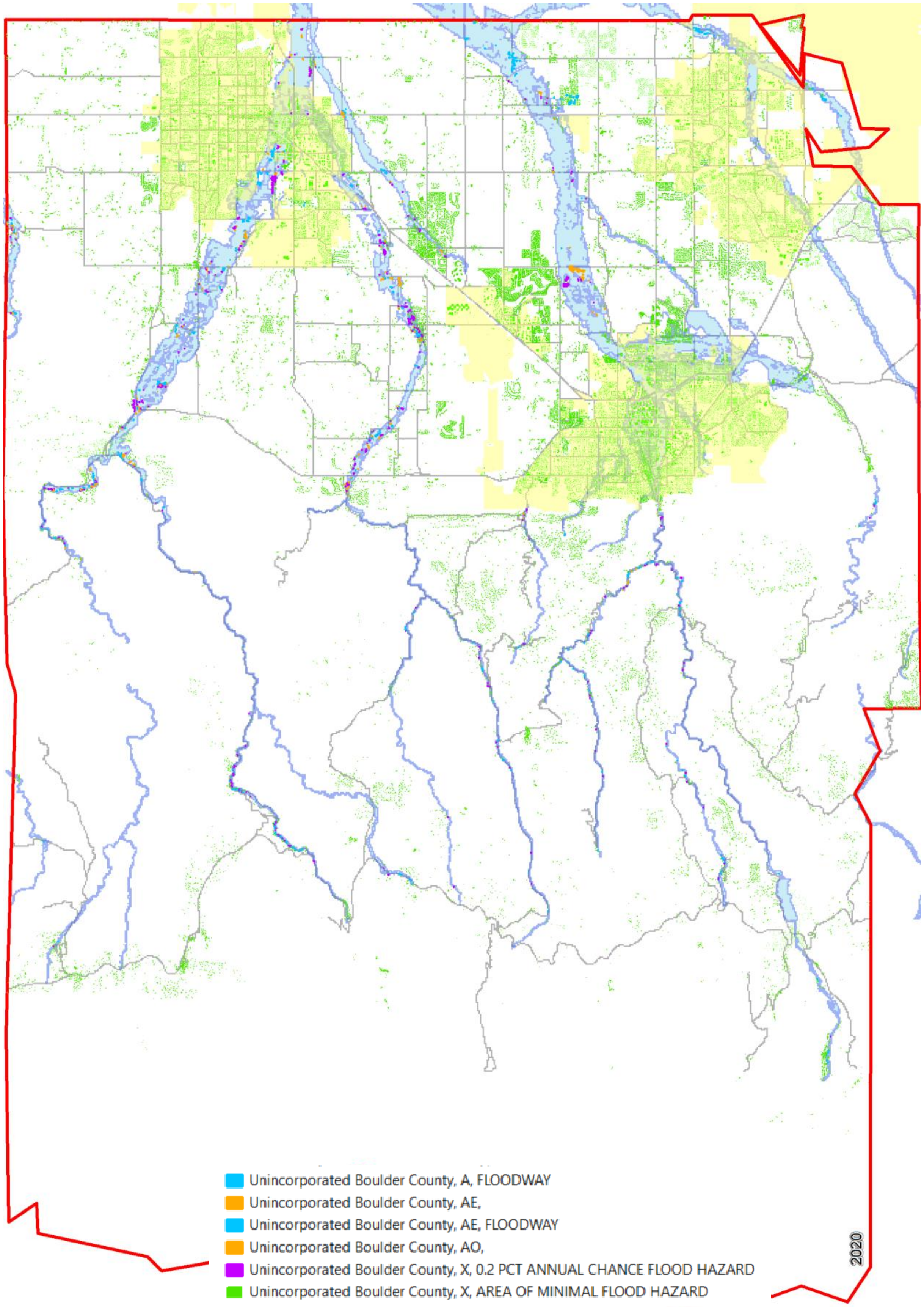
Damage_NonLMI: 146429536

Disasters_LMI: 0

Disasters_NonLMI: 595

ProbFlood_LMI: 0

ProbFlood_NonLMI: 0.00915356450570752


Unincorporated Boulder County, A, FLOODWAY
Unincorporated Boulder County, AE,
Unincorporated Boulder County, AE, FLOODWAY
Unincorporated Boulder County, AO,
Unincorporated Boulder County, X, 0.2 PCT ANNUAL CHANCE FLOOD HAZARD
Unincorporated Boulder County, X, AREA OF MINIMAL FLOOD HAZARD
2020

Community = All| Income Class Category = All

Metric	SFHA	0.2% Annual Chance Fringe	Outside Floodplain	All
All - All				
Num Buildings (Base|New|Total)	4661 | 55 | 4716	2524 | 0 | 2524	122929 | 267 | 123196	130114 | 322 | 130436
Percentage of All Buildings	30.83%	0.75%	0.21%	1.33%
Average Replacement Value [$M]	$1.47	$4.94	$1.62	$1.53
Num Damaged Buildings	1454	19	258	1731
Total Loss [$M]	$493.14	$21.29	$131.83	$646.26
Average Loss [$K]	$263.51	$1,022.19	$375.21	$288.49
Probability of Flooding over2 years	15.42%	0.38%	0.1%	0.66%
Average Max Depth of Flooding [ft]	3.13	1.71	23.26	6.11
Average FFE above Ground [ft]	2.71	2.26	3.48	2.82
Probability of Flooding if Basement	20.3%	0.25%	0.11%	0.48%
Probability of Flooding if No Basement	13.52%	0.44%	0.09%	0.9%
Commercial - All				
Num Buildings (Base|New|Total)	732 | 1 | 733	640 | 0 | 640	8763 | 19 | 8782	10135 | 20 | 10155
Percentage of All Buildings	30.29%	1.09%	0.13%	2.36%
Average Replacement Value [$M]	$5.91	$12.91	$25.33	$7.01
Num Damaged Buildings	222	7	11	240
Total Loss [$M]	$219.73	$19.69	$54.53	$293.96
Average Loss [$K]	$846.18	$2,626.64	$4,323.71	$1,057.49
Probability of Flooding over2 years	15.14%	0.55%	0.06%	1.18%
Average Max Depth of Flooding [ft]	1.41	1.32	468.28	22.8
Average FFE above Ground [ft]	1.59	1.86	1.27	1.58
Probability of Flooding if Basement	0%	0%	0%	0%
Probability of Flooding if No Basement	15.14%	0.55%	0.06%	1.18%
Residential - Single Family Home				
Num Buildings (Base|New|Total)	3381 | 4 | 3385	1658 | 0 | 1658	106000 | 48 | 106048	111039 | 52 | 111091
Percentage of All Buildings	32.38%	0.72%	0.23%	1.21%
Average Replacement Value [$M]	$0.51	$0.29	$0.48	$0.50
Num Damaged Buildings	1096	12	241	1349
Total Loss [$M]	$224.40	$1.60	$66.85	$292.84
Average Loss [$K]	$148.40	$86.26	$177.07	$152.97
Probability of Flooding over2 years	16.19%	0.36%	0.11%	0.61%
Average Max Depth of Flooding [ft]	3.42	1.94	3.41	3.41
Average FFE above Ground [ft]	3.01	2.5	3.55	3.1
Probability of Flooding if Basement	19.6%	0.26%	0.11%	0.46%
Probability of Flooding if No Basement	14.18%	0.45%	0.12%	0.88%
Residential - Multi-Family Home				
Num Buildings (Base|New|Total)	134 | 50 | 184	137 | 0 | 137	2984 | 200 | 3184	3255 | 250 | 3505
Percentage of All Buildings	39.67%	0%	0.19%	2.25%
Average Replacement Value [$M]	$3.62	$0.00	$4.20	$3.66
Num Damaged Buildings	73	0	6	79
Total Loss [$M]	$48.49	$0.00	$10.45	$58.93
Average Loss [$K]	$435.01	$0.00	$1,094.80	$485.12
Probability of Flooding over2 years	19.84%	0%	0.09%	1.13%
Average Max Depth of Flooding [ft]	5.89	0	4.42	5.78
Average FFE above Ground [ft]	0.94	0	4.5	1.21
Probability of Flooding if Basement	34.13%	0%	0.17%	1.55%
Probability of Flooding if No Basement	12.4%	0%	0.03%	0.79%
Residential - Mobile Home				
Num Buildings (Base|New|Total)	414 | 0 | 414	89 | 0 | 89	5182 | 0 | 5182	5685 | 0 | 5685
Percentage of All Buildings	15.22%	0%	0%	1.11%
Average Replacement Value [$M]	$0.04	$0.00	$0.00	$0.04
Num Damaged Buildings	63	0	0	63
Total Loss [$M]	$0.52	$0.00	$0.00	$0.52
Average Loss [$K]	$14.21	$0.00	$0.00	$14.21
Probability of Flooding over2 years	7.61%	0%	0%	0.55%
Average Max Depth of Flooding [ft]	0.92	0	0	0.92
Average FFE above Ground [ft]	3.49	0	0	3.49
Probability of Flooding if Basement	0%	0%	0%	0%
Probability of Flooding if No Basement	7.61%	0%	0%	0.55%
Residential - All				
Num Buildings (Base|New|Total)	3929 | 54 | 3983	1884 | 0 | 1884	114166 | 248 | 114414	119979 | 302 | 120281

Percentage of All Buildings	30.93%	0.64%	0.22%	1.24%
Average Replacement Value [$M]	$0.67	$0.29	$0.57	$0.65
Num Damaged Buildings	1232	12	247	1491
Total Loss [$M]	$273.41	$1.60	$77.29	$352.30
Average Loss [$K]	$158.52	$86.26	$199.36	$164.71
Probability of Flooding over2 years	15.47%	0.32%	0.11%	0.62%
Average Max Depth of Flooding [ft]	3.44	1.94	3.44	3.43
Average FFE above Ground [ft]	2.91	2.5	3.57	3.02
Probability of Flooding if Basement	20.3%	0.25%	0.11%	0.48%
Probability of Flooding if No Basement	13.08%	0.37%	0.1%	0.84%

Community = All| Income Class Category = LMI

Metric	SFHA	0.2% Annual Chance Fringe	Outside Floodplain	All
All - All				
Num Buildings (Base|New|Total)	202 | 0 | 202	21 | 0 | 21	5218 | 0 | 5218	5441 | 0 | 5441
Percentage of All Buildings	30.2%	0%	0.04%	1.16%
Average Replacement Value [$M]	$0.05	$0.00	$0.08	$0.05
Num Damaged Buildings	61	0	2	63
Total Loss [$M]	$0.69	$0.00	$0.08	$0.77
Average Loss [$K]	$16.83	$0.00	$29.20	$17.23
Probability of Flooding over2 years	15.1%	0%	0.02%	0.58%
Average Max Depth of Flooding [ft]	0.98	0	2.14	1.02
Average FFE above Ground [ft]	3.41	0	3	3.4
Probability of Flooding if Basement	50%	0%	0.1%	0.19%
Probability of Flooding if No Basement	14.93%	0%	0.01%	0.62%
Residential - Single Family Home				
Num Buildings (Base|New|Total)	16 | 0 | 16	6 | 0 | 6	1511 | 0 | 1511	1533 | 0 | 1533
Percentage of All Buildings	31.25%	0%	0.13%	0.46%
Average Replacement Value [$M]	$0.14	$0.00	$0.08	$0.13
Num Damaged Buildings	5	0	2	7
Total Loss [$M]	$0.20	$0.00	$0.08	$0.28
Average Loss [$K]	$35.11	$0.00	$29.20	$33.42
Probability of Flooding over2 years	15.62%	0%	0.07%	0.23%
Average Max Depth of Flooding [ft]	1.52	0	2.14	1.7
Average FFE above Ground [ft]	2.4	0	3	2.57
Probability of Flooding if Basement	50%	0%	0.18%	0.35%
Probability of Flooding if No Basement	13.33%	0%	0.04%	0.2%
Residential - Multi-Family Home				
Num Buildings (Base|New|Total)	0 | 0 | 0	3 | 0 | 3	639 | 0 | 639	642 | 0 | 642
Percentage of All Buildings	NaN%	0%	0%	0%
Average Replacement Value [$M]	$0.00	$0.00	$0.00	$0.00
Num Damaged Buildings	0	0	0	0
Total Loss [$M]	$0.00	$0.00	$0.00	$0.00
Average Loss [$K]	$0.00	$0.00	$0.00	$0.00
Probability of Flooding over2 years	0%	0%	0%	0%
Average Max Depth of Flooding [ft]	0	0	0	0
Average FFE above Ground [ft]	0	0	0	0
Probability of Flooding if Basement	0%	0%	0%	0%
Probability of Flooding if No Basement	0%	0%	0%	0%
Residential - Mobile Home				
Num Buildings (Base|New|Total)	186 | 0 | 186	12 | 0 | 12	3068 | 0 | 3068	3266 | 0 | 3266
Percentage of All Buildings	30.11%	0%	0%	1.71%
Average Replacement Value [$M]	$0.04	$0.00	$0.00	$0.04
Num Damaged Buildings	56	0	0	56
Total Loss [$M]	$0.49	$0.00	$0.00	$0.49
Average Loss [$K]	$15.20	$0.00	$0.00	$15.20
Probability of Flooding over2 years	15.05%	0%	0%	0.86%
Average Max Depth of Flooding [ft]	0.93	0	0	0.93
Average FFE above Ground [ft]	3.5	0	0	3.5
Probability of Flooding if Basement	0%	0%	0%	0%
Probability of Flooding if No Basement	15.05%	0%	0%	0.86%
Residential - All				
Num Buildings (Base|New|Total)	202 | 0 | 202	21 | 0 | 21	5218 | 0 | 5218	5441 | 0 | 5441
Percentage of All Buildings	30.2%	0%	0.04%	1.16%
Average Replacement Value [$M]	$0.05	$0.00	$0.08	$0.05
Num Damaged Buildings	61	0	2	63
Total Loss [$M]	$0.69	$0.00	$0.08	$0.77
Average Loss [$K]	$16.83	$0.00	$29.20	$17.23
Probability of Flooding over2 years	15.1%	0%	0.02%	0.58%
Average Max Depth of Flooding [ft]	0.98	0	2.14	1.02
Average FFE above Ground [ft]	3.41	0	3	3.4
Probability of Flooding if Basement	50%	0%	0.1%	0.19%
Probability of Flooding if No Basement	14.93%	0%	0.01%	0.62%

Community = All| Income Class Category = Non LMI

Metric	SFHA	0.2% Annual Chance Fringe	Outside Floodplain	All
All - All				
Num Buildings (Base|New|Total)	4459 | 55 | 4514	2503 | 0 | 2503	117711 | 267 | 117978	124673 | 322 | 124995
Percentage of All Buildings	30.86%	0.76%	0.22%	1.33%
Average Replacement Value [$M]	$1.53	$4.94	$1.63	$1.58
Num Damaged Buildings	1393	19	256	1668
Total Loss [$M]	$492.45	$21.29	$131.75	$645.49
Average Loss [$K]	$274.32	$1,022.19	$377.91	$298.73
Probability of Flooding over2 years	15.43%	0.38%	0.11%	0.67%
Average Max Depth of Flooding [ft]	3.22	1.71	23.42	6.31
Average FFE above Ground [ft]	2.68	2.26	3.48	2.8
Probability of Flooding if Basement	20.27%	0.25%	0.11%	0.48%
Probability of Flooding if No Basement	13.43%	0.44%	0.1%	0.92%
Residential - Single Family Home				
Num Buildings (Base|New|Total)	3365 | 4 | 3369	1652 | 0 | 1652	104489 | 48 | 104537	109506 | 52 | 109558
Percentage of All Buildings	32.38%	0.73%	0.23%	1.22%
Average Replacement Value [$M]	$0.51	$0.29	$0.48	$0.50
Num Damaged Buildings	1091	12	239	1342
Total Loss [$M]	$224.20	$1.60	$66.77	$292.56
Average Loss [$K]	$148.92	$86.26	$178.31	$153.59
Probability of Flooding over2 years	16.19%	0.36%	0.11%	0.61%
Average Max Depth of Flooding [ft]	3.43	1.94	3.43	3.42
Average FFE above Ground [ft]	3.01	2.5	3.56	3.11
Probability of Flooding if Basement	19.58%	0.26%	0.11%	0.46%
Probability of Flooding if No Basement	14.18%	0.45%	0.12%	0.9%
Residential - Multi-Family Home				
Num Buildings (Base|New|Total)	134 | 50 | 184	134 | 0 | 134	2345 | 200 | 2545	2613 | 250 | 2863
Percentage of All Buildings	39.67%	0%	0.24%	2.76%
Average Replacement Value [$M]	$3.62	$0.00	$4.20	$3.66
Num Damaged Buildings	73	0	6	79
Total Loss [$M]	$48.49	$0.00	$10.45	$58.93
Average Loss [$K]	$435.01	$0.00	$1,094.80	$485.12
Probability of Flooding over2 years	19.84%	0%	0.12%	1.38%
Average Max Depth of Flooding [ft]	5.89	0	4.42	5.78
Average FFE above Ground [ft]	0.94	0	4.5	1.21
Probability of Flooding if Basement	34.13%	0%	0.21%	1.82%
Probability of Flooding if No Basement	12.4%	0%	0.04%	1%
Residential - Mobile Home				
Num Buildings (Base|New|Total)	228 | 0 | 228	77 | 0 | 77	2114 | 0 | 2114	2419 | 0 | 2419
Percentage of All Buildings	3.07%	0%	0%	0.29%
Average Replacement Value [$M]	$0.02	$0.00	$0.00	$0.02
Num Damaged Buildings	7	0	0	7
Total Loss [$M]	$0.03	$0.00	$0.00	$0.03
Average Loss [$K]	$6.26	$0.00	$0.00	$6.26
Probability of Flooding over2 years	1.54%	0%	0%	0.14%
Average Max Depth of Flooding [ft]	0.81	0	0	0.81
Average FFE above Ground [ft]	3.43	0	0	3.43
Probability of Flooding if Basement	0%	0%	0%	0%
Probability of Flooding if No Basement	1.54%	0%	0%	0.14%
Residential - All				
Num Buildings (Base|New|Total)	3727 | 54 | 3781	1863 | 0 | 1863	108948 | 248 | 109196	114538 | 302 | 114840
Percentage of All Buildings	30.97%	0.64%	0.22%	1.24%
Average Replacement Value [$M]	$0.70	$0.29	$0.57	$0.67
Num Damaged Buildings	1171	12	245	1428
Total Loss [$M]	$272.71	$1.60	$77.22	$351.53
Average Loss [$K]	$165.90	$86.26	$200.75	$171.21
Probability of Flooding over2 years	15.49%	0.32%	0.11%	0.62%
Average Max Depth of Flooding [ft]	3.57	1.94	3.45	3.53
Average FFE above Ground [ft]	2.89	2.5	3.58	3
Probability of Flooding if Basement	20.27%	0.25%	0.11%	0.48%
Probability of Flooding if No Basement	12.93%	0.38%	0.11%	0.86%

7.2 Calibrating Travel Patterns

In many communities, average annual daily trips (AADT) are available for major roads. These measurements may be taken by the local or county transportation department or the state level department of transportation. City Simulator can estimate AADT based on the distribution of people throughout the community and their use of their commute paths on a daily basis. If flow data is available, this provides an opportunity to make sure the commute paths are realistic compared to base year flow rates. If they are not, then the following model attributes can be altered to bring the travel patterns closer to measured flow rates:

- Distribution of community population can be altered to shift the commute paths' frequency of use
- The commute paths can be altered to reflect preferences for roads with high measured flowrates.

Tool are provided within City Simulator to conduct this calibration process.

Boulder County: AADT was downloaded from CDOTs website which gave flow measurements at 10 locations across the county. These metrics were compared to the estimated base year AADT from City Simulator. On average, the modeled flow rates were found to be within 20% of the measured flowrates, with the model typically underestimating the flow rate. It was assumed the underestimation could be attributed to additional traffic from out-of-county.

As the flow rates were similar in magnitude on average and generally biased in the same direction, the City Simulator virtual population and commute paths were not altered and are used throughout the study to estimate disruption in the wake of floods. Though the disruption may be underestimated, the relative differences in disruption from location to location are reliable for decision-making.

8 Modeling Adaptation and Mitigation Measures

Adding adaption and mitigation measures in City Simulator provides a way to evaluate the benefits a measure or group of measures may bring the community. To add measures, create a new scenario using the scenario builder part of the tool. When you create the scenario, the City Simulator will duplicate the base scenario's geodatabase and rename the copy the name of your new scenario. You can then add one to many measures to your scenario, setting their properties as you go. When you're ready, you can run the scenario and compare the results to the base run either by looking at the scenario comparison screen, or by generating a scenario results report and comparing the resulting document to the results report for the base scenario.

The mitigation and adaption measures available to you are regulatory, general infrastructure improvement, and physical counter measures to climate change.

8.1 Regulatory Measures

Regulatory measures are those that can be applied by the community with the aim of reducing risk of flooding and flood damage. They include:

Prevent Building in Floodplain: this measure allows for preventing building of assets by type and by FEMA flood zone. The types include:

- All
- Critical Facilities (eg. fires stations, hospitals)
- At-risk population facilities (eg. nursing homes)
- Basements (ie. allows for building, but prohibits basements for properties in the selected zone)

The flood zones include:

- FEMA SFHA
- FEMA 0.2% annual chance flood fringe (ie. the portion of land that is 0.2% annual chance flood prone but not in the SFHA).

An additional function allows you to add a polygon map layer and prevent all building within the area of the map. This useful if you want to prevent building in the regulatory floodway.

When this measure is used, it is applied only to new building being proposed for development in the community. Existing buildings are not subject to these requirements.

Boulder County: The actions tested using the prevent building in floodplain measure were:

1. Prevent All Building in the SFHA
2. Prevent All Building in the SFHA + 0.2% annual change fringe
3. Prevent Critical and At-risk population Facilities in the SFHA
4. Prevent Critical and At-risk population Facilities in the SFHA + 0.2% annual change fringe

Freeboard: this measure allows you to require freeboard (height of FFE above base flood elevation (BFE) or above ground in places outside the floodplain). The parameters to be selected include:

- Freeboard level (can range from 0 to 5 feet with increments of 0.5 feet).
- Asset type: new buildings, major renovations, at-risk population facilities. Any combinations of these can be selected. If major renovations is selected, then if the renovation is a substantial improvement (cost is over 50% of the value of the structure), then the freeboard regulation is required. At-risk means critical facilities AND at-risk population facilities (see the prevent building in floodplain measure above).
- NFIP Zone: SFHA, 0.2% annual chance fringe, Outside 0.2% annual chance floodplain. Any combination of these can be selected.

Boulder County: The actions tested using the freeboard measure were:

1. Require 2' of freeboard above BFE when substantial improvements are made in the SFHA + 0.2% annual chance fringe
2. Require 2' of freeboard (FFE) above ground when substantial improvements are made outside the 0.2% annual change floodplain.

Remove Basements: this measure requires substantially improved homes (cost is over 50% of the value of the value of the structure) to remove basements should they have them. It applies only to existing buildings. The parameter that must be selected is the NFIP zone in which to apply the measure as listed below. Any combination of these can be selected.

- FEMA SFHA
- FEMA 0.2% annual chance flood fringe (ie. the portion of land that is 0.2% annual chance flood prone but not in the SFHA).
- Outside 0.2% annual chance floodplain.

The City Simulator by default assumes that 1% of homes do a substantial improvement project per year. If a remove basements regulation is in place, then this percentage increases in proportion to the discount provided up a maximum of 2% of homes if a 100% discount is provided on permit fees.

Boulder County: The actions tested using the remove basements measure were:

1. Require removal of basements when substantial improvements are made in the SFHA.
2. Require removal of basements when substantial improvements are made in the SFHA + 500-year fringe

Incentivize Voluntary Flood Protection: this measure incentivizes voluntary flood protection projects. As mentioned in the remove basements measure above, the default model specifies that 1% of homes do a substantial improvement project per year that results in flood protection for the home. It is assumed that the level of protection provided results in the home being substantially protected from flood; that is, the home will withstand up to the 100-year storm should a flood occur.

Note that the details of what is done to the home are not specified with this measure, only that the home has been substantially protected. Example of protection measures can include wet- and dry flood-proofing, elevating structures, and relocating utility equipment to attics.

The parameters that must be selected are the discount level and the NFIP zone in which to apply the measure. The discount level can range from zero to 100%. The zones are listed below. Any combination of these can be selected.

- SFHA
- 0.2% annual chance flood fringe (ie. the portion of land that is 0.2% annual chance flood prone but not in the SFHA).
- Outside 0.2% annual chance floodplain.

8.2 General Infrastructure Improvement Measures

General infrastructure improvement measures are those that are not specifically meant to counter-act climate change influence risk (e.g. building sea walls or acquiring homes) but that improve the robustness of the community in all situations.

Improve Culverts/Bridges: this measure instructs the City Simulator to raise and enlarge culverts, bridges, and sections of frequently flooding road so that they will withstand a storm of specified size. The sizes available for selections are the 2, 5, 10, 25, 50, 100, and 500-year rain storm.

The measure allows you to upload a list of city simulator stormwater node IDs. In the base scenario run, the City Simulator presents the top disrupting culverts, bridges, and low road segments. You can copy this list from the base scenario, select any set of assets from just the most disruptive to all that cause disruption.

When the City Simulator runs, it estimates the cost of improvement of each asset, if one is not provided. The cost model used was developed by CalTRANS, and is dependent on the square footage of the bridge deck or road section above the culvert. For low roads, the cost model is dependent on the number of lanes of road and the length of road to be elevated.

The measure also requires a payment approach, to allow for testing the timing of improvements and its impact on damages and disruption. The three options include:

- Conducting all improvements in the first year
- Conducting improvements annually with an annual spending target
- Conducting improvements only when assets are damaged from flooding.

Boulder County

The costs for improving each of 10 highly disruptive structures in Boulder County were estimated in detail by Benesch, Inc. The remaining structure's cost estimates were completed by measuring the structures deck area through measuring on a GIS base map and using the CalTrans method. Benesch also provide a cost model for elevating frequently flooding road segments. The number of lanes and lengths of road that needed elevating were evaluated using GIS to measure and the cost model was used to estimate costs for each segment.

The actions tested using the improve culvert/bridge measure were:

1. Improve All Culverts, Bridges, and frequently flooded roads that cause any disruption in the base scenario; Improve up to the 50-year storm protection level; complete all projects in the first year.

2. Improve All Culverts, Bridges, and frequently flooded roads that cause any disruption in the base scenario; Improve up to the 50-year storm protection level; complete all projects in the first year.

3. Improve All Culverts, Bridges, and frequently flooded roads that cause any disruption in the base scenario; Improve up to the 50-year storm protection level; complete all projects over the time line with a target $5M per year investment; work from most disruptive to least over the time line. Allow the investment to be larger if a single project requires more than the target.

4. Improve All Culverts, Bridges, and frequently flooded roads that cause any disruption in the base scenario; Improve up to the 100-year storm protection level; complete all projects over the time line with a target $5M per year investment; work from most disruptive to least over the time line. Allow the investment to be larger if a single project requires more than the target.

5. Improve All Culverts, Bridges, and frequently flooded roads that cause any disruption in the base scenario; Improve up to the 50-year storm protection level; complete all projects only in post disaster, with a target spending cap of $80M per storm. Work from most disruptive to least.

6. Improve All Culverts, Bridges, and frequently flooded roads that cause any disruption in the base scenario; Improve up to the 100-year storm protection level; complete all projects only in post disaster, with a target spending cap of $80M per storm. Work from most disruptive to least.

8.3 Physical Counter Measures to Climate Change

Physical Counter Measures to Climate Change include those that are specifically added to the community to combat impacts of sea level rise, larger storms, droughts, and so on. They include:

Acquire Buildings and Remove: this measure instructs City Simulator to acquire and raze buildings, preventing future development in the parcels in which they lie. The tool can either use a list of building IDs as the target structures to purchase or can constrain buyout to buildings in specified NFIP zones.

Much like the culvert improvement measure described above, you can extract a list of problem homes from the base scenario run, and them import these as the target homes when creating the measure.

You can alternatively specify SFHA and/or 0.2% annual change fringe as the target zone. If you use the zone method, the homes are purchased in order of likelihood of flooding, as determined by their rain-to-flood curves.

The measure estimates the cost of buyout using the total value attribute for each building, which is loaded as an attribute during base year loading and is assigned to new buildings depending on their type and subtype.

The measure allows for buyout schedule, ranging from buying all target properties

Boulder County: The actions tested using the incentivize property owner implemented flood protection measures were:

1. Buyout annually SFHA: Homes in the SFHA only are purchased three per year.

2. Buyout annually SFHA + 0.2% annual chance fringe: Homes in the SFHA + the 0.2% annual chance fringe are purchased three per year.

3. Buyout post-disaster SFHA: Homes in the SFHA only are purchased only after disasters with a $20M cap.

4. Buyout post-disaster SFHA + 0.2% annual chance fringe: Homes in the SFHA + 0.2% annual change fringe are purchased only after disasters with a $20M cap.

Appendix 4. High Value Road, Bridge, and Culvert Improvements

High Value Road, Bridge, and Culvert Improvements

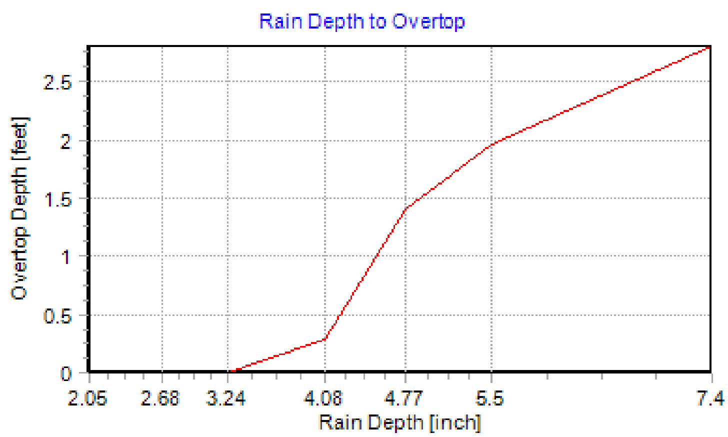
This appendix includes two sections. The first section details the top 10 most critical infrastructure needs. The second section lists roads, bridges, and culverts that are likely to be overtopped or damaged during modeled storm events. The most critical assets (those that support the greatest number of vehicle trips and those that are in areas with fewer/no options for alternative routes) are included in improvement scenarios highlighted in the Study.

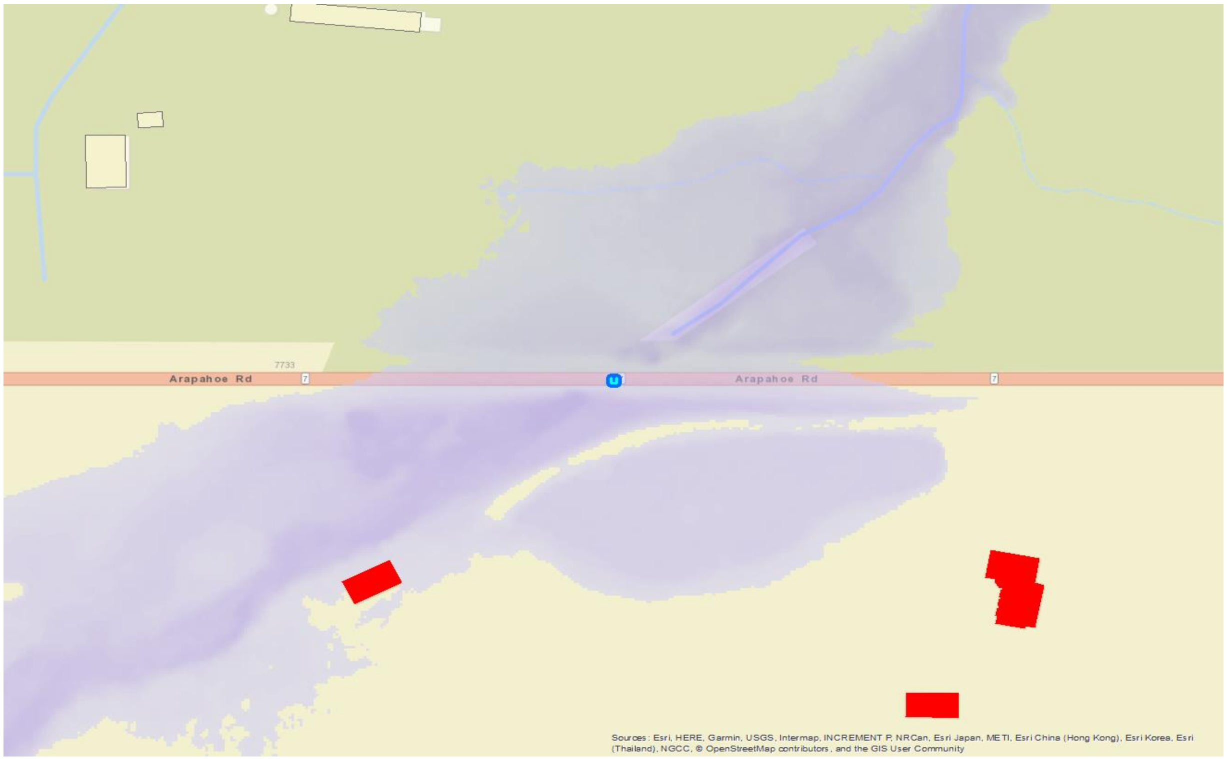
Four structures were identified outside of the original dataset and were not modeled within this analysis. These include three structures along East County Line Road that are half-owned by Weld County and two structures on 120th Street that are owned by the City of Lafayette. Several of these have the potential to be included in future top ten lists and will be included in future resiliency modeling efforts 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).

1. Top Ten Most Disruptive Infrastructure

#1 Infrastructure Improvement: Highway 7/Arapahoe Road at Dry Creek #3

- Road Name: Arapahoe Rd.
- BoCo ID: D-16-BW
- Class: Major Structure
- Simulator Node ID: 3798
- Avg. Ann. Trips Disrupted: 148,039



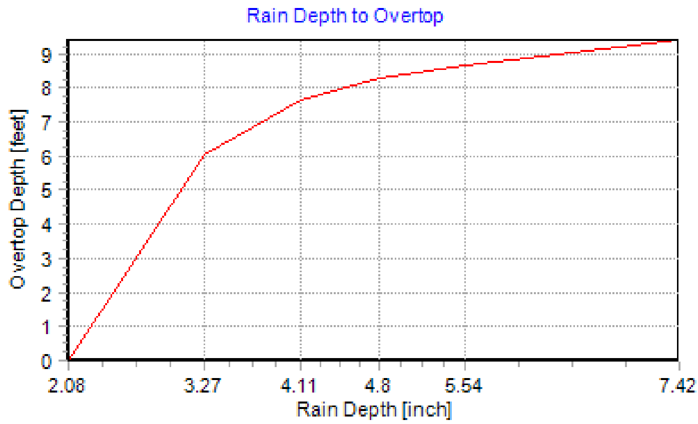


Map shows start year (2019) 500-year floodplain.

#2 Infrastructure Improvement: Kenosha Road at Boulder Creek

114K

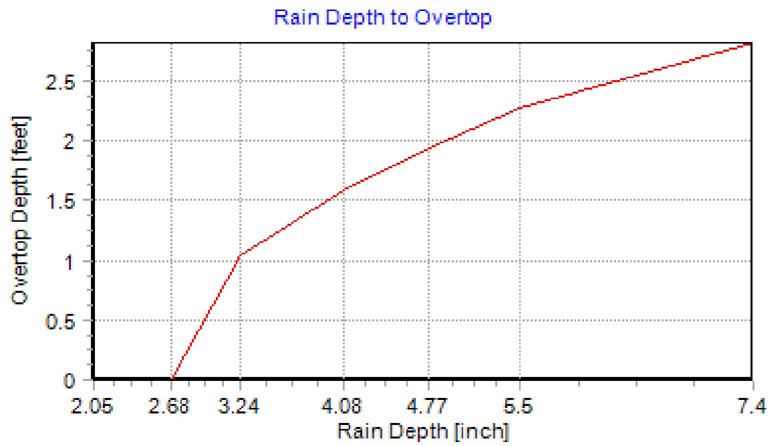
Average Annual Trips Disrupted



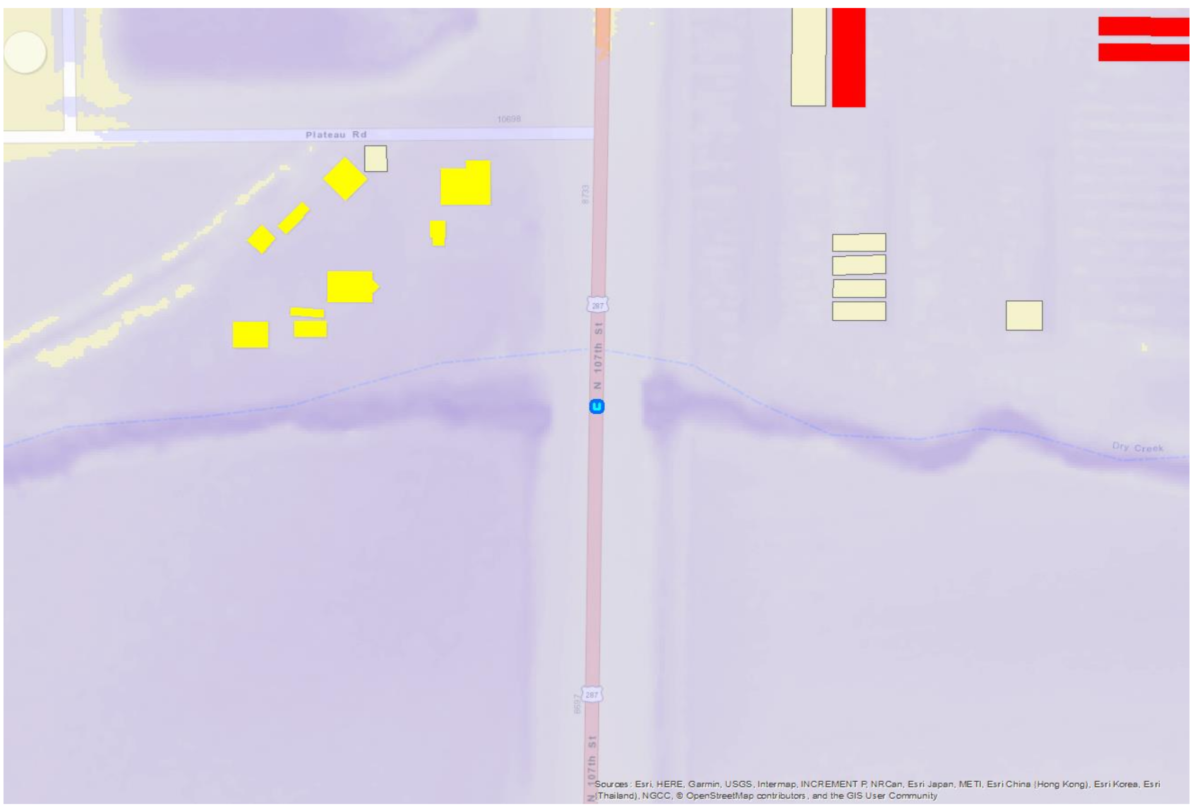
- Road Name: KENOSHA RD
- BoCo ID: BC-38-6.7-BO
- Class: Major Structure
- Simulator Node ID: 3848
- Avg. Ann. Trips Disrupted: 114,112

Map shows start year (2019) 500-year floodplain.

#3 Infrastructure Improvement: US 287 at Dry Creek 2 (CDOT)



- Road Name: N 107th St
- BoCo ID: BC-38-6.7-BO
- Class: Major Structure
- Simulator Node ID: 3795
- Avg. Ann. Trips Disrupted: 113,100

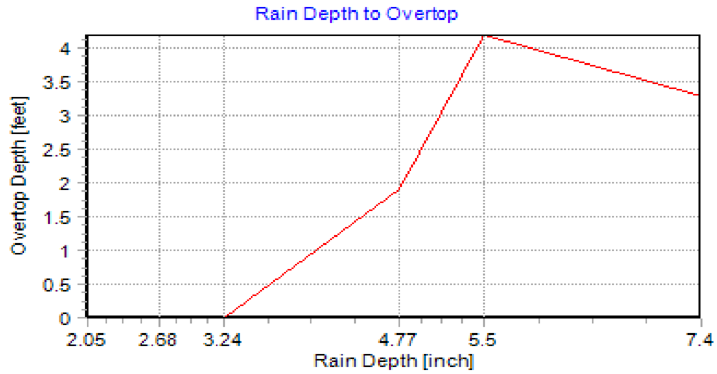


Map shows start year (2019) 500-year floodplain.

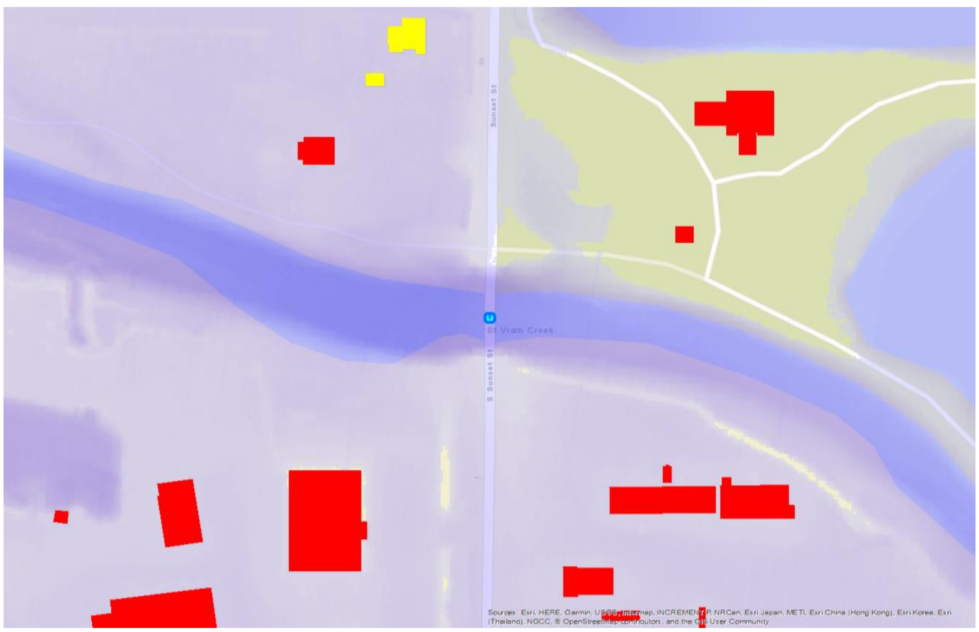
#4 Infrastructure Improvement: South Sunset Street at St. Vrain Creek

101K

Average Annual Trips Disrupted



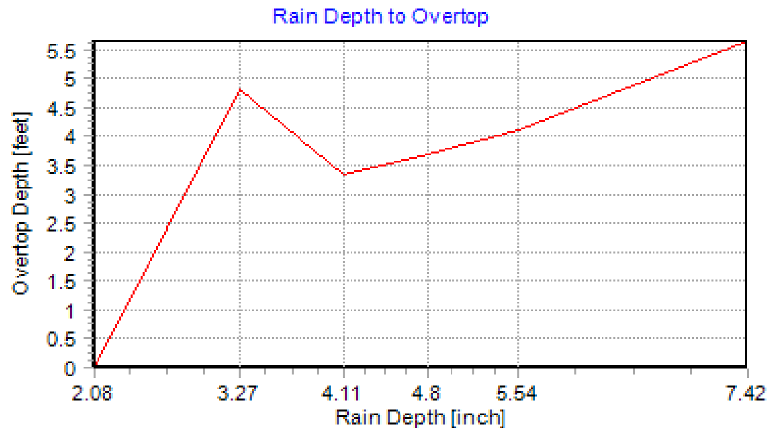
- Road Name: S. SUNSET ST
- BoCo ID: BC-15-1.2-SV
- Class: Major Structure
- Simulator Node ID: 3751
- Avg. Ann. Trips Disrupted: 101,534



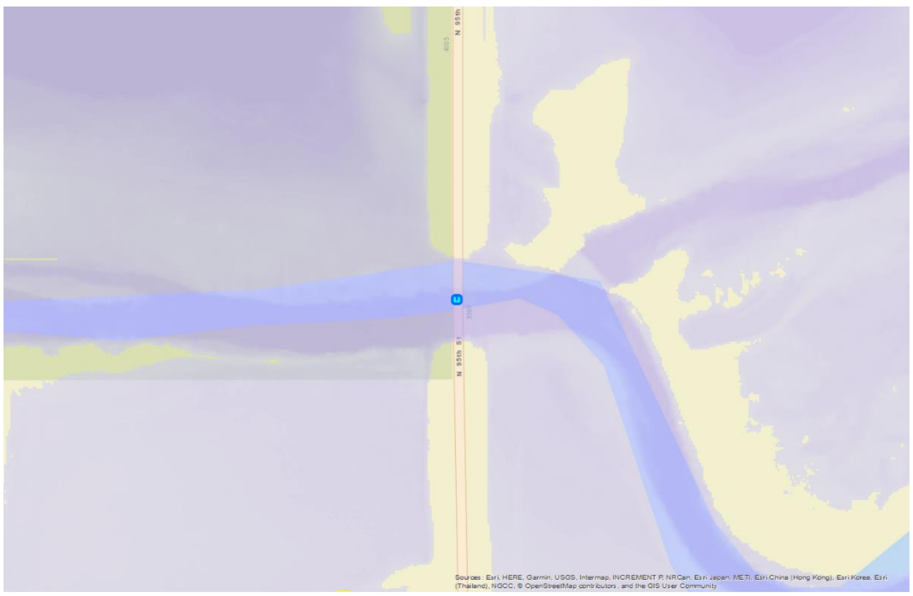
#5 Infrastructure Improvement: North 95th St at Boulder Creek

92K

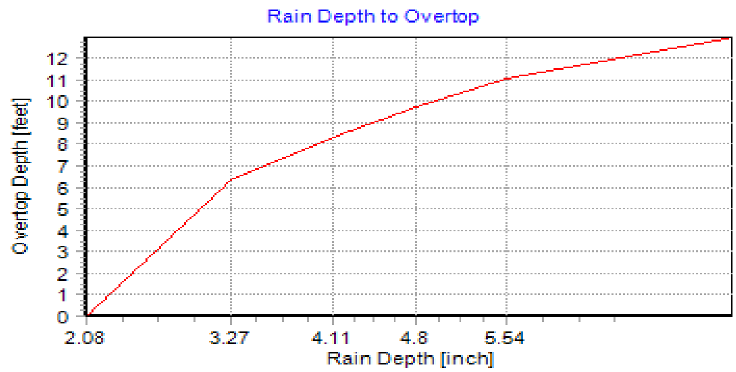
Average Annual Trips Disrupted



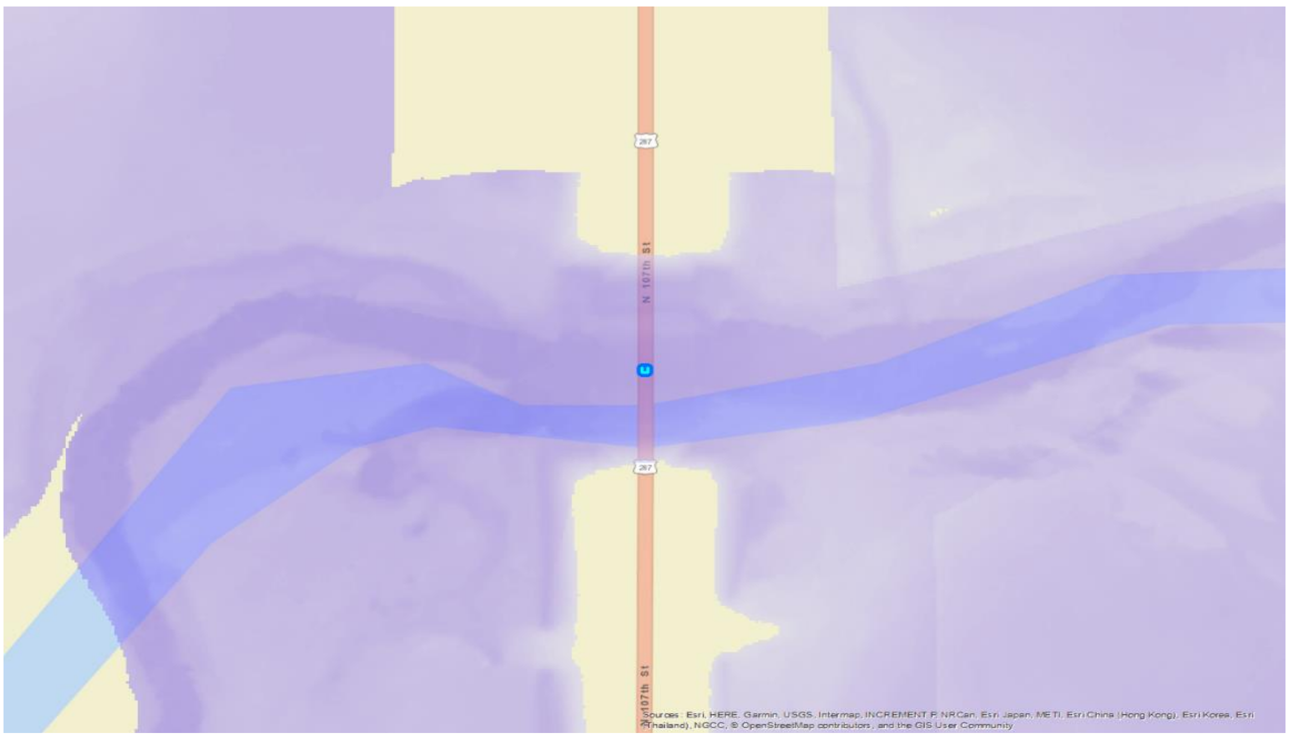
- Road Name: 95TH ST
- BoCo ID: BC-19-15.0-BO
- Class: Major Structure
- Simulator Node ID: 3845
- Avg. Ann. Trips Disrupted: 92,140



#6 Infrastructure Improvement: U.S. 287 at Boulder Creek (CDOT)



- Road Name: N 107th St.
- BoCo ID: CDOT_BC_287
- Class: Major Structure
- Simulator Node ID: 3846
- Avg. Ann. Trips Disrupted: 66,051



Map shows start year (2019) 500-year floodplain.

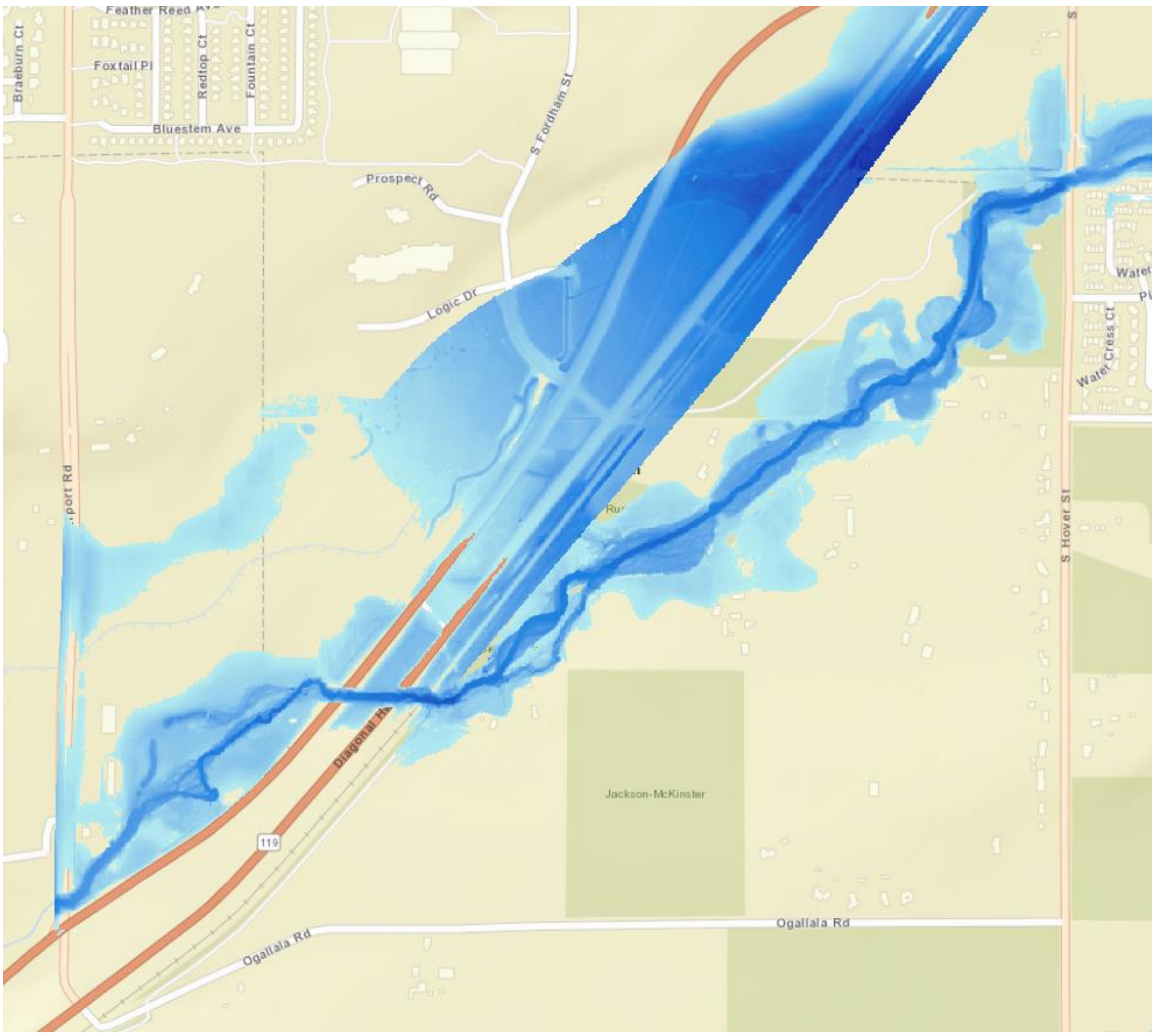
#7 Infrastructure Improvement: Asset ID: Diagonal Highway at Left Hand Creek

Diagonal Highway at Left Hand Creek

58,000 Average Annual Trips Disrupted

58K

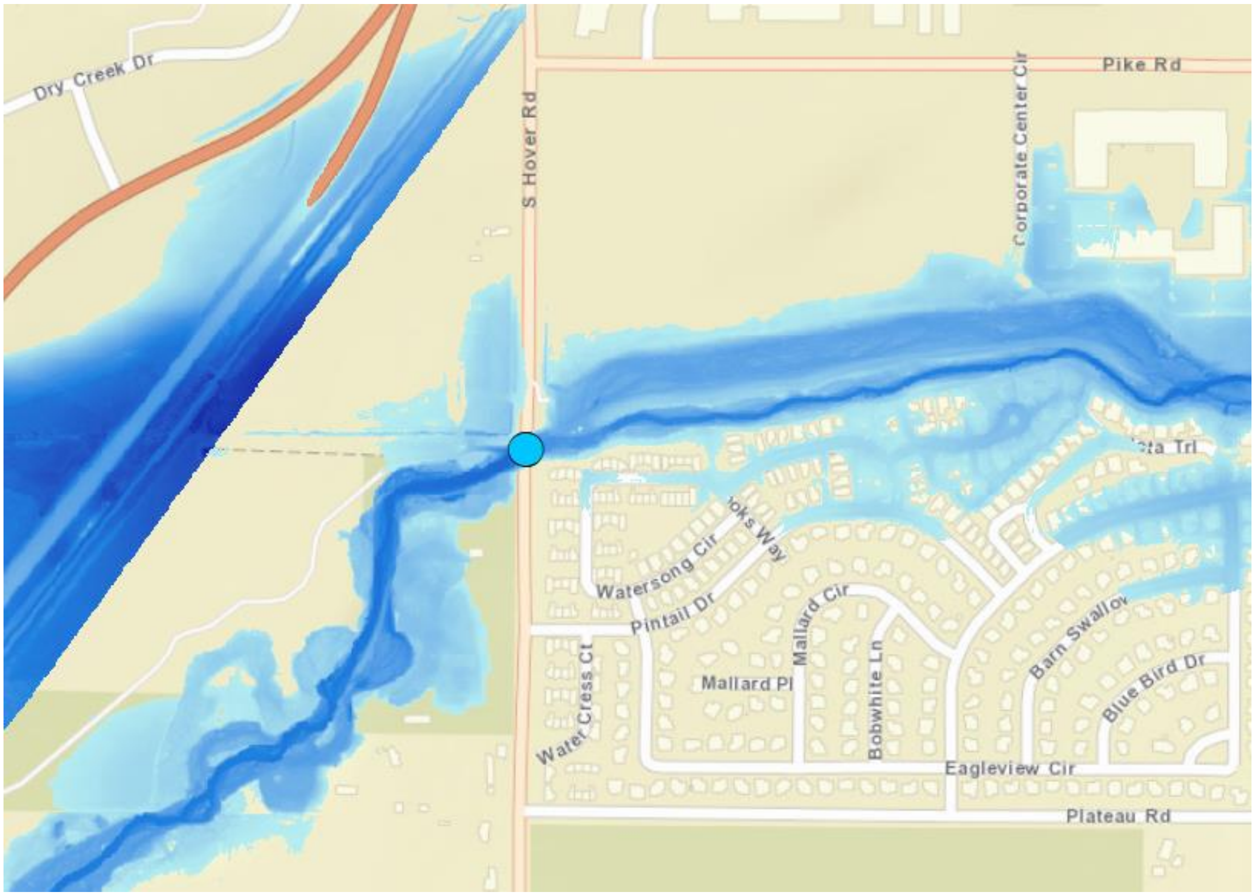
Average Annual Trips Disrupted



#8 Infrastructure Improvement: 3937: 95th Street / S. Hover Road at Lefthand Creek (Longmont)

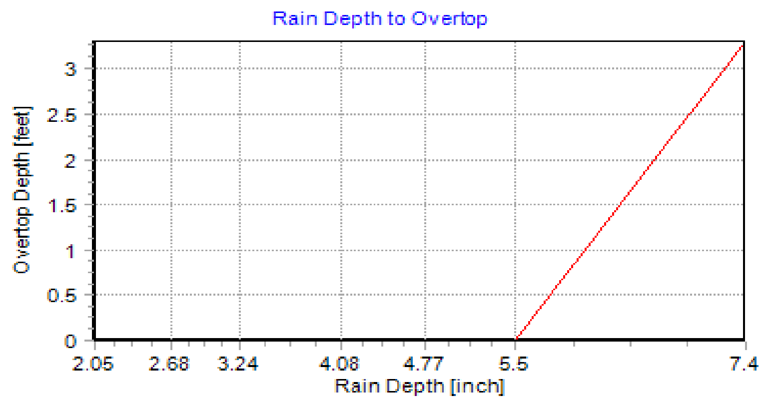
58K

Average Annual Trips Disrupted

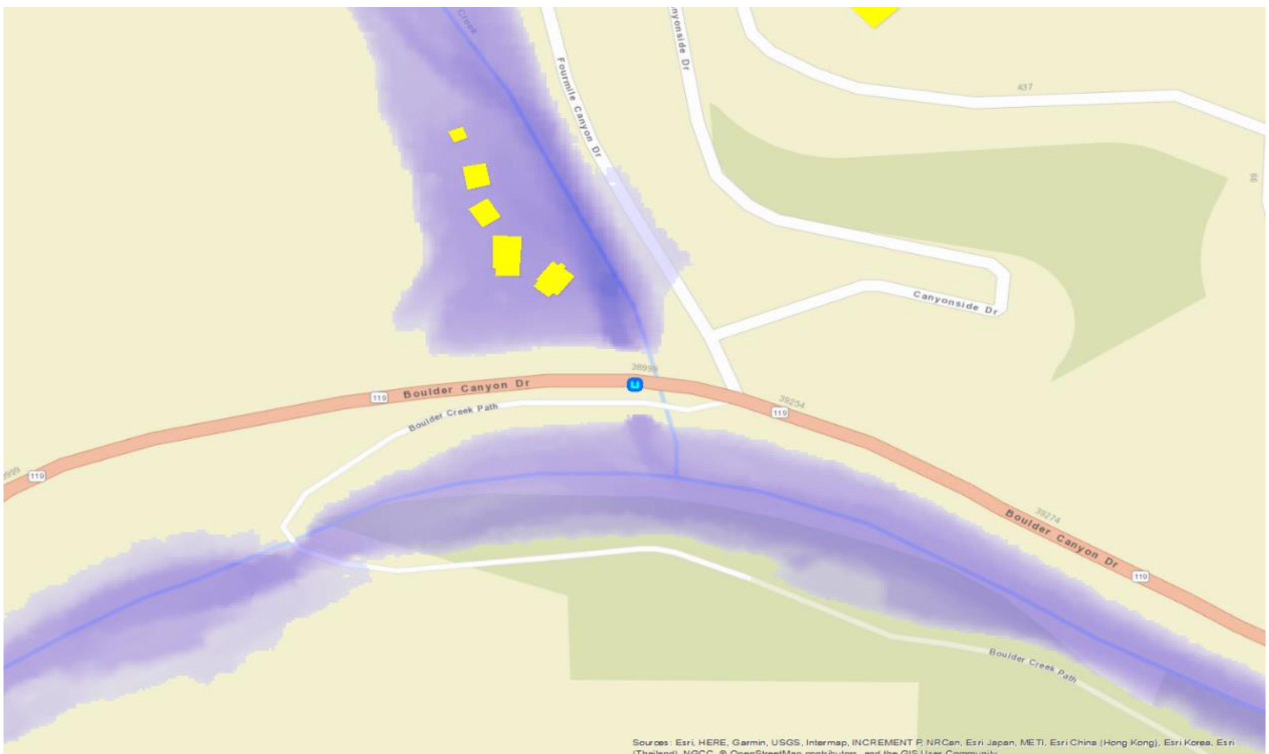

Dry Creek Dr
S Hover Rd
Pike Rd
Corporate Center Cir
Watersong Cir
Pintail Dr
Mallard Cir
Mallard Pl
Bobwhite Ln
Water Cress Ct
Barn Swallow
Blue Bird Dr
Eagleview Cir
Plateau Rd

#9 Infrastructure Improvement: Hwy 119/Boulder Canyon at Four Mile Creek (CDOT)

55K
Average Annual Trips Disrupted



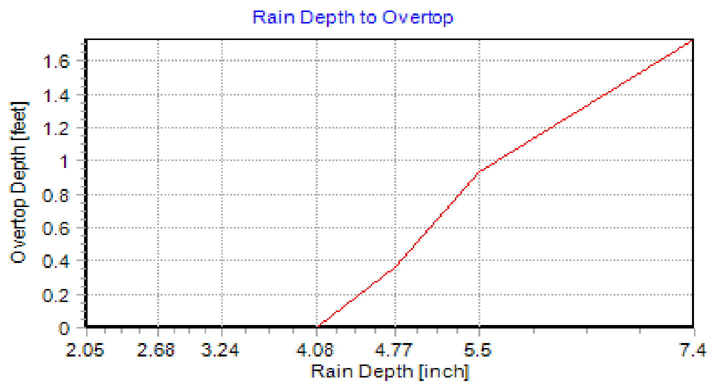
- Road Name: Boulder Canyon Dr
- BoCo ID: CDOT_FouC_119
- Class: Major Structure
- Simulator Node ID: 3805
- Avg. Ann. Trips Disrupted: 55,289



Map shows start year (2019) 500-year floodplain.

#10 Infrastructure Improvement: Niwot Road at Dry Creek No. 2

49K
Average Annual Trips



- Road Name: NIWOT RD
- BoCo ID: BC-34-6.6-DR2
- Class: Major Structure
- Simulator Node ID: 3729
- Avg. Ann. Trips Disrupted: 266

Map shows start year (2019) 500-year floodplain.

2. Disrupted Road, Bridge, and Culvert Infrastructure

City Sim ID	Asset ID	Asset Type	Road Name	Crossing	Owner	Average Annual Trips Disrupted	Remote-ness Index	Max duration of replacement / refurbishment due to event (days)	Number of overtopping events	Number of trips not taken due to disruption	Number of trips delayed due to disruption	Lost production due to disruption	Work missed due to disruption (hrs)	Max Overtopping Depth (in.)	Overtopping at 10-year storm (in.)	Overtopping at 25-year storm (in.)	Overtopping at 100-year storm (in.)	Overtopping at 500-year storm (in.)
3798	D-16-BW	Major Structure	SH 7	Dry Creek 3	CDOT	148,039	7	365	2	-	12,908	$133,032,842	4,642,491	3.56		0.28	1.96	2.81
3848	BC-38-6.7-BO	Major Structure	KENOSHA RD	Boulder Creek	Boulder County	114,112	8	365	2	-	5,100	$113,411,536	4,089,792	7.65	6.03	7.65	8.68	9.40
3795	D-16-DN	Major Structure	US 287	Dry Creek 2	CDOT	113,100	5	365	2	-	5,828	$67,339,376	2,533,432	3.31	1.04	1.59	2.27	2.82
3751	BC-15-1.2-SV	Major Structure	SUNSET ST	Saint Vrain Creek	Boulder County	101,534	0	365	2	-	5,232	$0	-	2.50			4.20	3.30
3845	BC-19-15.0-BO	Major Structure	N 95TH ST	Boulder Creek	Boulder County	92,140	8	365	2	-	4,118	$92,156,647	3,302,307	4.00	4.80	3.34	4.11	5.65
3846	CDOT_BC_287	Major Structure	US 287	Boulder Creek	CDOT	66,051	8	365	2	-	2,952	$64,261,859	2,367,268	8.33	6.33	8.33	11.04	12.98
3864	ROAD_3864	Road	SH 119 (DIAGONAL HWY)	Left Hand Creek	CDOT	58,222	4	30	2	-	31,052	$29,721,216	1,043,347	7.12	4.76	7.12	9.94	12.11
3937	ROAD_3937	Road	SH 119 (DIAGONAL HWY)	Left Hand Creek	CDOT	57,716	4	30	2	-	30,782	$29,467,704	1,034,275	4.00	1.00	3.35	6.21	8.58
3805	CDOT_FouC_119	Major Structure	SH 119 (BOULDER CANYON DR)	Fourmile Creek	CDOT	55,289	7	365	1	-	4,834	$49,727,396	1,733,859	4.00				3.31
3729	BC-34-6.6-DR2	Major Structure	NIWOT RD	Dry Creek 2	Boulder County	48,792	7	365	1	-	4,266	$43,389,520	1,530,129	2.44			0.93	1.73
3779	BC-33-1.2-LT	Major Structure	N 73RD ST	Left Hand Creek	Boulder County	43,774	6	270	1	-	5,188	$33,488,153	1,176,638	1.93			0.01	1.03
3785	BC-31-3.9-SV	Major Structure	N 75TH ST	Saint Vrain Creek	Boulder County	35,525	7	365	1	-	3,106	$32,966,279	1,114,060	4.00			2.33	4.30
3939	ROAD_3939	Road	PRATT PKWY	Saint Vrain Creek	City of Longmont	32,486	1	30	2	-	17,326	$4,138,386	145,538	11.05	8.88	11.05	13.88	16.31
3781	BC-132-0.1-BO	Major Structure	MAGNOLIA DR	Boulder Creek	Boulder County	31,888	9	365	1	2,788	2,788	$28,703,070,357	5,367,346	4.00			1.72	6.24
3800	D-15-X	Major Structure	US 36	Left Hand Creek	CDOT	24,347	9	365	2	2,100	2,100	$21,225,650,664	4,098,066	4.00		0.72	2.91	3.93
3886	ROAD_3886	Road	HOVER ST	Saint Vrain Creek	City of Longmont	20,891	1	30	2	-	11,142	$2,646,588	93,593	5.68	3.96	5.68	9.25	9.54
3776	BC-31-8.6-LT	Major Structure	N 81ST ST	Left Hand Creek	Boulder County	20,542	6	365	1	-	1,796	$13,953,164	552,162	4.00			2.91	3.90
3755	BC-81-5.4-JA	Major Structure	LEFTHAND CANYON DR	James Creek	Boulder County	19,306	8	365	1	-	1,688	$21,590,486	691,945	4.00			2.17	4.05

City Sim ID	Asset ID	Asset Type	Road Name	Crossing	Owner	Average Annual Trips Disrupted	Remote-ness Index	Max duration of replacement / refurbishment due to event (days)	Number of overtopping events	Number of trips not taken due to disruption	Number of trips delayed due to disruption	Lost production due to disruption	Work missed due to disruption (hrs)	Max Overtopping Depth (in.)	Overtopping at 10-year storm (in.)	Overtopping at 25-year storm (in.)	Overtopping at 100-year storm (in.)	Overtopping at 500-year storm (in.)
3849	CDOT_BC_52	Major Structure	SH 52	Boulder Creek	CDOT	16,200	9	365	2	724	724	$13,388,147,838	2,726,700	9.18	7.34	9.18	12.53	13.70
3809	BC-124E-0.1-NB	Major Structure	COLD SPRING RD	North Boulder Creek	Boulder County	14,438	8	365	2	-	744	$14,292,936	517,467	4.00	0.71	1.86	4.18	6.93
3733	BC-572705-0.27-DR2	Major Structure	NIWOT MEADOW FARM RD	Dry Creek 2	Boulder County	13,771	7	365	1	-	1,204	$12,005,020	431,851	4.00			1.79	6.01
3802	D-15-I	Major Structure	US 36	Saint Vrain Creek	CDOT	13,702	9	365	1	1,198	1,198	$11,657,129,499	2,306,342	4.00			3.95	6.04
3924	ROAD_3924	Road	SH 7 (ARAPAHOE RD)	Dry Creek 3	CDOT	12,101	7	30	1	-	12,908	$10,874,619	379,495	2.19			0.65	1.47
3768	BC-005602-1.2B	Minor Structure	BASELINE RD	Dry Creek 3	Boulder County	10,800	6	30	2	-	5,760	$8,280,468	290,304	4.00		3.08	3.42	3.83
3888	ROAD_3888	Road	HOVER ST	Saint Vrain Creek	City of Longmont	10,584	1	30	1	-	11,290	$1,336,629	47,418	4.00			0.19	2.23
3882	ROAD_3882	Road	S HOVER ST	Saint Vrain Creek	City of Longmont	10,058	1	30	2	-	10,382	$1,276,372	45,058	2.59		0.10	0.05	1.40
3927	ROAD_3927	Road	LEE HILL DR	Fourmile Canyon Creek	Boulder County	9,709	6	30	1	-	10,356	$7,615,944	260,971	1.63				0.87
3734	BC-36-2.8-DR2	Major Structure	MONARCH RD	Dry Creek 2	Boulder County	9,666	6	365	2	-	432	$7,845,785	259,822	4.00	1.64	2.62	3.78	5.01
3740	34379	Culvert	GOLD RUN RD	Gold Run	Boulder County	9,626	8	30	2	-	5,134	$9,993,312	345,005	4.00	2.50	3.27	4.17	4.36
3741	34380	Culvert	GOLD RUN RD	Gold Run	Boulder County	9,626	8	30	2	-	5,134	$9,993,312	345,005	4.00	1.67	2.23	3.08	4.05
3742	34382	Culvert	GOLD RUN RD	Gold Run	Boulder County	9,626	8	30	2	-	5,134	$9,993,312	345,005	4.00	1.61	2.27	3.14	3.92
3743	BC-008901-3.1	Minor Structure	GOLD RUN RD	Gold Run	Boulder County	9,626	8	30	2	-	5,134	$9,993,312	345,005	3.84	1.37	1.83	2.46	3.19
3745	BC-008901-3.6	Minor Structure	GOLD RUN RD	Gold Run	Boulder County	9,626	8	30	2	-	5,134	$9,993,312	345,005	4.00	1.30	2.23	3.24	3.84
3730	BC-008901-3.8	Minor Structure	GOLD RUN RD	Gold Run	Boulder County	9,626	8	30	2	-	5,134	$9,993,312	345,005	3.27	0.38	1.41	1.86	2.61
3973	ROAD_3973	Road	GOLD RUN RD	Gold Run	Boulder County	9,626	8	30	2	-	5,134	$9,993,312	345,005	4.00	1.17	1.78	2.50	3.52
3884	ROAD_3884	Road	US 287	Saint Vrain Creek	CDOT	9,105	1	30	2	-	4,856	$1,095,024	40,790	11.25	9.25	11.25	14.68	14.99
3978	ROAD_3978	Road	FOURMILE CANYON DR	Fourmile Creek	Boulder County	9,064	8	30	2	-	4,834	$9,316,608	324,845	4.00		1.57	5.75	8.84

City Sim ID	Asset ID	Asset Type	Road Name	Crossing	Owner	Average Annual Trips Disrupted	Remote-ness Index	Max duration of replacement / refurbishment due to event (days)	Number of overtopping events	Number of trips not taken due to disruption	Number of trips delayed due to disruption	Lost production due to disruption	Work missed due to disruption (hrs)	Max Overtopping Depth (in.)	Overtopping at 10-year storm (in.)	Overtopping at 25-year storm (in.)	Overtopping at 100-year storm (in.)	Overtopping at 500-year storm (in.)
3769	BC-10-3.1-SV	Major Structure	HYGIENE RD	Saint Vrain Creek	Boulder County	7,845	9	365	2	684	684	$7,318,014,094	1,320,407	4.00		0.26	3.45	6.61
3926	ROAD_3926	Road	N 95TH ST	Boulder Creek	Boulder County	7,721	8	30	2	-	4,118	$7,722,624	276,730	4.00	5.38	3.90	4.65	5.70
3762	BC-010614-1.9	Minor Structure	LEFTHAND CANYON DR	Left Hand Creek	Boulder County	7,590	9	30	1	8,096	8,096	$7,057,080,732	1,277,549	1.02				0.54
3758	BC-106-7.3-LT	Minor Structure	LEFTHAND CANYON DR	Left Hand Creek / Glendale Gulch	Boulder County	7,590	9	30	1	8,096	8,096	$7,057,080,732	1,277,549	4.00			1.54	3.98
3946	ROAD_3946	Road	AIRPORT RD	Saint Vrain Creek	City of Longmont	6,904	4	30	2	-	3,682	$3,591,168	123,715	6.11	3.97	6.11	8.26	11.84
3847	BC-9-0.9-BO	Major Structure	N 109TH	Boulder Creek	Boulder County	6,519	7	365	1	-	570	$5,801,649	204,448	2.03			0.55	1.34
3866	ROAD_3866	Road	N 95TH ST	Left Hand Creek	Boulder County / City of Longmont	6,405	4	30	2	-	3,416	$3,179,400	114,778	5.04	3.67	5.04	7.98	10.10
3775	BC-010614-1.3	Minor Structure	LEFTHAND CANYON DR	Left Hand Creek	Boulder County	6,356	9	30	1	6,780	6,780	$5,934,868,524	1,069,884	4.00			0.59	2.50
3881	ROAD_3881	Road	S SUNSET ST	Saint Vrain Creek	City of Longmont	6,225	1	30	2	-	6,426	$808,802	27,889	4.00		0.36	2.40	4.13
3940	ROAD_3940	Road	S FRANCIS ST	Saint Vrain Creek	City of Longmont	6,079	1	30	2	-	3,242	$773,262	27,233	4.00	0.14	1.48	3.96	6.49
3936	ROAD_3936	Road	AIRPORT RD	Left Hand Creek	City of Longmont	6,004	5	30	2	-	3,202	$3,817,170	134,484	4.33	2.46	4.33	7.81	9.99
3942	ROAD_3942	Road	BOSTON AVE	Saint Vrain Creek	City of Longmont	5,959	0	30	2	-	3,178	$0	-	4.00	1.42	2.10	3.22	5.09
3750	BC-23-1.9-LTH	Major Structure	N 83RD ST	Little Thompson River	Boulder County	5,787	10	365	1	506	506	$5,668,114,266	1,000,058	4.00				2.33
3880	ROAD_3880	Road	S MAIN ST	Left Hand Creek	CDOT	5,661	3	30	1	-	6,038	$2,050,461	76,079	2.33				1.24
3744	BC-008901-3.5	Minor Structure	GOLD RUN RD	Gold Run	Boulder County	5,615	8	30	2	-	5,134	$5,829,432	201,253	2.43	0.03	0.62	1.19	1.85
3857	ROAD_3857	Road	VALMONT RD	Dry Creek 3	Boulder County	5,572	8	30	2	-	2,972	$5,627,664	199,718	2.75	0.10	1.47	2.34	2.56
3858	ROAD_3858	Road	US 287	Boulder Creek	CDOT	5,535	8	30	2	-	2,952	$5,385,072	198,374	8.29	6.31	8.29	10.95	12.86
3877	ROAD_3877	Road	S MAIN ST	Left Hand Creek	CDOT	5,477	3	30	1	-	5,842	$1,976,877	73,609	1.97				1.05
3935	ROAD_3935	Road	US 287	Dry Creek 2	CDOT	5,464	5	30	1	-	5,828	$3,253,110	122,388	1.53			0.41	1.01

City Sim ID	Asset ID	Asset Type	Road Name	Crossing	Owner	Average Annual Trips Disrupted	Remote-ness Index	Max duration of replacement / refurbishment due to event (days)	Number of overtopping events	Number of trips not taken due to disruption	Number of trips delayed due to disruption	Lost production due to disruption	Work missed due to disruption (hrs)	Max Overtopping Depth (in.)	Overtopping at 10-year storm (in.)	Overtopping at 25-year storm (in.)	Overtopping at 100-year storm (in.)	Overtopping at 500-year storm (in.)
3920	ROAD_3920	Road	BASELINE RD	Dry Creek 3	Boulder County	5,400	6	30	1	-	5,760	$4,140,234	145,152	1.16				0.61
3754	BC-94-2.3-LT	Major Structure	LEFTHAND CANYON DR	Left Hand Creek	Boulder County	5,238	9	365	1	458	458	$4,791,479,667	881,723	4.00			2.15	4.66
3770	BC-35-0.2-SV	Major Structure	CRANE HOLLOW DR	Saint Vrain Creek	Boulder County	5,078	8	365	1	-	444	$5,271,571	182,004	4.00			3.07	4.93
3811	BC-128E-3.9-NB	Major Structure	COLD SPRING RD	North Boulder Creek	Boulder County	5,007	8	365	2	-	258	$5,077,296	179,444	4.00	0.73	1.85	4.44	5.88
3794	BC-WAGONWHEEL_GAP-0.0-FMC (Previously BC-WG-0.0-FMC)	Major Structure	WAGONWHEEL GAP RD	Fourmile Canyon Creek	Boulder County	4,987	7	365	1	-	436	$4,279,052	156,384	4.00				2.26
3793	BC-WAGONWHEEL_GAP-0.3-FMC (Previously BC-WG-0. 3-FMC)	Major Structure	WAGONWHEEL GAP RD	Fourmile Canyon Creek	Boulder County	4,987	7	365	1	-	436	$4,279,052	156,384	4.00			1.49	3.94
3792	BC-WAGONWHEEL_GAP-0.7-FMC (Previously BC-WG-0.7-FMC)	Major Structure	WAGONWHEEL GAP RD	Fourmile Canyon Creek	Boulder County	4,987	7	365	1	-	436	$4,279,052	156,384	4.00				2.76
3791	BC-WAGONWHEEL_GAP-0.9-FMC (Previously BC-WG-0.9-FMC)	Major Structure	WAGONWHEEL GAP RD	Fourmile Canyon Creek	Boulder County	4,987	7	365	1	-	436	$4,279,052	156,384	4.00				3.01
3774	BC-008902-0.0	Minor Structure	LICKSKILLET RD	Left Hand Creek	Boulder County	4,974	9	30	2	5,134	5,134	$4,615,818,613	837,150	4.00		0.45	2.12	4.05
3787	BC-3-7.5-SV	Major Structure	N 119TH ST	Saint Vrain Creek	Boulder County	4,967	4	365	2	-	222	$2,630,298	89,013	4.00	1.40		3.00	4.30
3943	ROAD_3943	Road	SUNSET ST	Saint Vrain Creek	Boulder County / City of Longmont	4,905	0	30	1	-	5,232	$0	-	4.00			1.44	4.29
3825	BC_GROSSDAM_RD	Major Structure	GROSS DAM RD	South Boulder Creek	Boulder County	4,878	9	365	2	218	218	$4,161,617,039	821,023	4.00	2.08	2.08	2.24	3.47
3933	ROAD_3933	Road	N 73RD ST	Left Hand Creek	Boulder County	4,864	6	30	1	-	5,188	$3,720,906	130,738	4.00				2.26
3759	BC-011802-5.7	Culvert	GOLD RUN RD	Gold Run	Boulder County	4,813	8	30	1	-	5,134	$4,996,656	172,502	1.53				0.81
3738	BC-3-8.1-DR2	Major Structure	N 119TH ST	Dry Creek 2	Boulder County	4,774	6	365	2	-	246	$3,534,111	128,323	4.00	0.17	1.56	2.74	3.78

City Sim ID	Asset ID	Asset Type	Road Name	Crossing	Owner	Average Annual Trips Disrupted	Remote-ness Index	Max duration of replacement / refurbishment due to event (days)	Number of overtopping events	Number of trips not taken due to disruption	Number of trips delayed due to disruption	Lost production due to disruption	Work missed due to disruption (hrs)	Max Overtopping Depth (in.)	Overtopping at 10-year storm (in.)	Overtopping at 25-year storm (in.)	Overtopping at 100-year storm (in.)	Overtopping at 500-year storm (in.)
3739	BC-011800-0.9	Minor Structure	LOGAN MILL RD	Fourmile Creek	Boulder County	4,683	8	30	2	-	4,834	$4,813,581	167,836	4.00		0.16	2.44	4.05
3736	BC-002506-0.3A	Minor Structure	N 79TH ST	Dry Creek 2	Boulder County	4,485	6	30	2	-	2,392	$3,436,524	120,557	3.95	0.67	1.43	2.35	3.20
3812	UNKNOWN 3	Major Structure	SWITZERLAND PARK RD	North Boulder Creek	Boulder County	4,404	8	365	2	-	384	$4,624,200	157,839	3.12	0.13	0.43	1.09	2.17
3813	UNKNOWN 2	Major Structure	SWITZERLAND PARK RD	North Boulder Creek	Boulder County	4,392	8	365	1	-	384	$4,611,600	157,409	3.44			1.20	2.39
3810	BC-124E-1.2-NB	Major Structure	HUMMER DR	North Boulder Creek	Boulder County	4,376	8	365	2	-	256	$4,214,963	156,836	4.00	0.82	1.32	2.34	3.76
3760	BC-002511-0.4A	Minor Structure	N 75TH ST	Dry Creek 3	Boulder County	4,358	7	30	2	-	2,324	$3,907,554	136,651	4.00		1.75	3.32	4.45
3925	ROAD_3925	Road	N 119TH ST	Boulder Creek	Boulder County	3,922	8	30	1	-	4,184	$3,870,720	140,582	1.71			0.17	0.99
3885	ROAD_3885	Road	GAY ST	Saint Vrain Creek	City of Longmont	3,908	0	30	2	-	4,034	$0	-	4.00		0.44	1.90	3.85
3748	BC-26-5.3-LT	Major Structure	NIMBUS RD	Left Hand Creek	Boulder County	3,820	7	365	1	-	334	$3,109,756	119,799	4.00			2.29	4.42
3887	ROAD_3887	Road	AIRPORT RD	Saint Vrain Creek	City of Longmont	3,630	4	30	1	-	3,872	$1,861,860	65,050	2.59				1.38
3853	ROAD_3853	Road	US 287	Coal Creek near of Public Rd and north of US 287	CDOT	3,474	4	30	1	-	3,706	$1,768,032	62,261	3.10			2.05	2.61
3771	BC-41-1.4-SV	Major Structure	N 63RD ST	Saint Vrain Creek	Boulder County	3,454	9	365	1	302	302	$3,028,801,487	581,398	4.00			5.48	7.12
3977	ROAD_3977	Road	N 81ST ST	Left Hand Creek	Boulder County	3,368	6	30	2	-	1,796	$2,287,404	90,518	4.16	1.89	4.16	9.49	10.64
3982	ROAD_3982	Road	COUNTY RD	Coal Creek	City of Louisville	3,272	2	30	1	-	3,490	$835,884	29,316	4.00			6.53	7.97
3767	BC-005223-2.0	Minor Structure	VALMONT RD	Dry Creek 3	Boulder County	3,251	8	30	2	-	2,972	$3,282,804	116,502	2.77		0.75	1.49	2.17
3964	ROAD_3964	Road	N 83RD ST	Dry Creek 2	Boulder County	3,229	7	30	1	-	3,444	$2,863,707	101,254	1.55				0.82
3923	ROAD_3923	Road	SH 119 (BOULDER CANYON DR)	Boulder Creek	CDOT	3,086	4	30	2	-	1,646	$1,532,832	55,306	9.97	3.81	9.97	13.02	15.97

City Sim ID	Asset ID	Asset Type	Road Name	Crossing	Owner	Average Annual Trips Disrupted	Remote-ness Index	Max duration of replacement / refurbishment due to event (days)	Number of overtopping events	Number of trips not taken due to disruption	Number of trips delayed due to disruption	Lost production due to disruption	Work missed due to disruption (hrs)	Max Overtopping Depth (in.)	Overtopping at 10-year storm (in.)	Overtopping at 25-year storm (in.)	Overtopping at 100-year storm (in.)	Overtopping at 500-year storm (in.)
3956	ROAD_3956	Road	EMPIRE DR	Coal Creek	Boulder County	2,989	2	30	1	-	3,188	$733,278	26,779	1.99				1.05
3780	BC-103-1.3-MSV	Major Structure	RIVERSIDE DR	Middle Saint Vrain Creek	Boulder County	2,974	9	365	1	260	260	$3,186,379,786	500,542	4.00			0.10	4.51
3975	ROAD_3975	Road	N 75TH ST	Saint Vrain Creek	Boulder County	2,912	7	30	1	-	3,106	$2,702,154	91,316	4.00			1.02	3.49
3863	ROAD_3863	Road	N 95TH ST	Dry Creek 2 north of the creek/road crossing	Boulder County	2,835	5	30	2	-	2,926	$1,754,336	63,494	2.08		0.10	0.68	1.42
3873	ROAD_3873	Road	S BOWEN ST	Left Hand Creek	City of Longmont	2,749	3	30	2	-	1,466	$1,039,248	36,943	4.00		1.04	2.14	4.24
3971	ROAD_3971	Road	S 120TH ST	Rock Creek	City of Lafayette	2,490	6	30	1	-	2,656	$1,890,126	66,931	4.00			2.61	3.73
3773	BC-59-2.4-LT	Major Structure	N 41ST ST	Left Hand Creek	Boulder County	2,431	9	365	2	212	212	$2,077,999,985	409,249	2.88		0.09	1.41	2.19
3896	ROAD_3896	Road	PIKE RD	Left Hand Creek	City of Longmont	2,336	4	30	1	-	2,492	$1,133,580	41,866	4.00			0.45	3.79
3919	ROAD_3919	Road	S PUBLIC RD	Coal Creek	City of Lafayette	2,299	4	30	1	-	2,452	$1,152,816	41,194	4.00			9.20	10.28
3941	ROAD_3941	Road	SH 119 (KEN PRATT BLVD)	Saint Vrain Creek	CDOT	2,280	4	30	2	-	1,216	$1,095,864	40,858	10.64	10.02	10.64	12.83	17.00
3752	S-645213-1.6	Minor Structure	LINDEN DR	Two Mile Creek	Boulder County	2,276	5	30	2	-	1,214	$1,359,120	50,988	3.71		1.32	2.45	3.12
3961	ROAD_3961	Road	NIWOT MEADOW FARM RD	Dry Creek 2	Boulder County	2,258	7	30	2	-	1,204	$1,968,036	70,795	4.58	3.58	4.58	7.03	9.69
3891	ROAD_3891	Road	US 36 (N FOOTHILLS PKWY)	Saint Vrain Creek	CDOT	2,246	9	30	2	1,198	1,198	$1,911,004,836	378,089	4.00	0.07	3.16	9.27	11.62
3861	ROAD_3861	Road	N 79TH ST	Dry Creek 2	Boulder County	2,242	6	30	1	-	2,392	$1,718,262	60,278	2.19			0.37	1.33
3893	ROAD_3893	Road	US 36 (UTE HWY)	Saint Vrain Creek	CDOT	2,147	8	30	1	-	2,290	$2,068,416	76,944	4.00			1.86	3.88
3980	ROAD_3980	Road	SH 72 (COAL CREEK CANYON DR)	South Boulder Creek	CDOT	1,882	9	30	2	1,004	1,004	$1,694,131,920	316,862	4.00	0.49	1.71	4.20	7.17
3869	ROAD_3869	Road	S SUNSET ST	Left Hand Creek	City of Longmont	1,879	4	30	1	-	2,004	$936,264	33,667	1.61				0.86
3895	ROAD_3895	Road	S SUNSET ST	Left Hand Creek	City of Longmont	1,879	4	30	1	-	2,004	$936,264	33,667	1.35				0.72

City Sim ID	Asset ID	Asset Type	Road Name	Crossing	Owner	Average Annual Trips Disrupted	Remote-ness Index	Max duration of replacement / refurbishment due to event (days)	Number of overtopping events	Number of trips not taken due to disruption	Number of trips delayed due to disruption	Lost production due to disruption	Work missed due to disruption (hrs)	Max Overtopping Depth (in.)	Overtopping at 10-year storm (in.)	Overtopping at 25-year storm (in.)	Overtopping at 100-year storm (in.)	Overtopping at 500-year storm (in.)
3931	ROAD_3931	Road	OVERLAND RD	South Saint Vrain Creek	Boulder County	1,838	9	30	2	980	980	$1,883,069,682	309,288	3.97	1.21	1.69	2.47	3.27
3898	ROAD_3898	Road	2ND AVE	Saint Vrain Creek	City of Longmont	1,753	0	5	1	-	11,222	$0	-	0.52				0.27
3917	ROAD_3917	Road	US 36 (DENVER-BOULDER TURNPIKE)	Coal Creek	CDOT	1,568	3	30	1	-	1,672	$595,224	21,067	4.00			10.73	12.71
3856	ROAD_3856	Road	SH 119 (BOULDER CANYON DR)	Boulder Creek near Sugarloaf Rd	CDOT	1,556	9	30	1	1,660	1,660	$1,470,650,688	261,948	4.00			1.82	5.14
3922	ROAD_3922	Road	SH 119 (BOULDER CANYON DR)	Boulder Creek near Sugarloaf Rd	CDOT	1,556	9	30	1	1,660	1,660	$1,470,650,688	261,948	4.00				2.26
3879	ROAD_3879	Road	S PRATT PKWY	Left Hand Creek	City of Longmont	1,554	3	30	1	-	1,658	$636,741	20,891	4.00				3.20
3871	ROAD_3871	Road	QUEBEC AVE	Left Hand Creek near S Terry St	City of Longmont	1,551	3	30	1	-	1,654	$607,572	20,840	4.00				2.93
3868	ROAD_3868	Road	PRATT PKWY	Left Hand Creek northeast of Pike Rd	City of Longmont	1,545	4	30	1	-	1,648	$770,868	27,686	4.00			1.01	3.92
3854	ROAD_3854	Road	US 287	Coal Creek	CDOT	1,502	3	30	1	-	1,602	$587,223	20,185	4.00			3.09	4.67
3806	CDOT_LHC_P2P	Minor Structure	SH 72	Left Hand Creek	CDOT	1,423	9	30	1	1,518	1,518	$1,345,092,684	239,540	2.39			0.54	1.52
3860	ROAD_3860	Road	SH 52 (MINERAL RD)	Boulder Creek	CDOT	1,358	9	30	2	724	724	$1,121,911,830	228,494	9.31	7.48	9.31	12.62	13.79
3878	ROAD_3878	Road	S BOWEN ST	Left Hand Creek	City of Longmont	1,350	3	30	1	-	1,440	$536,382	18,144	2.11				1.12
3890	ROAD_3890	Road	HYGIENE RD	Saint Vrain Creek	Boulder County	1,282	9	30	2	684	684	$1,196,405,574	215,870	4.35	3.12	4.35	6.56	8.68
3930	ROAD_3930	Road	N 63RD ST	Left Hand Creek	Boulder County	1,166	7	30	2	-	622	$1,089,858	36,574	4.49	2.11	4.49	6.73	8.89
3874	ROAD_3874	Road	S FORDHAM ST	Left Hand Creek	City of Longmont	1,135	4	30	2	-	1,038	$635,432	20,345	4.00		0.74	3.51	4.48
3821	BC-009405-1.7	Minor Structure	OVERLAND RD	South Saint Vrain Creek	Boulder County	1,072	9	30	2	980	980	$1,098,457,314	180,418	3.71	0.32	0.86	1.38	2.62

City Sim ID	Asset ID	Asset Type	Road Name	Crossing	Owner	Average Annual Trips Disrupted	Remote-ness Index	Max duration of replacement / refurbishment due to event (days)	Number of overtopping events	Number of trips not taken due to disruption	Number of trips delayed due to disruption	Lost production due to disruption	Work missed due to disruption (hrs)	Max Overtopping Depth (in.)	Overtopping at 10-year storm (in.)	Overtopping at 25-year storm (in.)	Overtopping at 100-year storm (in.)	Overtopping at 500-year storm (in.)
3913	ROAD_3913	Road	N 109TH ST	Boulder Creek	Boulder County	1,069	7	30	2	-	570	$951,090	33,516	8.05	6.14	8.05	9.10	10.42
3932	ROAD_3932	Road	JAMES CANYON DR	James Creek	Boulder County	1,052	8	30	1	-	1,122	$1,223,376	37,699	4.00			1.31	4.14
3960	ROAD_3960	Road	BRIGADOON DR	Left Hand Creek	Boulder County	1,050	7	30	1	-	1,120	$937,272	32,928	4.00			1.21	3.07
3822	BC-008300-1.0	Minor Structure	CR 83	Fourmile Canyon Creek	Boulder County	1,028	8	30	2	-	548	$1,066,128	36,826	4.00	1.02	1.77	3.03	4.23
3929	ROAD_3929	Road	CR 83	Fourmile Canyon Creek	Boulder County	1,028	8	30	2	-	548	$1,066,128	36,826	4.00	0.15	1.30	2.88	4.38
3876	ROAD_3876	Road	S PRATT PKWY	Left Hand Creek	City of Longmont	930	3	30	1	-	992	$385,182	12,499	4.00				4.01
3974	ROAD_3974	Road	SH 72 (PEAK TO PEAK SCENIC BYWAY)	Middle Saint Vrain Creek	CDOT	894	9	30	1	954	954	$939,282,006	150,541	4.00				2.64
3968	ROAD_3968	Road	CRANE HOLLOW DR	Saint Vrain Creek	Boulder County	832	8	30	2	-	444	$864,192	29,837	5.27	3.13	5.27	8.86	11.13
3892	ROAD_3892	Road	SH 66 (UTE HWY)	Saint Vrain Creek	CDOT	823	9	30	1	878	878	$792,697,542	138,548	4.00				2.52
3900	ROAD_3900	Road	COLD SPRING RD	North Boulder Creek	Boulder County	814	8	30	2	-	744	$805,560	29,165	4.00		0.85	3.14	6.31
3870	ROAD_3870	Road	S BOWEN ST	Left Hand Creek	City of Longmont	812	3	30	2	-	838	$322,570	10,911	4.00		0.11	1.98	4.12
3983	ROAD_3983	Road	US 36	Saint Vrain Creek	Town of Lyons	810	6	30	2	-	432	$657,468	21,773	4.00	1.29	2.41	3.55	5.17
3872	ROAD_3872	Road	LEFTHAND DR	Left Hand Creek near S Bowen St	City of Longmont	802	3	30	2	-	828	$288,979	10,781	4.00		0.24	1.90	3.90
3957	ROAD_3957	Road	DILLON RD	Rock Creek	City and County of Broomfield	778	7	30	1	-	830	$698,691	24,402	4.00			9.83	11.10
3904	ROAD_3904	Road	SWITZERLAND PARK RD	North Boulder Creek	Boulder County	720	8	30	2	-	384	$756,000	25,805	4.02	3.50	4.02	5.09	6.65
3875	ROAD_3875	Road	MISSOURI AVE	Left Hand Creek	City of Longmont	713	3	30	2	-	736	$274,787	9,583	4.00		0.44	3.18	5.52
3979	ROAD_3979	Road	PRATT PKWY	Left Hand Creek	City of Longmont	628	4	30	1	-	670	$300,636	11,256	4.00			1.09	4.51

City Sim ID	Asset ID	Asset Type	Road Name	Crossing	Owner	Average Annual Trips Disrupted	Remote-ness Index	Max duration of replacement / refurbishment due to event (days)	Number of overtopping events	Number of trips not taken due to disruption	Number of trips delayed due to disruption	Lost production due to disruption	Work missed due to disruption (hrs)	Max Overtopping Depth (in.)	Overtopping at 10-year storm (in.)	Overtopping at 25-year storm (in.)	Overtopping at 100-year storm (in.)	Overtopping at 500-year storm (in.)
3966	ROAD_3966	Road	NIMBUS RD	Left Hand Creek	Boulder County	626	7	30	2	-	334	$509,796	19,639	4.01	2.86	4.01	6.46	7.97
3938	ROAD_3938	Road	MISSOURI AVE	Left Hand Creek	City of Longmont	594	3	30	1	-	634	$226,485	7,988	4.00			2.73	5.13
3778	BC-51-5.3-LT	Major Structure	N 49TH ST	Left Hand Creek	Boulder County	549	8	365	1	-	48	$530,846	19,676	4.00			2.85	4.58
3928	ROAD_3928	Road	SH 72 (PEAK TO PEAK SCENIC BYWAY)	South Saint Vrain Creek	CDOT	532	9	30	1	568	568	$501,931,638	89,630	2.16				1.14
3749	BC-25-4.7-LT	Major Structure	AIRPORT RD	Left Hand Creek	Boulder County	500	5	5	1	-	3,202	$318,097	11,207	0.96				0.51
3883	ROAD_3883	Road	BOSTON AVE	Saint Vrain Creek	City of Longmont	493	0	30	1	-	526	$0	-	4.00			3.28	6.02
3949	ROAD_3949	Road	HUMMER DR	North Boulder Creek	Boulder County	480	8	30	2	-	256	$462,336	17,203	4.00	0.66	1.15	2.16	3.35
3962	ROAD_3962	Road	N 119TH ST	Dry Creek 2	Boulder County	461	6	30	2	-	246	$341,460	12,398	5.12	4.34	5.12	5.93	7.54
3897	ROAD_3897	Road	SH 119 (KEN PRATT BLVD)	Dry Creek 1	CDOT	431	2	30	1	-	460	$109,116	3,864	4.00				2.72
3865	ROAD_3865	Road	LEFTHAND CANYON DR	Left Hand Creek	Boulder County	429	9	30	1	458	458	$392,744,235	72,272	4.00			3.03	5.93
3963	ROAD_3963	Road	N 119TH ST	Saint Vrain Creek	Boulder County	416	4	30	2	-	222	$220,416	7,459	10.34	9.76	10.34	11.70	13.01
3951	ROAD_3951	Road	WAGONWHEEL GAP RD	Fourmile Canyon Creek	Boulder County	409	7	30	1	-	436	$350,742	12,818	4.00			8.29	14.45
3912	ROAD_3912	Road	N 41ST ST	Left Hand Creek	Boulder County	398	9	30	2	212	212	$339,727,518	66,907	8.47	4.90	8.47	11.03	12.15
3950	ROAD_3950	Road	FOURMILE CANYON DR	Fourmile Creek	Boulder County	338	8	30	2	-	180	$366,576	12,096	4.00	1.68	3.74	5.14	6.14
3731	5971	Culvert	N 61ST ST	Saint Vrain Creek	Boulder County	330	9	30	2	302	302	$289,639,486	55,598	2.14		0.61	1.25	1.72
3786	9971	Culvert	N 61ST ST	Saint Vrain Creek	Boulder County	330	9	30	2	302	302	$289,639,486	55,598	4.00		0.69	2.07	4.27
3862	ROAD_3862	Road	LEFTHAND CANYON DR	Left Hand Creek	Boulder County	330	9	30	1	352	352	$308,488,206	55,546	4.00				3.23
3815	CDOT_NBC_119	Major Structure	SH 119	North Boulder Creek	CDOT	320	8	365	1	-	28	$377,126	11,478	2.77				1.47

City Sim ID	Asset ID	Asset Type	Road Name	Crossing	Owner	Average Annual Trips Disrupted	Remote-ness Index	Max duration of replacement / refurbishment due to event (days)	Number of overtopping events	Number of trips not taken due to disruption	Number of trips delayed due to disruption	Lost production due to disruption	Work missed due to disruption (hrs)	Max Overtopping Depth (in.)	Overtopping at 10-year storm (in.)	Overtopping at 25-year storm (in.)	Overtopping at 100-year storm (in.)	Overtopping at 500-year storm (in.)
3965	ROAD_3965	Road	N 41ST ST	Left Hand Creek	Boulder County	315	9	30	1	336	336	$280,853,430	53,021	2.85			0.24	1.62
3934	ROAD_3934	Road	PLATEAU RD	Dry Creek 2	City of Longmont	308	5	30	2	-	164	$198,030	6,888	3.56	1.19	1.75	2.43	3.03
3906	ROAD_3906	Road	N 63RD ST	Saint Vrain Creek	Boulder County	283	9	30	1	302	302	$248,262,417	47,656	4.00			2.46	3.93
3737	BC-002607-0.4	Minor Structure	PROSPECT RD	Dry Creek 2	Boulder County	269	5	30	2	-	246	$165,987	6,027	2.34	0.55	0.86	1.36	1.88
3889	ROAD_3889	Road	9TH AVE	Saint Vrain Creek	City of Longmont	251	2	30	1	-	268	$58,926	2,251	1.95				1.03
3944	ROAD_3944	Road	PRICE RD	Saint Vrain Creek	City of Longmont	249	0	30	1	-	266	$0	-	4.00			1.89	3.91
3903	ROAD_3903	Road	ANDERSON HILL	James Creek	Town of Jamestown	248	9	30	2	132	132	$227,986,902	41,659	4.00	2.83	3.78	5.79	8.01
3914	ROAD_3914	Road	WHISPERING PINES RD	Fourmile Canyon Creek	<<unknown>>	247	8	30	2	-	226	$259,896	8,859	4.00		0.98	2.22	5.16
3901	ROAD_3901	Road	RIVERSIDE DR	Middle Saint Vrain Creek	Boulder County	244	10	30	1	260	260	$261,215,190	42,120	4.00				8.32
3902	ROAD_3902	Road	RIVERSIDE DR	Middle Saint Vrain Creek	Boulder County	244	9	30	1	260	260	$259,226,214	41,028	4.00				7.48
3954	ROAD_3954	Road	COLD SPRING RD	North Boulder Creek	Boulder County	242	8	30	1	-	258	$245,280	8,669	4.00			1.51	3.16
3948	ROAD_3948	Road	US 36 (NORTH SAINT VRAIN DR)	North Saint Vrain Creek	CDOT	219	9	30	1	234	234	$186,534,738	36,925	4.00			2.21	6.87
3859	ROAD_3859	Road	SH 52 (MINERAL RD)	Dry Creek 2 west of Monarch Park Pl, east of the creek/road crossing	CDOT	204	6	30	1	-	218	$150,444	5,494	4.00			0.99	3.13
3867	ROAD_3867	Road	US 287 (S MAIN ST)	Dry Creek 2 north of Plateau Rd	CDOT	194	5	1	1	-	6,216	$116,420	4,351	0.15				0.08
3945	ROAD_3945	Road	SAINT VRAIN RD	Saint Vrain Creek	City of Longmont	171	4	30	1	-	182	$85,344	3,058	4.00			0.33	2.76
3981	ROAD_3981	Road	SH 72 (COAL CREEK CANYON DR)	South Boulder Creek	CDOT	169	10	30	1	180	180	$164,029,320	29,160	1.70				0.90

City Sim ID	Asset ID	Asset Type	Road Name	Crossing	Owner	Average Annual Trips Disrupted	Remote-ness Index	Max duration of replacement / refurbishment due to event (days)	Number of overtopping events	Number of trips not taken due to disruption	Number of trips delayed due to disruption	Lost production due to disruption	Work missed due to disruption (hrs)	Max Overtopping Depth (in.)	Overtopping at 10-year storm (in.)	Overtopping at 25-year storm (in.)	Overtopping at 100-year storm (in.)	Overtopping at 500-year storm (in.)
3816	BC-008201-1.7	Minor Structure	BIG OWL RD	Cabin Creek	Boulder County	146	9	30	2	78	78	$155,896,182	24,617	4.00	1.89	2.26	2.82	4.26
3959	ROAD_3959	Road	NORTHWEST PKWY	Rock Creek	Northwest Parkway LLC	142	7	30	1	-	152	$125,097	4,469	4.00			10.23	12.00
3969	ROAD_3969	Road	QUAIL RD	Left Hand Creek	City of Longmont	135	3	30	1	-	144	$46,935	1,814	2.83				1.50
3753	S-645215-1.3	Minor Structure	NORTH CEDAR BROOK RD	Two Mile Canyon Creek	Boulder County	133	5	30	1	-	142	$77,595	2,982	4.00			2.86	3.61
3772	BC-39-4.8-LT	Major Structure	N 63RD ST	Left Hand Creek	Boulder County	97	7	5	1	-	622	$90,822	3,048	0.58				0.31
3911	ROAD_3911	Road	OXFORD RD	Left Hand Creek	Boulder County	93	9	5	1	594	594	$81,202,186	15,622	0.85				0.45
3910	ROAD_3910	Road	N 49TH ST	Left Hand Creek	Boulder County	90	8	30	2	-	48	$87,024	3,226	4.20	2.42	4.20	6.74	7.75
3819	CDOT_SSVC_72	Major Structure	SH 72	South Saint Vrain Creek	CDOT	89	9	5	1	568	568	$83,655,273	14,938	0.93				0.50
3855	ROAD_3855	Road	FLAGG DR	Coal Creek south of SH 7 and east of Flagg Dr	Boulder County	69	6	30	1	-	74	$47,754	1,865	4.00				4.48
3894	ROAD_3894	Road	SH 7 (BASELINE RD)	Coal Creek	CDOT	69	6	30	1	-	74	$47,754	1,865	1.54				0.82
3837	S-171101-0.4	Minor Structure	COPPERDALE LN	Coal Creek	Boulder County	68	9	5	1	432	432	$59,650,064	11,362	0.51				0.27
3947	ROAD_3947	Road	SH 7 (SOUTH SAINT VRAIN DR)	South Saint Vrain Creek	CDOT	64	10	30	2	34	34	$66,092,400	11,016	9.49	6.48	9.49	14.41	20.83
3921	ROAD_3921	Road	SH 7 (BASELINE RD)	Coal Creek	CDOT	41	6	30	1	-	44	$25,956	1,109	2.81				1.49
3953	ROAD_3953	Road	GEER CANYON DR	Geer Canyon	Boulder County	34	9	30	2	18	18	$28,836,288	5,681	4.00	2.74	3.25	4.18	5.51
3976	ROAD_3976	Road	SH 72 (COAL CREEK CANYON DR)	South Boulder Creek	CDOT	31	9	1	1	1,004	1,004	$28,235,532	5,281	0.47				0.25
3835	NWPWKY_RoC_DILLON	Major Structure	DILLON RD	Rock Creek	Northwest Parkway LLC	26	7	1	1	-	830	$23,290	813	0.24				0.13
3918	ROAD_3918	Road	SH 119 (BOULDER CANYON DR)	Boulder Creek	CDOT	26	9	30	1	28	28	$27,634,776	4,418	4.00			1.29	6.20
3952	ROAD_3952	Road	CR 82E	Cabin Creek	Boulder County	26	9	30	2	14	14	$28,235,532	4,418	4.00	1.30	1.81	2.81	4.41

City Sim ID	Asset ID	Asset Type	Road Name	Crossing	Owner	Average Annual Trips Disrupted	Remote-ness Index	Max duration of replacement / refurbishment due to event (days)	Number of overtopping events	Number of trips not taken due to disruption	Number of trips delayed due to disruption	Lost production due to disruption	Work missed due to disruption (hrs)	Max Overtopping Depth (in.)	Overtopping at 10-year storm (in.)	Overtopping at 25-year storm (in.)	Overtopping at 100-year storm (in.)	Overtopping at 500-year storm (in.)
3967	ROAD_3967	Road	N 109TH ST	Boulder Creek	Boulder County	19	7	1	1	-	614	$17,057	602	0.19				0.10
3817	BC-008202-0.9	Minor Structure	CR 82E	Cabin Creek	Boulder County	15	9	30	2	14	14	$16,470,727	2,577	4.00	0.51	0.98	2.49	3.34
3899	ROAD_3899	Road	COPPERDALE LN	<<stream has no name>>	Boulder County	14	9	1	1	432	432	$11,930,013	2,272	0.44				0.23
3905	ROAD_3905	Road	CR 82E	Cabin Creek	Boulder County	6	9	30	1	6	6	$6,307,938	947	3.58			0.96	2.35
3909	ROAD_3909	Road	JASPER RD	Boulder Creek	Boulder County	5	7	1	1	-	164	$4,322	161	0.01				0.01
3818	84580 (Previously BC_WFLTR_CR82E)	Culvert	CR 82E	West Fork Little Thompson River	Boulder County	2	10	30	2	2	2	$1,927,695	378	2.97	0.64	0.91	1.09	2.09
3955	ROAD_3955	Road	CR 82E	West Fork Little Thompson River	Boulder County	2	10	30	2	2	2	$1,927,695	378	2.43	0.32	0.68	1.00	1.76

Appendix 5. Full List of Resiliency Actions Considered

1. Establish stand-by contractors for extreme event response and recovery.

Establish stand-by contractors for extreme event response and recovery.

2. Develop a post-disaster recovery and redevelopment plan.

Prepare a county-wide, post-disaster redevelopment planning strategy with specific policies to address projected conditions and foreseeable disaster recovery or redevelopment issues. The strategy should identify how the County will operationally manage the range of resiliency improvements or needs following a large, destructive hazard event. This includes short-term recovery measures such as the provision of safe, temporary housing for displaced populations, to more intermediate and long-term recovery activities such as expedited permitting procedures and the replacement of permanent, affordable housing that is more resilient and adaptive to future conditions.

The plan should identify potential Public Assistance Mitigation (Section 406) opportunities like removing constrictions from the floodplain, upgrading undersized culverts, elevating roads and bridges, and even re-routing roads. The plan shall complement Boulder County Recovery Plan v1.17 which outlines the high-level roles, expectations, and authority of Boulder County in the hours, days, weeks, and months following a disaster event. The involvement of each department is paramount to executing a successful recovery process following a disaster. Department planning is different from Continuity of Operations Planning and both should have their own planning process when created or updated. Additionally, these strategies will result in the submission of a department-level draft recovery plan to the Office of Resilience and Recovery (ORR). A broad team from within each department will ensure a more thorough approach and distributed ownership."

4. Develop a strategic public communications plan for Boulder County Transportation Department

Develop a strategic public communications plan for Boulder County Transportation Department improve public engagement in planning and decisions. Develop assistance programs that introduce communities to the full range of communications, public engagement, planning, and policy implementation tools to realize their watershed health and community resiliency goals.

Develop strategies to shift public/county interactions away from specific issues and toward opportunities to connect and build a common understanding. Plan should develop ways to engage the public that foster productive discussion of competing ideas, engage a broader cross-section of the population, use a broad range of communication avenues, support an atmosphere of collaboration and compromise, and increase public confidence that their views have been heard and considered. A comprehensive countywide strategy with clear methods, actions, and roles around engaging the public could build on the existing County engagement methods with a renewed focus on ‘community partnerships."

5. Develop natural hazard risk communications strategies and plans

Natural hazards potentially affecting the county should continue to be identified and made known to the public and public officials. The county should promote a high level of public awareness about the risks of these identified hazards which may impact people, property, and the environment. The county should be an informational resource to Boulder County residents on issues and data related to natural hazards. Help people protect themselves from flood hazards.

6. Develop transportation department specific, strategic planning and programming priorities

Develop transportation department specific, strategic planning and programming priorities, to align work toward a common vision and set of goals.

Develop strategic priorities to improve the budget process by guiding decisions, giving added transparency to Department Heads, and further enabling the Transportation Department to offer a compelling and cohesive story about the leaderships' vision for the community's future, both internally and externally.

The demand for county transportation services is understandably high given the needs of our community. Resources are available but are limited in their ability to support additional investment in resiliency measures outside of projects that are already funded and in process.

Programs tend to continue for long periods of time without being evaluated for success, or for whether or not they should be modified or continued. It would be beneficial to have a Transportation department specific strategic planning process to define priorities that help guide transportation programming."

7. Develop materials to educate occupants at education facilities and workplaces about site-specific risks.

Buildings occupied on a daily basis by the same people provide an opportunity for the occupants to be trained and made aware of their site-specific risks.

8. Expand the action recommendations in the County's Multi-Hazard Mitigation Plan

Further enhance the action recommendations in the County's Multi-Hazard Mitigation Plan to identify those projects most likely to be implemented in the wake of a major flood, when post-disaster hazard mitigation grant funding might become available for things such as floodplain property buyouts.

9. Implement site-specific projects and recommendations from creek and watershed master plans within unincorporated Boulder County, and advocate for those located elsewhere

Implement projects and recommendations (site-specific project lists available) within unincorporated Boulder County from the following master plans:

Incorporate site-specific recommendations of creek, drainageway and Outflow plans into capital projects where warranted. Prioritize resiliency along with safety, structural, lifecycle and functional needs.

Current Plans;

· Boulder Creek Restoration Master Plan

· Coal Creek and Rock Creek Major Drainageway Plan

· Fourmile Creek Watershed Master Plan

· Little Thompson Watershed Restoration Master Plan

· St. Vrain Creek Watershed Master Plan

· Upper Coal Creek Watershed Restoration Master Plan"

10. Develop a Green Infrastructure Guide

Research and promote resilient design elements, collaborate on plans and projects that integrate these elements. For example, Denver's "Ultra-Urban Green Infrastructure Guidelines (2016)" is making green infrastructure a part of the city's long-term stormwater management strategy by incorporating large-scale green infrastructure with small or site-scale green infrastructure. On a large scale, green infrastructure refers to a network of parks, open spaces, drainageways, and floodplains which help mitigate the impacts caused by impervious (hard) surfaces. Site-scale green infrastructure refers to smaller, engineered, structural practices which mimic larger natural systems and use vegetation, soils, and roots to slow and filter stormwater runoff. "

12. Have and maintain an agency-wide Emergency Operations Plan that gets reviewed and updated on a regular basis

Have and maintain an agency-wide Emergency Operations Plan that gets reviewed and updated on a regular basis.

13. Have and maintain a Continuity of Operations (COOP) Plan and a COOP site

A Continuity of Operations (COOP) Plan and a COOP site whose capabilities are assessed on a regular basis.

14. Score Boulder County's resiliency maturity by department/group.

Develop a list of questions that allow managers and directors to quickly assess the organizations capabilities and resiliency maturity. The list could include questions relating to:

· Roles/responsibilities

· Capabilities/resources

· Communication/coordination

· Training/continual improvement

· Performance management

Ensure design standards and procurement criteria allow newly available materials if they are superior to traditional materials to be considered during new construction and repair activities (e.g. allowing low-water crossings). Design standards and procurement criteria to be review every 4 years and new innovations included if appropriate."

16. Implement the Recommendations for Action outlined at the end of the "Resilience for All" document/ study

Support the Recommendations for Action outlined at the end of the "Resilience for All" document / study. Recommendations are in form of a potential checklist to meet the needs of Boulder County's Spanish speaking community and in turn creating a more resilient community:

· Provide the connection, guidance, attempt to alleviate and or remove the barriers that clients face when accessing services/resources

· Embrace word of mouth as a trusted source of referral and connection to resources.

· Determine collaboration between department resource agencies. Professionals must work together and streamline the lines of communication that will allow clients to access resources.

· Provide existing bilingual emergency resources to all community partners currently working with the multicultural organizations.

· Provide existing bilingual emergency resources to all community partners currently working with the multicultural organizations.

· Create a safe [local] neutral point of resource for consumers to formalize complaints.

· Finance non-profits that focus on outreach teaching English.

· Financially recruit, reward, and retain cultural brokers in local agencies and community.

· Implement programming such as Bi-literacy seal or bilingual pay scales. "

17. Develop and adopt plans and policies for emergency access and egress.

Develop and adopt plans and policies for emergency access and egress to all residential areas before, during, and after hazard events to be integrated into the Comprehensive Plan and development/site plan review process, in addition to other plans or procedures as appropriate. Also evaluate ingress/egress to critical facilities like hospitals, utilities, etc. to determine if resilience measures need to be added.

18. Promote having resiliency elements in local plans in Boulder County.

Work to have plans within Boulder County's jurisdiction include a resiliency element. The element would identify critical assets and services that are vulnerable and/or threatened and need support. Elements would prioritize local opportunities to reduce vulnerabilities in line with asset criticality and consequence management. The policy will institutionalize communication across departments and agencies for resiliency preparation, response, and recovery. The policy will also encourage multi-jurisdictional cooperation in the mitigation, response, and recovery from risks associated with hazards.

19. Provide bilingual resiliency materials and engagement.

Require that resiliency studies and related local plans engage with Spanish speaking, and other non-English speaking, communities. The Transportation Department must understand that monolingual Spanish speakers don't access information the same way as monolingual English Speakers. Non-English speakers in Boulder County need the additional level of support in terms of community education, outreach, and marketing related to community resiliency. "Typical" government outreach strategies don't usually reach vulnerable populations. Vulnerable populations are busy just trying to survive and don't necessarily have the time or capacity to attend public meetings, sign up for listservs. Boulder County must actively engage with vulnerable populations using methods that work for them.

21. Develop policies to ensure the transportation system is responsive to undocumented people during a natural disaster.

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 the fear being deported, which does happen in some cases.

22. Reconcile building codes and land use policy across jurisdictions

Work to clarify and integrate building codes and land use policy across jurisdictions and improve communication of policies. Plans note numerous issues during flood recovery where both homeowners and local jurisdictions have been unable to clarify how best to move forward due to conflicting policy information.

24. Develop a structured maintenance regime and require periodic updates of design standards and maintenance regimes to climate change

Increases in temperature can exceed design standards and create excess cracking that must be repaired. Similarly, increases in precipitation will increase the cracking by impacting the strength of the roadbed as well as causing additional erosion along the edges of some roadways.

25. Require climate change elements for all regional plans within Boulder County

Requiring regional land use, transportation, floodplain, etc. plans to consider climate change helps to build synergy between municipalities and disciplines, and cohesion among Boulder County municipalities regarding Climate Change assumptions, concerns, approaches, etc. (see related "Resiliency how-to planning guide" action)

27. Incorporated resiliency into project prioritization criteria for transportation, land use, and floodplain project selection

Incorporating resiliency criteria into project section across disciplines helps institutionalize resiliency.

28. Implement a priority-based budgeting program for the Transportation Department

Historically, Boulder County departments base the upcoming year's budget off the last year's base budget and make requests for incremental increases. It is recommended that the Transportation Department evaluate the historic base budget to kick off a priority-based budgeting process and then continuing to evaluate base budget items along with other programming for alignment with County Priorities.

30. Develop policies to ensure public infrastructure is built in anticipation of homeowner adjustments to drainage system that protect their own property

During and after the 2013 floods, homeowners had adjusted their homes or land to reduce their risk: berms to divert water, swales to direct it off the property, culverts to allow streams to pass underground, sump pumps in basements. For the most part, homeowners undertook these adaptations on their own, assessing their own risk, their own cost, and their own benefit. Rarely were these adaptations done with an eye to upstream and downstream impacts, or in coordination with other property owners. In some cases these features push flood waters into roads or public property. While this type of flood mitigation can, in part, be controlled through enforcement of building codes, if public infrastructure is built in anticipation of these types of autonomous behavior, resilience is increased.

31. Include debris considerations into elevation standards

In areas of high debris potential, floodplain administration should evaluate the relative merit of debris in elevation standards that currently only consider backwater from structures and not debris, as well as to require more stringent structural standards for exposed foundations or foundations in highly erodible banks. Flood protection elevation standards typically presume the flow to consist of water only. Therefore, when the flood is likely to include hyper-concentrated flow containing a very heavy sediment load and floating debris, it is prudent to recognize the tendency for flood levels to super-elevate above water-only flood levels, and for debris to cause additional damage both above and below the base flood level. Increased elevation standards and more stringent structural requirements would add a needed factor of safety for heavy debris streams and could be based on a benefit to cost analysis to establish appropriate increases in standards.

34. Develop training and exercise procedures to establish and practice emergency recovery roles e.g. damage assessment

Prepare County employees for their roles during recovery. This includes putting recovery plans into place; and providing an opportunity to test plans and validate the effectiveness of training, and to revised plans and training as needed.

Conduct tabletop exercises and use routine events to drill recovery management protocols.

37. Establish metrics for achieving community resilience

Develop a set of performance-based indicators 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 future improvements. Metrics can help decision makers prioritize resiliency improvements but also will help to ensure that they are carried forward and implemented as planned. They can also help the County to better understand and evaluate the benefits and cumulative return on its resilience investments.

42. Target public outreach through neighborhood social media

Both preparedness and resilience need to be promoted with messaging specifically targeted to particular neighborhood to fine-tune the information to best resonate and trigger action. Used strategically (e.g. not overused [spamming]) social media and NextDoor are good tools to reach the community at this granular level. The county has an “agency” profile on NextDoor that the BOCC communications staff use. Messages that must be broader in order to suit a wide audience generally are not specific enough to ‘hit home’ and trigger meaningful action. More consistent and specific messages can build the sustained coordination that raises the profile of resilience and build greater trust which could lead to more action.

44. Establish work order codes for flooding events

Establish work order codes for flooding events to improve tracking of labor, equipment, and materials costs over time.

45. Include emergency response in maintenance program purchasing and preparation

Factor emergency response into long-term maintenance program planning and operation. For example:

· Purchase equipment, factoring in likely future needs based on extreme weather events or climate changes (e.g., versatile equipment in Alabama to double as snow plows, mobile stockpiles of 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."

47. Develop a post-wildfire flood risk reduction program

Develop a post-wildfire program with actions to be taken in areas that are downstream from burn area that could be triggered by any future wildfires. 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 estimating flows and providing maps of the changed conditions, higher standards (e.g., rebuild with extra freeboard), buffer roadways, and encourage those in the affected areas to purchase flood insurance if they don’t already have it. Colorado Springs adopted similar measures after the Waldo Canyon fire of 2011. To better estimate which area might be most vulnerable, use the USGS Pre-fire Debris Flow estimation methods. Climate change will likely increase the fire risk.

53. Adopt knowledge management and transfer processes

Utilize knowledge management tools and develop processes that ensure a systemic transfer of knowledge and relationships are maintained for incoming replacement staff. Identify ways to build in transitional support for transferring networks and knowledge as people leave jobs and new people come on.

54. Develop a database outlining sediment removal and routine maintenance requirements for each creek in the county.

Develop a process to manage and track sediment removal and routine maintenance requirements for structures in each creek in the county.

Crossings should be monitored and excessive sediment cleaned out when necessary. In order to estimate the frequency at which proposed maintenance will likely be needed at a particular crossing, a maintenance budget and additional analyses would be needed at each crossing."

58. Develop a resiliency how-to planning guide

Develop a resource guide for incorporating resiliency into local community planning and land use planning processes. The guide and subsequent planning processes will help institutionalize communication across departments and agencies for resiliency preparation, response, and recovery.

Because hazards cross jurisdictional boundaries, planning efforts should uniformly foster multi-jurisdictional cooperation in the mitigation, response, and recovery from risks associated with hazards."

61. Develop Pre-Disaster Flood Mitigation Plan

The county should continue to develop and refine the countywide Pre-Disaster Flood Mitigation Plan.

63. Develop and promote higher freeboard incentives

Develop and promote incentives for builders or property owners who voluntarily go beyond current regulatory freeboard requirements (2 feet) for structures located in the Floodplain Overlay Zoning District. This should also include incentives for owners with structures in the 500-flood zone to voluntarily elevate or floodproof to higher standards. Incentives may include permit fee waivers and significant public outreach and education on the financial and risk reduction benefits of going beyond existing requirements, with emphasis on lower flood insurance premiums. Example illustrations and persuasive messaging is available from ASFPM ("The Costs and Benefits of Building Higher") and other sources.

64. Promote nature-based design for new development projects

Support and encourage development projects, including new construction and substantial improvements or retrofits, that take advantage of ecosystem services and nature-based design for flood risk reduction. Project examples include but are not limited to green infrastructure projects and sustainable, climate-adaptive design for structures (i.e., green roofs, stormwater retention, etc.). Projects may be structure-specific or applied across defined geographic areas. This resiliency scenario should be further discussed and refined with the team in order to determine more specific individual actions that are best suited for Boulder County.

A good example is Washington DC's "Stormwater Retention Credit Trading Program" which 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 (GI) or by removing impervious surfaces. See here for more info: https://doee.dc.gov/src. Similar examples of financial incentives exist for communities in the form of tax credits or fee reductions, but the County should also consider other types of incentives that can be offered through existing planning mechanisms (e.g., permit waivers, regulatory relief/flexibility such as TDRs, etc.). Another good example is the "resilience quotient" system being implemented in Norfolk, VA 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 opts to meet specified standards for elevation and drainage. More info available upon request."

65. Future conditions floodplain mapping

Adopt a policy that all H&H studies for future floodplain mapping projects include future conditions modeling that accounts for projected increases in the frequency and magnitude of extreme rainfall events due to climate change and for future land development if/where applicable. Per the Boulder County Climate Change Preparedness Plan, the City of Boulder already bases all flood studies on future land use conditions (full build out conditions) but not anticipated future climate conditions. While these map products may not be linked to FEMA's mandatory purchase requirements under the NFIP, they should still be adopted as the County's regulatory floodplain / Floodplain Overlay Zoning District for purposes of construction standards for new development, substantial improvements, and/or post-flood rebuilding. Once complete, the use of updated flood risk models and maps based on downscaled climate projections to determine potential flood extents and depths for future flood events can be used to determine updated Flood Protection Elevations (FPEs) for new or substantially-improved/repaired construction in identified flood hazard areas.

Regulate new/substantially improved development to a higher mapping standard for the County that includes future conditions modeling based on the best available data, including but not limited to downscaled climate projections. FEMA has supported some pilot work on this, but it is not a technical mapping standard. However the County can delineate and regulate its own designated "community floodplain" as it chooses, even if not the same SFHA identified on FEMA FIRMs through the NFIP. If not incorporated into higher regulatory standards the information could be shown and shared through mapping products made available to the public."

66. Require floodplain maps to be updated after major floods and restoration

Updated floodplain maps are needed due to changes brought about by damage and changes caused by flood events as well as the subsequent rebuilding efforts. These activities are likely to limit the accuracy of floodplain maps and do not represent the most up to date floodplain conditions.

67. Limit/prohibit floodplain development

Encourage non-structural uses within designated special flood hazard areas to help prevent future damages and economic loss, and to protect and enhance the natural and beneficial functions of floodplains. Flood risk reduction through hazard avoidance is often the most cost-effective and practical technique available to communities. It is also consistent with and can be mutually-supportive of other policies and actions designed to preserve or enhance the natural environment and/or parks and other recreational or open space amenities. The County should adopt and implement a policy that limits or prohibits new development within known flood hazard areas of greatest concern, separate from FEMA SFHAs (for example, Fluvial/Erosion Hazard Zones, Velocity Hazard Zones, or other areas of high hazard as defined by the County, which may be delineated using new flood hazard data from CHAMP). The County should also consider limiting specific uses or building types within certain hazard zones (e.g., prohibit or limiting the storage of hazardous materials from all or parts of the SFHA, prohibiting basements within the 500-year floodplain, etc.). This general resiliency scenario needs to be further discussed and refined with the team in order to determine more specific individual actions that are best suited for Boulder County.

The county should strongly discourage and strictly control land use development from locating in designated floodplains, as identified in the Boulder County Zoning Maps.

The county should strongly discourage and strictly control land use development from locating in areas below dams, spillways, and levees that would require the State Engineer to upgrade the classification of these structures."

68. Promote "Do It Yourself" flood mitigation measures

As part of its broader public education and outreach efforts for disaster preparedness and flood mitigation, the County should actively promote low-cost projects that individual property owners may implement themselves. Including FEMA's brochure titled "Protect Your Home from Flooding" with other outreach materials or publications as done for the County's CRS program is recommended. Most cost-effective flood mitigation activities for property owners do not come in the form of a FEMA mitigation grant but rather small-scale projects such as sealing foundation and basement walls, elevating electrical/mechanical equipment, installing sump pumps, etc.

69. Erosion Hazard Mapping

In coordination with the CWCB and CHAMP, adopt new mapping and regulatory standards for areas within the County that are at high risk to fluvial erosion (identified as a special flood-related hazard). Fluvial Hazard Zones (FHZs) should be identified and used to augment existing special flood hazard areas as identified on the County's effective Flood Insurance Rate Map and Floodplain Zoning Overlay District (for regulatory purposes). The FHZ initiative could be modeled after the program developed by the Vermont Department of Environmental Conservation and would greatly benefit from the well documented strategies, protocols, and products established within that program. Land development regulations may include the creation of FHZ “avoidance zones” and specific setback requirements from FHZs to protect new structures and renovated structures from near-term erosion and potential future flooding.

70. Increase stakeholder engagement for MHMP update process

Expand the membership of the Hazard Mitigation Planning Committee (HMPC) to include more stakeholders from outside County government to maximize credit for Step 2 (Involve the Public) under Activity 510 (Floodplain Management Planning). It is recommended that during the next MHMP Update the County establish a resident or stakeholder advisory subcommittee for this purpose, with members augmenting a core steering committee but acting as full HMPC members throughout the process (e.g., actively participating in all HMPC meetings with the ability to provide input, vote, and receive all the materials that regular members do). Ideally at least one-half of the full HMPC (including steering and subcommittee members) should be representatives of the public or other stakeholders. This action will help the County capture key stakeholder input throughout the plan update process and also meet a prerequisite for increasing its current CRS Class (Class 4 or better requires 50% of the maximum credit for this planning step). The new HMPC structure should also be sustained for future plan updates through amended plan maintenance procedures as adopted in Section 7 of the MHMP.

These types of non-governmental advisory committees can provide opportunities for stakeholders to be more directly involved in many ways (beyond simply attending a public meeting or responding to a survey); however it was mainly recommended for the potential big increase in CRS credit points under Activity 510. If the County isn't seeking to increase its CRS Class."

71. Local floodplain buyout program

Develop a locally-financed floodplain buyout program to 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.). This action should also be linked with the recommended Flood Mitigation Investment Program action. Avoid FEMA eligibility and BCA concerns (see Lit Review 170). If is a presidentially declared disaster, the local funds could also be used to match federal funds. Acquired land could also be used to expand greenway trails adding transportation redundancy.

Resiliency scenarios for locally-financed investments need to be further discussed with the team to determine feasible options of revenue sources for the County to pursue (annual budgeting, CIP, special purpose districts, debt financing, public-private partnerships, etc.). Emerging best practices such as 100RC's "10% Resilience Pledge," resilience bonds, Resilience Improvement Districts, etc. should also be considered.

An example of this is Charlotte-Mecklenburg's Floodplain Buyout Program which has been funded mostly through local money. For more information see here:
https://charlottenc.gov/StormWater/Flooding/Pages/FloodplainBuyoutProgram.aspx"

72. "Quick Buy" program

As part of the Local Floodplain Buyout Program described above, the County should also consider developing a locally-financed ""Quick Buy"" option that is aimed at rapidly acquiring eligible 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 inevitably suffer from applicants losing interest and dropping out due to their implementation schedules.

One of the biggest reasons for drop out from FEMA's buyout program (including for the 2013 flood) is due to the time it takes to actually implement them. The concept of the Quick Buy program is to eliminate the time and administrative hurdles associated with state/federal grants.

73. Enhance flood control and drainage system maintenance procedures

Develop a program to routinely (annually at a minimum) inspect public and private drainage systems and remove debris or otherwise improve as appropriate, with special attention paid to known problem areas that may require more frequent inspections (including and perhaps especially those areas outside of mapped special flood hazard areas). 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. 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). Review and consider mitigating vulnerabilities when conducting scheduled maintenance activities.

Consider evaluating private and public infrastructure separately because the cost of each is very different."

74. Flood mitigation investment program

Establish a permanent, source of funding to implement flood mitigation projects that aren't bound to eligibility restrictions or other constraints associated with external sources (e.g., FEMA Hazard Mitigation Assistance grants). These funds could be leveraged as the local cost-share for projects for external resiliency grants. The program should be directly linked with the Multi-Hazard Mitigation Plan and other resilience-related plans or programs and could also be linked with a "rainy day" fund established by the County for post-disaster recovery and redevelopment needs that can't be met through other funding sources. This resiliency scenario for locally-financed investments needs to be further discussed with the team to determine feasible options of revenue sources for the County to pursue (annual budgeting, CIP, special purpose districts, debt financing, public-private partnerships, etc.). Emerging best practices such as 100RC's "10% Resilience Pledge," resilience bonds, Resilience Improvement Districts, etc. should also be considered.

76. Promote flood insurance

Develop an education and outreach program to promote adequate flood insurance coverage for residents and small businesses so that they can be financially protected from potential flood events. This should include providing persuasive information to owners of uninsured properties located in identified Special Flood Hazard Areas (SFHAs), but also to those located in areas that are not considered high risk. In particular, the County should coordinate with non-profit and community-based organizations that serve vulnerable populations within the county on the availability of low-cost or subsidized insurance for non-SFHA properties (including renter policies). The County should carefully review and follow the activities credited under CRS Activity 370 (Flood Insurance Promotion) in order to develop an effective program and to maximize CRS credit points for this action.

Activity 370 guidance may offer some good practices, but the County should go with what works for them – not FEMA/CRS."

77. Deliver a more cohesive flood risk education and outreach program

The County's current education and outreach activities for floodplain management are considered sporadic (including program and project specific web pages, as well as project specific community meetings, newsletters, and listserv emails from multiple departments). Given its limited resources but a strong desire to implement a more structured and effective program, Boulder County will (1) identify and prioritize its goals for public education and outreach on flood risk awareness, preparedness, and mitigation; and (2) develop and deliver the program components to achieve those goals. This action should continue to be informed and updated by the County's Floodplain Program Manager in partnership with CU Denver as it relates to the pending capstone proposal. It can also serve to better align and/or integrate the many outreach projects the County implements and receives credit for under CRS Activity 330. The ultimate objective is to create a more consistent, sustainable, and effective program for meaningful public education and outreach that results in measurable improvements for flood risk reduction (e.g., increased flood insurance coverage, individual flood preparedness or mitigation activities, etc.).

79. Flood risk tracking and mitigation tool

Develop a GIS-based flood risk assessment and mitigation planning tool to continuously measure flood risk and prioritize mitigation measures over time. Using best available data, including digital flood hazard data and other local data layers (buildings, parcels, cadastral, etc.), Boulder County will build and maintain a dynamic, real-time tracking tool for purposes of determining flood risk at various scales (aggregate, parcel, or groups of parcels) and prioritizing flood mitigation projects based on specific community-based evaluation criteria. This tool could also track projects that have been implemented and evaluate how they perform after a flood event to validate the cost-benefits of resilience. Proof of concept exists for this in Charlotte-Mecklenburg County, NC where a similar tool has already been developed and is currently being updated with the ability to be replicated at varying scales by other communities (demo presentation can likely be arranged). Overall, this tool would be similar to the FEMA vision for a Mitigation Portfolio tool. The tool could incorporate elements of a tool like City Simulator that also projects future risk.

80. Interactive flood risk communication and mapping tool

Update and enhance Boulder County's existing online ""Official Floodplain Map"" to include more detailed flood risk data (i.e., annual chance of flooding, velocity zones, etc.) and mitigation information (property protection measures, flood insurance costs, etc.) at the individual parcel or building scale. Applying best practices from other states and communities could help users to identify, assess, and reduce their flood risk (including the purchase of flood insurance and low-cost mitigation measures) based on the specific attributes of their property. This tool could be integrated with the recommended Flood Risk Tracking and Mitigation Tool action and could incorporate elements of a tool like City Simulator to project future risk. Example of where all of this has been done and continues to improve: http://meckmap.mecklenburgcountync.gov/3dfz/"

81. Define and identify High Hazard Zones (HHZs) for unincorporated areas of Boulder County

Although the County has identified and mapped Special Flood Hazard Areas (SFHAs) as defined by FEMA and/or the CWRB, it is also recognized that there are specific areas of unacceptable risk or high hazard within these SFHAs (i.e., based on depth and/or velocity) that may require different flood risk management techniques, such as enhanced risk communication or higher regulatory standards. The definition and identification of High Hazard Zones (HHZs) for this purpose is recommended to better tailor the County's floodplain management activities for specific areas (and not assume blanket application across an entire SFHA). The City of Boulder has defined their own HHZ as the area of the floodplain where there is the greatest risk of loss of life (and should not be occupied by people during a flooding event). It is more expansive than the floodway but not as extensive as the flood fringe, based on depth/velocity curves that determine where the potential exists for people to be swept off their feet. Boulder County should further consider defining its own HHZs for which to base more geographically specific regulations (e.g., protecting life/safety but also new development, substantial improvements and/or post-flood rebuilding), and this action should be revisited/refined based on the new flood hazard data soon to be provided by CWCB through CHAMP. This could include mapping targeted slope stability issues and debris flows under flood conditions.

84. Periodically update Boulder County's database of structures within the 100- and 500 -year floodplain.

At regular intervals, update the database of structures within the 100-and 500-year floodplain. Updates should be scheduled prior to major resiliency related planning efforts.

87. Modified substantial damage/improvement definitions

Propose updated definitions for Substantial Damage and Substantial Improvement in existing floodplain regulations (Section 4-400 of the Boulder County Land Use Code). The County should consider adopting (a) provisions for counting substantial damage/improvements cumulatively over time (with a specified look-back period, such as 10 years), and/or (b) a lower threshold d for substantial damage/improvement determinations (less than the current threshold of 50%).

This could apply to different zones or special overlay districts should the County want to do that. It could make sense if there are specific areas of concern (e.g., erosion hazard zones)."

88. Develop and implement a climate change adaptation plan

Undertake an assessment to determine how climate change might affect flood frequency and magnitude in the county. Consider potential revisions to rainfall-runoff models and corresponding drainage criteria design, the county, in coordination with the city and Urban Drainage and Flood Control District (UDFCD), should consider studying the issue in more depth and assessing whether floodplain management practices might need to change in the future.

Develop and implement a climate change adaptation plan to identify current vulnerabilities, address economics of recovery and determine strategies to protect the community against the potential negative impacts associated with climate change. "

89. Obtain drainage agreements to facilitate sediment control where channels are flanked by private land

Many of the county structures flanked by adjacent to private property, that require landowner permission to maintain both the structure and adjacent channel. County should continue to obtain maintenance easements for long-term drainage and resiliency needs.

90. Develop a debris operational plan

A debris management plan is a document based on anticipated identified threats, risks, vulnerabilities, capabilities, and resources. The management plan establishes the organizational structure, roles and responsibilities, application policies, reporting processes, sequence of events, anticipated duties and other key components. The debris management plan also includes the anticipated debris-specific issues based on the predicted disaster threats, used as a modelling example.

The debris operational plan is a post disaster guidance document that modifies the assumptions from the debris management plan and accounts for the specific criteria of a unique disaster event to adapt the debris response and recovery activities.

91. Set policy to comply with the time-to-recovery goals outlined in Resilient Design Performance Standard for Infrastructure and Dependent Facilities

Boulder County Transportation Department will commit to meeting time-to-recovery goals outlined in Resilient Design Performance Standard for Infrastructure and Dependent Facilities.

92. Process/policy to ensure infrastructure projects comply with Resilient Design Performance Standards outlined by the Boulder County CDBG-DR Collaborative

Comply with the Resilient Design Performance Standard which build on the Resilience Prioritization Criteria outlined in the Colorado Resiliency Framework. In incorporating these criteria, each infrastructure project designed using the Resilient Design Performance Standard will contribute to achieving the vision and goals for resiliency in the state.

Dev. Develop a trans/flood set of resilient design performance standards that are specific enough to be incorporated into design review Build on the Resilient Design Performance Standards outlined by the Boulder County Collaborative to develop a trans/flood set of resilient design performance standards that are specific enough to be incorporated into design review

93. Develop scour risk-based prioritization of bridge improvements

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

94. Develop procedures and capabilities to maximize infrastructure resilience funding from FEMA

Develop pre-disaster policies and procedures that will 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) following future presidentially declared disasters. PA 406 provides subgrantees with financial assistance to not simply restore, but to rather strengthen and bolster the resiliency of its assets through additional protective measures. The program has generally been underutilized and is often not actively promoted by PA program representatives (or advocated for by applicants) during the rush to repair damaged infrastructure and restore vital services as quickly as possible. With formal procedures in place the County will be more apt to seize these funding opportunities first, and before any such projects are considered or identified for other recovery assistance that is slower to happen, including the FEMA Hazard Mitigation Grant Program (HMGP). Such procedures could also 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), which will be funded by FEMA as a 6 percent set aside from disaster expenses to allow for a greater investment in mitigation before a disaster.

95. Update design standards to favor bridges over of 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 resiliency over multiple cell pipe culverts. Bridges are less susceptible to clogging and failure from upstream debris collection, as well as compatible with the ecologic and geomorphic concepts.

Alternatively, culvert systems should consider the use floodplain culverts, to provide additional hydraulic capacity and limit downstream scour and erosion at the main culvert.

Consider designs that provide adequate flow conveyance and also effective sediment and debris transport and aquatic organism passage at new or improved stream crossings. Incorporate standards that favor stream-friendly, sustainable, resilient bridge and culvert design, which could reduce flood damage and maintenance requirements."

96. Policy to construct new roadways and roadway crossings above the 100-year floodplain

Propose that Boulder County construct road improvements above the 100-year floodplain where risks are identified to prevent damage to long stretches of roadway during large storm events. In accordance to Boulder criteria, new bridges are required to be elevated above the 100-year flood level. Minor structures are not.

97. Program redundancy into roadways when planning new facilities or major improvements of critical corridors.

During the 2013 flood event, six of the seven roads between the plains and the mountain communities in Boulder County failed because they were at the bottoms at canyons next to rivers and creeks and were washed away. Resilience can be improved by increasing the diversity of routing into the mountain or by increasing the robustness of one or more canyon roads to withstand more extreme floods.

Many mountain roads share the same narrow canyon corridor with adjacent streams and drainageways. The county should strive to build single road-river systems that improve the stream ecosystem, restores river function, and ultimately, is more resilient to future floods."

99. Augment resilience funding options

Seek additional ways to fund resilience actions.

100. Urban heat island mitigation

Mitigate impacts of extreme heat on urban heat islands in Boulder County, especially in areas with heavy pedestrian traffic, access to transit, and alternative transportation corridors (e.g., bike paths). Climate change will likely increase the risk from more extreme heat days.

101. Modify Public Work Manual for resilience

Evaluate potential changes to the County's transportation design criteria to factor in resilience: material choice for roadways to resist extreme heat, increase inlet heights, crown of road height, sidewalk height to better drain water. Use of low-water crossings should be considered. Consider green infrastructure near transit stops to offset urban heat island effect and relieve for riders.

102. Seek agreements with USFS for use of USFS owned, but use restricted transportation facilities, as bypass routes following events.

During the 2013 flood event, six of the seven roads between the plains and the mountain communities in Boulder County failed because they were at the bottoms at canyons next to rivers and creeks and were washed away. Resilience can be improved by creating bypass routes to be used following an event. Where use of transportation facilities are sometimes restricted (i.e. some USFS roads), agreements will be needed. Having agreements in place before an even will insure that the bypass is available for use and shorten the time it takes to make use of the facility.

103. Develop an Emergency Service and Evacuation Plan to assure that in disaster critical transportation corridors remain functional or can be rapidly reinstated.

Develop an Emergency Service and Evacuation 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 critical roadway.

As more of the Boulder County workforce move to outlying communities in search of more affordable housing, transportation infrastructure becomes increasingly important, particularly maintaining functional primary transportation corridors and transit routes during the most extreme events and prioritizing getting roads up and running again immediately following events.

During the September flood event, Highway 72 and Twin Spruce Gap Road were closed due to flooding and roadway damage. As a result, much of the canyon was isolated, emergency access was limited, and travel required extensive detouring to reach nearby communities along the Front Range."

104. Adopt a formal rating system for prioritizing infrastructure projects

One that includes factors that represent resiliency goals among other factors. Adopt a rating system to ensure resiliency, social equity, quality of life, and other factors are considered when prioritizing infrastructure upgrades and replacement. Such a system is used as a set of guidelines that aid in optimizing the sustainability of an infrastructure project during the planning and preliminary design phases, as well as to quantify the relative sustainability of the project.

105. Develop a program and agreements to provide evacuation transportation to carless and less mobile populations

Develop a program and 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 careless and less mobile populations receive assistance during natural disasters. Via has a policy of checking in with their clients during a natural disaster, this should become a formal agreement.

106. Develop emergency diversion routes

Develop emergency diversion routes and associated symbols to be displayed on existing road signage to outline diversion routes.

107. Install VMS signs on major routes to display safety information in the event of an emergency

Install VMS signs on major routes that can display road conditions but also safety information in the event of an emergency or disaster.

108. Vulnerable population resiliency needs assessment: transportation systems

Develop a countywide study that assesses the risks and stresses of vulnerable populations/low-income neighborhoods and propose improvements to makes these communities more resilient in terms of multimodal transportation mobility and emergency access following shocks. The study should work with cultural brokers to identify risks and stresses and should include mapping of communities with access challenges. Ensuring transportation systems and flood risk management strategies are socially equitable and serve vulnerable populations is mentioned in several of the study goal areas and objectives but is not well represented in literature review documents. This study would generate additional resiliency actions focused towards vulnerable populations.

109. Develop climate preparedness/adaptation checklists

Develop a series of climate preparedness/adaptation checklists that can be used when evaluating, selecting and prioritizing transportation or other infrastructure projects. Checklist may include evaluating effectiveness of storm water management, adapting hydraulic openings for culverts and bridges, pumping capacity of drainage systems, protection against scouring for bridges, and improved erosion control systems. 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.

110. Apply best practices and enhanced parameters for resilient design

Integrate climate-adaptive and resilient design and/or operational protocols for the County's transportation projects and programs. Incorporate resiliency standards and best practices into the planning of projects and programs and project development for individual projects. and improvement plans for upgrading or building new facilities, equipment and systems, and into routine maintenance and operations as opportunities arise. 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 local or metro DOTs. This includes the development of innovative resiliency standards based on asset-specific vulnerability analyses which have successfully dealt with uncertainty in future conditions modeling through iterative and adaptive risk management methods.

111. Climate vulnerability assessment for transportation infrastructure

Conduct a detailed vulnerability assessment of the County's existing and planned transportation infrastructure that identifies the physical elements and areas of the transportation system that are most sensitive to projected climate changes. This should include specific adaptation actions and resiliency policies for each transportation asset with due consideration of other social, economic, and environmental factors - including but not limited to identified vulnerable populations and their reliance on existing transportation assets.

112. Establish a Resiliency/Climate Change Program to keep up-to-date on the latest science, best practices, decision support tool, and disseminate findings to others

Following the lead of California's Climate-Safe Infrastructure Working Group to the CA State Legislature and the Strategic Growth Council, the Transportation Department can establish a Climate Change Research Program, and decision-support tools and other assistance that disseminate their findings, so as to meet the needs for improved understanding and forward-looking science information.

113. Enable staff to interact with climate scientists and resiliency subject matter experts as part of professional development efforts

Funding should be allocated to enable Transportation Department staff to substantively and collaboratively interact with climate scientists and other relevant experts in the creation of useful advice, guidance and tools on a regular and ongoing basis, in a way and at a level appropriate to their needs. http://resources.ca.gov/climate/climate-safe-infrastructure-working-group/"

116. Update all climate-sensitive infrastructure standards and guidelines that they can directly affect

The Transportation Department should update all relevant (i.e., climate-sensitive) infrastructure standards and guidelines that they can directly affect. Alternatively, or in addition, they should develop new state-specific guidelines where there are gaps to address climate resiliency by incorporating forward-looking climate information in those standards and codes. Until new standards and codes are in place, the department should develop guidelines that go above and beyond minimum standards and codes. http://resources.ca.gov/climate/climate-safe-infrastructure-working-group/"

117. Educate policy-makers and the public about the necessity of bearing the costs of improving resiliency

Because improving resilience is not a zero-sum activity, adding resilience in one area cannot be balanced by relaxing resilience requirements somewhere else. Adding requirements for resilience will come at a cost, so unfunded mandates are not feasible. The true costs over the full life-cycle of infrastructure projects should be assessed broadly, and the Transportation Department and County should make efforts to help policy-makers and the public better understand the necessity of bearing these costs. Educational, promotional and other outreach should be conducted to generate support for the expenditures.

118. Develop a work plan to address any climate-safe infrastructure training and professional development gaps of its infrastructure-related workforce

The Transportation Department needs to have the skilled workforce to get climate-safe infrastructure appropriately designed, built, operated and maintained. The County should develop a work plan on how to address the training and professional development gaps of its infrastructure-related workforce and begin to implement that work plan as soon as feasible.

119. Establish evacuation meeting spots where transit can take people to safe locations during natural disasters

New Orleans uses Evacuation Art to denote EvacuSpots where a city bus will take people who have no other means to leave the city to the Union Passenger Terminal if there is a mandatory evacuation. Boulder County could work with its incorporated jurisdictions to establish similar evacuation meeting spots for people with no or limited transportation.

120. Encourage green alley improvements and construction

The City of Chicago is committed to creating a greener, more sustainable environment by using best practices in alley improvements and construction. Different combinations of green alley techniques can be used to suit a variety of conditions. Permeable pavement, high albedo concrete, energy efficient light fixtures, recycled concrete base material, stormwater infiltration trench"

121. Create policy to ensure all large subdivisions have two means of evacuating during flooding and wildfire events

The City of Austin wrote a code whereby all large subdivisions must have two means of evacuating during flooding and wildfire events, and it can’t be on the same road. Boulder County could consider similar.

122. Increase transit service during economic crises to protect vulnerable populations

Vulnerable populations become increasingly reliable on transit during economic crises, at a time when transit providers may be trying to cut services as a cost saving measure. Develop policies and plans to ensure that during an economic crisis, transit services remain in place or are increased.

123. Develop agreements/partnerships with transit providers to establish post-disaster transit service plan

Currently, there are unofficial agreement with BVSD and SVVSD and RTD to evacuate people where needed. Written agreements are needed and reimbursement terms need to be determined.

124. Floodplain channel improvements on Boulder Creek at Saint Vrain Creek confluence

At the confluence with the St. Vrain Creek, Boulder Creek has breached along the north bank at a different location since the Alternative Analysis was submittal. The project plan would reflect maintaining the current stream alignment with the Boulder Creek / St. Vrain Creek confluence remaining at its existing location. Given the stream segment and breach occurs on City of Longmont Open Space, improvements in this area will be more related to maintenance of the existing stream configuration and ecological enhancements.

125. Address flooding at Boulder Creek and 95th Street

Flooding events have become more common at 95th Street. At the request of Boulder County, an interim improvement was developed to help prevent overtopping of the roadway during these more frequent storms, while still maintain the current bridge configurations and relation to downstream private property. This interim plan proposes changes to the roadway and integrates with stream restoration needs upstream of 95th Street on City of Boulder Open Space property. Although the interim condition is presented with the conceptual design, the master plan improvements and cost estimate reflect a longer term solution.

126. Boulder Slough Storm Sewer

During the September 2013 flood, flows that entered the Boulder Slough spilled from its banks upstream and downstream of 15th Street and flooded residences within the Goss Grove neighborhood. An alternative has been proposed at 14th street to intercept flows beyond the ditch capacity and convey the overflow to Boulder Creek via a storm sewer.

127. Replace Coal Creek bridges at Kenosha Road, 120th Street, Empire Drive, County Road and 2nd Avenue

The Kenosha Road, 120th Street, and Empire Drive bridges over Coal Creek are overtopped in 50-year and greater events. The structure at the County Road and Coal Creek crossing was overtopped in the 50-year event and failed during the 2013 flood. The 2nd Avenue bridge over Coal Creek is overtopped in the 100-year event.

128. Replace Rock Creek structure at Horizon Avenue

The structure at the Horizon Avenue and Rock Creek crossing is overtopped in the 10-year event.

129. Replace structure at Rock Creek and Dillon Frontage Road

The culvert at the Dillon Frontage Road and Rock Creek crossing was overtopped in the 10-year event and received national media attention when it washed out in the 2013 flood.

130. Replace Rock Creek structure at 120th Street and conveyance improvements, and remove buildings

The 120th Street bridge over Rock Creek is overtopped in 50-year and greater events. During the Conceptual Design Phase, it was discovered that overbank flows during the 100-year event threatened to overtop 120th Street south of the bridge regardless of structural improvements. Overbank conveyance improvements in this reach in conjunction with the road crossing upgrade channelized flood flows, preventing them from overtopping 120th Street, and remove all buildings along the reach from the 100-year floodplain. Because of this, the proposed design was changed from floodway preservation to overbank conveyance improvements

131. Coal Creek drop structure STA 61+50

Reach 1 - A 3-foot drop structure is proposed downstream of the Boulder and Weld County Ditch at station 61+50 to protect the ditch and the Kenosha Road bridge from future channel degradation.

132. Coal Creek County Line Road drop structure

A drop structure is proposed downstream of the East County Line Road bridge to protect the bridge from future channel degradation.

133. Coal Creek bank stabilization Reach 12

Reach 12 - Bank stabilization is proposed to protect the wastewater treatment plant, solar power station, East County Line Road, and in several other locations.

134. Coal Creek bank stabilization and drop structures Reach 22

A 1-foot drop structure is proposed on this reach at station 729+00 downstream of the railroad bridge to stabilize the channel invert and protect the bridge. An additional 3-foot drop structure is proposed at station 745+00 downstream of the pedestrian bridge. The channel is sinuous in this reach and channel bank erosion threatens the railroad grade at stations 725+00 and 737+00. The recreation path along Coal Creek is also threatened by channel bank erosion in multiple locations along the reach. In addition to the existing channel bank armoring, bank stabilization measures are recommend in several parts of the reach to protect infrastructure.

135. South Public Road bridge drop structure

Reach 23 - A 2-foot drop structure is proposed downstream of the South Public Road bridge to protect it from channel invert degradation.

136. Coal Creek Reach 27 drop structures

Drop structures are proposed downstream of the railroad bridge at station 940+00, downstream of County Road, and downstream of the Coal Creek Trail bridge at station 998+40 to protect the bridges from channel degradation.

137. Coal Creek Reach 28 structure elevation checks

Reach 28 - The two structures within the 100-year floodplain were not inundated with stormwater during the 2013 flood, which exceeded the 100-year event in this reach. It is recommended that these structures obtain elevation certificates to more accurately determine whether or not they are within the 100-year floodplain...

138. Coal Creek Reach 28 armoring

During the 2013 flood, the area upstream of, within, and downstream of the Highway 36 crossing experienced channel bank erosion. The trail downstream of the crossing also experience significant damage. Large riprap armoring is recommended for these locations.

139. Coal Creek Reach 29 floodway improvements

Reach 29 - Floodway Preservation is proposed for this reach. The 100-year floodway channel has an average top width of 277 feet. A 3-foot drop structure is recommend downstream of McCaslin Boulevard to protect the structure from channel degradation. Two additional 3-foot drop structures are proposed in the reach to reduce the average grade.

140. Coal Creek Reach 31 check structure

Reach 31 - A check structure is proposed downstream of the Mayhoffer Singletree Trail crossing to protect the pedestrian bridge from potential vertical channel instability

141. Coal Creek Reach 32 erosion protection

Reach 32 - County Road 25 and the Community Ditch irrigation structure should be protected from erosion, but the reminder of the reach can be safely allowed to meander and change course naturally.

142. Coal Creek Reach 40 overbank conveyance improvements

Overbank Conveyance Improvements are proposed for this reach above station 2024+00 to remove all five adjacent commercial and industrial structures from the 100-year floodplain. Implemented in conjunction with the proposed structures at Horizon Avenue and 120th Street, the proposed Overbank Conveyance Improvement removes all buildings, 120th Street, and Horizon Avenue from the 100-year floodplain within Reach 40.

143. Rock Creek Reach 41 bank stabilization

The Rock Creek Trail parallels the creek for the entire reach. The channel approaches commercial property at stations 2103+00 and 2074+00. Bank stabilization is proposed next to the commercial properties and near the trail.

144. Rock Creek Reach 43 bank stabilization

Reach 43 - The erosion does have the potential to compromise a pedestrian bridge abutment in the vicinity and bank stabilization is proposed at the location. Channel bank stabilization is also proposed at station 2208+00, where the incised bank is 5 feet from the Rock Creek Trail.

145. Rock Creek Reach 50 bank stabilization

Reach 50 - Additional bank stabilization is proposed at station 2470+00 on the left bank, where the channel approaches Highway 36, and at station 2460+00 on the right bank immediately upstream of the Highway 36 culvert.

146. Rock Creek Reach 51 bank stabilization

Reach 51 - Bank stabilization is recommended near station 2501+00, where incised banks potentially threaten a recreation path and BMX pump track.

147. Private Bridge Inventory

Create inventory of private bridge crossings on drainageways to facilitate cataloging, permitting, inspections, and post-event efforts.

148. Private Bridge Maintenance & Replacement Program

Consider creating a county-administered program to fund maintenance and replacement of privately-owned bridges on major drainageways. Landowners could apply for grant funding to perform maintenance on or replace entirely their bridges. Permitting processes could be utilized to ensure the new bridges meet applicable floodplain requirements.

149. Post-Event Private Bridge Assistance

In the event of private bridge damage or destruction due to a flood event, the county can assist landowners with finding resources to repair or replace the bridges. The assistance could include helping landowners find contractors, engineers and funding sources.

150. Overland Road at South Saint Vrain

Replace older, undersized culvert structure that overtops at less than 100 year event. Overland Road serves as the only second access available to Jamestown if James/Lefthand Canyon access is not available.

151. 61st Street at Four Mile Canyon Creek

Four Mile Canyon Creek has a split flow near 61st Street. Only a portion is contained within the channel to the main culvert. A portion splits to the north and overtops the road near the curve during larger events. Determine how to add capacity at the secondary crossing.

152. 2D Flow Modeling

Utilize 2D flow modeling for hydraulic analysis. The enhanced capabilities could result in smaller structures than would otherwise be built.

153. Asset Management database and tools

Adopt GIS-based asset management system. Past projects, future projects, known issues, vulnerabilities, etc. could all be added to allow quick searching by area/project/etc. Potential to reduce future design costs and speed up the project prioritization and design processes. True asset management tools can help predict lifecycle cost, inform maintenance and inspection schedules, and lead to better managed assets.

154. Floodplain Development Permit Requirements in Plans

Ensure all known FPDP requirements are included by standardized notes or other items included in construction plans. Helpful to both designers and contractors and minimizes risk through standardization.

155. Value Planning / Value Engineering

Utilize Value Planning / Value Engineering during the project design process. VE/VP reviews can result in increased value from a project by reducing current/future costs and/or enhancing the capabilities/value of what’s being built.

156. Real Time Work Zone Data

Utilize GPS or other technology to track real-time locations of lane closures, road work, etc. Access the data via smartphone apps.

157. CDOT Drainage Design Manual Lessons Learned

CDOT is currently in process of updating the Drainage Design Manual. It will probably include a section on lessons learned from the 2013 flooding. Review the lessons learned for anything applicable to Boulder County.

158. Freeboard waivers, discounts, or rebates

Provide fee waivers, discounts, or rebates for site plan reviews and building permits issued for new construction or substantial improvement/repair projects that apply flood protection measures above the County’s required Flood Protection Elevation (FPE).

159. Remove higher freeboard regulatory barriers

Remove regulatory barriers and/or potential disincentives to voluntarily apply flood protection measures above the 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, or at a minimum ensure the County will grant special use permits in such cases).

160. Higher freeboard incentives

Promote the primary benefits of freeboard to all property owners (reduced flood insurance premiums in addition to decreased risk of flood losses) through the use of compelling and reader-friendly flyers/graphics to support the case.

161. Incentives for other voluntary flood protection measures

In lieu (or in addition to) freeboard incentives, the County should provide incentives for additional but lower-cost (or DIY) flood protection measures that property owners can take on their own. At a minimum these should include the following:

(1) Promoting the voluntary purchase of flood insurance for all property owners (also identified as an action). A special promotional campaign should be launched for the low-cost coverage available through FEMA’s Preferred Risk Policy (PRP) to owners and tenants of eligible buildings located outside of the County’s mapped Special Flood Hazard Areas.

(2) Distributing or directing property owners to resources that have proven effective in other areas such as FEMA’s brochure titled “Protect Your Home from Flooding: Low-Cost Projects You Can Do Yourself” (see hyperlink at right).

(3) Removing regulatory barriers and/or potential disincentives to voluntarily apply flood protection measures. This includes addressing those measures that shouldn’t necessarily require a building permit and/or shouldn’t count as costs applied towards its cumulative Substantial Damage/Substantial Improvement (SD/SI) rule.

A key objective for Boulder County should be to inform and educate the public about the risk of flooding outside of mapped flood hazard areas. Various national statistics can be provided (e.g., more than 25% of flood insurance claims come from properties that are not in an identified high-risk zone; one-third of federal disaster assistance for flooding goes to non-SFHA properties, etc.), however it’s recommended that information more specific to Boulder County and/or other Front Range communities be provided."

162. Extend freeboard requirements to 500-year floodplain

Extend freeboard requirements to 500-year floodplain Extend FPE / freeboard requirement (two feet above the 0.2% flood elevation or highest adjacent natural grade) for all new construction of residential and non-residential structures.

163. Prohibit critical facilities in the 500-year floodplain

Prohibit critical facilities in the 500-year floodplain Extend the prohibition of critical facilities to 500-year floodplain areas below 6,000 feet in elevation; or as an alternative specify certain types of critical facilities to be prohibited (e.g., those that must remain accessible during the 0.2% flood event because they are the base of operations for emergency responders, are particularly difficult to evacuate during a flood event, or provide services essential to the life, health, and safety of the community).

164. Apply higher standards for critical facilities in the 500-year floodplain

Apply higher standards for critical facilities in the 500-year floodplain In lieu of outright prohibition (above), require new and substantially improved critical facilities 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 0.2 percent annual chance (500-year) flood.

165. Prohibit structures for at-risk populations in the 500-year floodplain

Prohibit structures for at-risk populations in the 500-year floodplain Prohibit structures that house "at-risk populations" (e.g., schools, nursing homes, group home or assisted living centers, daycare facilities, etc.).

166. Prohibit new basements in the 500-year floodplain

Prohibit new basements in the 500-year floodplain Prohibit new basements.

167. Prohibit hazardous materials in the 500-year floodplain

Prohibit hazardous materials in the 500-year floodplain Prohibit storage of hazardous, toxic, or explosive materials unless elevated to the 0.2% flood elevation plus 2 feet.

168. Require dry land access for new development in the 500-year floodplain

Require dry land access during 500-year flood events for new development proposals (designed so building sites, walkways, driveways, and roadways are located on land with a natural grade with elevation not less than the 500-year flood).

169. Require elevated parking areas in the 500-year floodplain

Require parking areas be elevated to above the 500-year flood level for new, non-single-family buildings.

170. Require setbacks for the 500-year floodplain

Require setbacks for new or substantial improved buildings (e.g., 50’, 100’, 200’…) from the 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).

171. Require buffer zones for the 500-year floodplain

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

172. Countywide freeboard requirements

Develop alternative freeboard requirements that can be applied throughout the entire county (not limited to SFHAs) Apply alternative elevation requirements (not based solely on the BFE/FPE) to any new development permit in the County. For example, consider this regulatory approach in Cutler Bay, FL which enforces a 1-foot freeboard in the SFHA but also the following higher standards.

Any residential structure will meet the highest of the following criteria:

1. Base flood elevation as depicted on the current FIRM plus one foot (one foot of freeboard);
2. Highest adjacent crown of road plus one foot;
3. Back of sidewalk elevation plus one foot;
4. Street abutting property plus one foot;
5. Highest edge of cross section of road plus one foot.

Any nonresidential structure will meet the highest of the following criteria:

1. Base flood elevation as depicted on the current FIRM plus one foot (one foot of freeboard);
2. Highest adjacent crown of road plus one foot. "

173. Develop on-site stormwater retention requirements

Develop on-site stormwater retention requirements for all new development Require on-site stormwater retention by prohibiting water from running across one property on to another. See below regulatory language from Cutler Bay, FL, however this type of standard may not be necessary for most areas of unincorporated Boulder County (better suited for flat and urbanized locations with stormwater management problems).

It shall be unlawful and a violation of this article to dispose of any rainwater, stormwater runoff or other liquids by allowing or causing the same flow on, over or across any adjoining property, ROW, easement, and drainage canal either private or public. Exceptions to this condition may be allowed on a limited basis for necessary repairs to swimming pools, based on a case by case review and approval of the town's public works department as long as necessary treatment of the water meets the minimum standards as established by Miami- Dade County DERM, SFWMD or the governing agency.

Appendix 6. Resiliency Action Evaluation & Scenario Model Memorandum

Memorandum

Date:	January 2, 2019
To:	Boulder County, Project Management Team: Floodplain Management and Transportation System Resiliency Study and Action Plan
From:	Atkins North America **Email:** Steve.Hoover@atkinsglobal.com
Subject:	Evaluation Metrics

This memorandum documents the proposed metrics for evaluating potential resiliency actions developed through Boulder County's Floodplain Management and Transportation System Resiliency Study and Action Plan project. The metrics documented in this memo are the basis for determining the degree to which potential resiliency actions meet each of the sub-criteria of the decision model (the decision model is the subject of the Resiliency Action Evaluation and Scenario Model Memo, and illustrated in Figure 1).

Figure 1. Overall Evaluation Model. Evaluation Metrics Measure Sub-Criteria Values

Evaluation Metrics by Goal and Objective.

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

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

      0% attainment of objective = The proposed resiliency action does not involve resiliency-related coordination internally among and between departments, and/or externally between agencies, organizations, and the public.

      25% attainment of objective = The action initiates a one-time or limited resiliency-related coordination between departments and/or externally between agencies, organizations, or the public.

      50% attainment of objective = The action fosters reoccurring resiliency-related coordination between departments and externally between agencies, organizations, or the public for a set timeframe and reoccurring coordination is not formalized (i.e. formalized meaning such coordination is a documented step in scopes, MOUs, procedures, workplans, etc.).

      75% attainment of objective = The action formally requires reoccurring resiliency-related coordination between departments, and/or externally between agencies, organizations, and the public, but for a limited timeframe.

      100% attainment of objective = The action formally requires reoccurring resiliency-related coordination between departments, and externally between agencies, organizations, and the public for an open-ended timeframe.

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

      0% attainment of objective = Action does not determine or evaluate risk for short-term or long-term conditions.

      33% attainment of objective = Action makes a one-time determination and evaluation of risk for short-term or long-term conditions.

      67% attainment of objective = Action makes a one-time determination and evaluation of risk for short-term or long-term conditions *and* makes it very likely that action will foster additional determinations and evaluations in the future.

      100% attainment of objective = Action regularly determines and evaluates risks for short-term and long-term conditions.

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

      0% attainment of objective = Action does not foster initialization of regular evaluation, prioritization, and implementation of risk-mitigating solutions and innovations.

      50% attainment of objective = Action provides a one-time evaluation, prioritization, and supports funding and implementation of risk-mitigating solutions.

      100% attainment of objective = Action formalizes a platform for risk-mitigating solutions and innovations, to be regularly evaluated, prioritized, funded, and implemented regularly, at set intervals, for an open-ended timeframe.

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

0% attainment of objective = Action does not involve integrating resiliency into policies, regulations, decision-making processes, and budgets.

33% attainment of objective = Action initiates a one-time integration of resiliency into a decision-making process or budget.

67% attainment of objective = Action fosters integration of resiliency into policies or regulations and/or integrates resiliency into decision-making processes or budgets more than once.

100% attainment of objective = Long-term and sustained integration of resiliency into policies, regulations, decision-making processes, or budgets is the central outcome of this action.

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

0% attainment of objective = Action does not consider resiliency or other factors when prioritizing infrastructure for upgrades and replacement.

50% attainment of objective = Resiliency, along with other factors, are considered but not required when prioritizing infrastructure for upgrades and replacement

100% attainment of objective = Action requires resiliency to be a factor when prioritizing all infrastructure upgrades and replacement.

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

0% attainment of objective = Action does not provide people with education about resiliency or plans to respond to shocks.**50% attainment of objective** = Action initiates a one-time initiative or opportunity to provide people with education about resiliency or help prepare plans to respond to shocks. Action seems reasonable effective in educating people.

100% attainment of objective = Action initiates ongoing initiatives or opportunities to provide people with education about resiliency or help prepare plans to respond to shocks. Action seems highly effective in educating people.

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

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.

0% attainment of objective = Action does not identify risks and vulnerabilities for the purpose of making infrastructure and services to withstand shocks or fail in predictable ways.

33% attainment of objective = Action identifies risks and vulnerabilities for the purpose of making infrastructure and services to withstand shocks or fail in predictable ways. But does not address them

67% attainment of objective = The action proposes solutions which addresses an identified risk or vulnerability by making infrastructure and services to withstand shocks or fail in predictable ways.

100% attainment of objective = Action identifies a broad range of risks and vulnerabilities and proposes (a) concrete solution(s) so that infrastructure and services are made to withstand shocks and/or designed to fail in predictable ways to minimize impacts. Or, the Action addresses previously identified broadly ranging risks or vulnerabilities by making infrastructure and services to withstand shocks or fail in predictable ways.

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

0% attainment of objective = Action does not prepare transportation systems or manage flood risk to withstand shocks..

50% attainment of objective = An action to prepare transportation systems or manage flood risk to withstand shock has some direct or indirect benefit to vulnerable populations.

100% attainment of objective = An Action to prepare transportation systems or manage flood risk to withstand shock benefits the public equitably and protects vulnerable populations. Or, the location benefiting from an Action that helps communities withstand shocks is historically underserved.

c. Actions to prepare transportation systems and manage flood risk emphasize assets that are critical, are connected to other systems, and are significant to peoples' lives.

0% attainment of objective = Action does not prepare transportation systems or manage flood risk to withstand shocks with emphasis on assets that are critical, are connected to other systems, and are significant to people's lives..

33% attainment of objective = Action to prepare transportation systems or manage flood risk to withstand shocks did not consider the criticality of the asset (or assets protected by the action).

67% attainment of objective = Action to prepare transportation systems or manage flood risk to withstand shocks focuses on critical asset(s).

100% attainment of objective = Action to prepare transportation systems or manage flood risk to withstand shocks focuses on critical asset(s), are connected to other systems, and are significant to peoples' lives.

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

0% attainment of objective = Action is not based on a previously identified and documented project, need, plan, etc.

25% attainment of objective = Action is the product of an identified need documented in a plan.

50% attainment of objective = Action is the product of an identified need documented in multiple plans.

75% attainment of objective = Action is a specific project, policy, or recommendation identified in plan(s).

100% attainment of objective = Action is a specific high-priority project, policy, or recommendation identified in plan(s).

3) Respond to shocks: Transportation systems and flood risk management respond effectively to shock events.

a. Essential activities are preserved following shock events.

0% attainment of objective = Action does not involve preserving activities following shock events.

50% action preserves activities following shock events, but the criticality of those activities is unknown.

100% attainment of objective = Action takes proactive steps to preserving identified essential activities following shock events.

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

0% attainment of objective = Action does not involve recovery from shocks or minimizing interruptions.

50% attainment of objective = Action involves recovery from shocks, but there is no evidence that it is connected to a broader method for prioritizing efforts to minimize interruptions.

100% attainment of objective = Action involves recovery from shocks and it is connected to a broader method for prioritizing efforts to minimize interruptions.

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

0% attainment of objective = Action does not relate to the provision of mobility following a shock.

50% attainment of objective = Action identifies transportation system needs that if addressed would improve multimodal community mobility and emergency access and egress following shocks.

100% attainment of objective = Action would directly or indirectly improve transportation systems, multimodal community mobility, or emergency access and egress following shocks.

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

0% attainment of objective = Action does not include floodplain management strategies.

33% attainment of objective = Action involves floodplain management strategies, but their ability to mitigate shocks and reduce harm are marginal.

67% attainment of objective = Action features floodplain management strategies that are adequate to respond to and mitigate shocks and reduce harm.

100% attainment of objective = Action is focused on floodplain management strategies that proactively respond to and mitigate shocks and reduce harm.

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

0% attainment of objective = Action does not involve "bouncing forward" through shock recovery.

50% attainment of objective = Action promotes "bouncing forward" after shock events and enabling Boulder County communities to improve capability of affected transportation infrastructure and systems to better withstand future shocks and stresses.

100% attainment of objective = Action requires recovery from shocks that enable Boulder County communities to improve capability of affected transportation infrastructure and systems to better withstand future shocks and stresses.

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.

0% attainment of objective = Action does not involve transportation systems or related flood risk management responses to shocks.

50% attainment of objective = Action provides some direct or indirect benefit to vulnerable populations in terms of transportation systems or flood risk management responses to a shock event and enabling mobility and access to services, jobs, commerce, and community.

100% attainment of objective = Action related to transportation systems or flood risk management response to shock enables mobility and access to services, jobs, commerce, and community that benefits the public equitably and protects vulnerable populations . Or, the location benefiting from the Action is historically underserved.

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

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

0% attainment of objective = Action does not involve identifying or monitoring on-going or potential transportation system stresses or flood risks.

50% attainment of objective = Action identifies on-going and potential transportation system stresses or flood risks.

100% attainment of objective = Action identifies on-going and potential transportation system stresses or flood risks and establishes a program for monitoring or revisiting stress identification on a repeating basis.

b. Solutions to flood risk stress on the transportation system risks are developed.

0% attainment of objective = Action does not involve developing solutions that address flood risk stress on the transportation system.

33% attainment of objective = Action identifies solutions to flood risk stress on the transportation system.

67% attainment of objective = Action promotes solutions to flood risk stress on the transportation system.

100% attainment of objective = Action develops and requires implementation of solutions to flood risk stress on the transportation system.

c. Reduction of flood risk and transportation system stresses benefit the public equity and protects vulnerable populations.[2]

0% attainment of objective = Action does not involve reduction of flood risk or transportation system stresses for vulnerable populations.

50% attainment of objective = Action provides some direct or indirect benefit to vulnerable populations in terms of reducing flood risk or transportation system stresses.

100% attainment of objective = Action centers around the reduction of flood risk or transportation system stresses that benefits the public equitably and protects vulnerable populations.

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

0% attainment of objective = Action does not address transportation system or manage flood risk stresses.

50% attainment of objective = Action addresses transportation system or manages flood risk stresses but does not emphasize assets that are critical, are connected to other systems, or are significant to peoples' lives.

100% attainment of objective = Action addresses transportation system or manages flood risk stresses and emphasizes assets that are critical, are connected to other systems, and are significant to peoples' lives.

5) Cost Measures

a. Financial Cost

Level	Approx. Cost	Assumption
0	$2 million or more	Significant project
0.25	Up to 2 million	Large project/program
0.5	Up to $500,000	Medium effort requiring consultant or other outside support.
0.75	Up to $100,000	Low cost. Minor consultant or other outside support needed.
1	No cost	No (nor nearly no) cost– can likely be embedded with existing work responsibilities/budget.

b. Level of Effort (Boulder Staff)

Level	Description	Assumption
0	High Effort	Significant Boulder County Staff time and energy will be required. Likely to overwhelm staff/dept. resources
0.33	Medium Effort	Will involve alterations to staff/dept. tasks/responsibilities and increased workload.
0.67	Low Effort	Will involve some alterations to staff/dept. tasks/responsibilities and workload
1	Minimal Effort	Minimal or no alteration to staff/dept. task/responsibilities or workload

c. Public and Political Cost

Level	Description	Assumption

0	Controversial	Action will likely be politically controversial and may put Boulder County in the spot light. Action is likely to be opposed by large groups of the public.
0.5	Somewhat controversial	Action may be controversial in isolated areas but for the most part uncontroversial. Action is not likely to generate strong positive or negative views by the public.
1	Uncontroversial	Action will likely go unnoticed or will receive political support. Action is supported by the public.

Appendix 7. Possible Grant Funding Sources

BLM Wildland-Urban Interface Community and Rural Fire Assistance

This program, administered by the Bureau of Land Management (BLM), implements the National Fire Plan and assists communities at risk from catastrophic wildfire by providing assistance to develop local capacity and other activities related to assessment and mitigation planning, community and homeowner education, hazardous fuel reduction, local employment, and fire protection. These funds are available to states and local governments at risk as published in the Federal Register, Indian Tribes, public and private education institutions, nonprofit organizations, and rural fire departments serving a community with a population of 10,000 or less in the wildland-urban interface.

CDPHE Section 319/Nonpoint Source Program Grant Program

The 1987 amendments to the Clean Water Act (CWA) established the Section 319 Nonpoint Source Management Program Section 319 addresses the need for greater federal leadership to help focus state and local nonpoint source efforts. Under Section 319, states, territories and tribes receive grant money that supports a wide variety of activities including technical assistance, financial assistance, education, training, technology transfer, demonstration projects and monitoring to assess the success of specific nonpoint source implementation projects.

CSFS Forest Restoration & Wildfire Risk Mitigation Grant Program

CSFS is accepting Forest Restoration and Wildfire Risk Mitigation (FRWRM) grant applications for 1) fuels and forest health projects, and/or 2) capacity building projects on non-federal lands in Colorado. Eligible applicants include local community groups, local government entities, public and private utilities, state agencies, and non-profit groups. The FRWRM program was established through Senate Bill 17-050 and funded in 2018 by House Bill 18-1338 to provide state support in the form of competitive grant funds to encourage community-level actions across the state to:

- Reduce the risk of wildfire to people, property, and infrastructure in the wildland-urban interface (WUI)
- Promote forest health and forest restoration projects
- Encourage utilization of woody material for traditional forest products and biomass energy
- Successful applicants will receive final award approval with approximate project start date on June 1, 2019.

This funding source has potential applicability to Top Actions 3.2.5 and 3.2.4.

CSFS Colorado Forest Legacy Program

The Colorado State Forest Service’s (CSFS) Forest Legacy Program (FLP) authorizes the CSFS or U.S. Forest Service to purchase permanent conservation easements on private forestlands to prevent those lands from being converted to non-forest uses. The program provides an opportunity for private landowners to retain ownership and management of their land, while receiving compensation for unrealized development rights.

This funding source has potential applicability to Top Action 3.2.4.

CSFS Restoring Colorado’s Forests Fund

In the aftermath of destructive wildfires, reforestation of burned land helps protect water supplies, restores wildlife habitat and reduces flooding and erosion. The Fund provides tree seedlings for planting on privately owned and state-managed lands throughout Colorado that have been most severely impacted disasters. Areas that are most critical to water protection and wildlife habitat, and that provide the most public benefit, will be targeted for planting efforts.

This funding source has potential applicability to Top Action 3.2.4.

DOLA Conservation Trust Fund

The Department of Local Affairs distributes Conservation Trust Fund (CTF) dollars quarterly, on a per capita basis, to over 470 eligible local governments like Boulder County that provide park and recreation services in their service plans. Funding can be used for the acquisition, development, and maintenance of new conservation sites or for capital improvements or maintenance for recreational purposes on any public site. A public site is defined by the department as a publicly owned site, or a site in which a public entity/local government holds an interest in land or water.

DOLA Energy and Mineral Impact Assistance Fund

This fund administered by the Colorado Department of Local Affairs assists political subdivisions (municipalities, counties, school districts, special districts and other political subdivisions, and state agencies) that are socially and/or economically impacted by the development, processing, or energy conversion of minerals and mineral fuels. Eligible projects include, but are not limited to, local government planning, as well as capital projects such as water and sewer improvements, road improvements, construction/improvements to recreation centers, senior centers and other public facilities, and fire protection buildings and equipment.

DOLA Rural Economic Development Initiative

The Rural Economic Development Initiative (REDI) program is designed to help rural communities comprehensively diversify their local economy and create a more resilient Colorado. Three types of projects are eligible:

First, Local Government Economic Planning Grants ($100,000 limit). Projects must result in a plan that will help to diversify the local economy. Examples include: strategic plans, engineering plans, land use feasibility, and/or marketing studies. Consulting services for specific project implementation are also eligible.

Second, infrastructure grants that support economic diversification ($500,000 limit). Projects must result in infrastructure that supports the diversification of the local economy. Examples include facility expansion, business incubators, industrial park infrastructure.

Third, grants that support the growth and development of rural entrepreneurial eco-systems. Projects supporting community, economic or workforce development are potentially eligible for REDI assistance. Projects that support entrepreneurship, leverage private investment or public/private partnerships (e.g. innovation centers, co-working spaces, maker-spaces, business expansion and scaling up) could be eligible.

EDA Economic Development Administration Planning and Local Technical Assistance Programs

The Economic Development Administration (EDA) has established natural disaster mitigation and resiliency as a national strategic priority for investment. This program provides funds to assist with creating regional economic development plans and to strengthen the capacity of local organizations like Boulder County to undertake and promote effective economic development programs, including disaster resiliency plans.

This founding source could potentially be used for support Top Actions 3.4.2 and 3.2.1.

EPA Smart Growth Grants and Other Funding

The U.S. Environmental Protection Agency's Office of Sustainable Communities occasionally offers grants to support activities that improve the quality of development and protect human health and the environment.

FEMA Emergency Management Performance Grants Program

The purpose of the Emergency Management Performance Grants Program is to provide grants to states to assist state, local, tribal, and territorial governments in preparing for threats and hazards. Program grants focus on planning, operations, equipment acquisitions, training, exercises, and construction and renovation in enhancing and sustaining all-hazards emergency management capabilities. Colorado Division of Homeland Security and Emergency Management would have to apply to FEMA for funds on behalf of Boulder County. Support for grant applications would require Colorado Division of Homeland Security and Emergency Management support and coordination.

FEMA Hazard Mitigation Assistance

FEMA's Hazard Mitigation Assistance grant programs provide funding to protect life and property from future natural disasters. Currently, FEMA administers three programs that provide funding for eligible mitigation planning and projects that reduces disaster losses and protect life and property from future disaster damages. The three programs are the Hazard Mitigation Grant Program (HMGP), the Flood Mitigation Assistance (FMA) Program, and the FEMA Building Resilient Infrastructure and Communities (Formerly the Pre-Disaster Mitigation [PDM] Program). The Colorado Division of Homeland Security & Emergency Management (DHSEM), Mitigation and Recovery Section (MARS), administers FEMA Hazard Mitigation Assistance (HMA) programs. Eligible applicants must have a FEMA-approved Local Hazard Mitigation Plan in order to be eligible for HMA grant funds.

FEMA Building Resilient Infrastructure and Communities (Formerly Pre-Disaster Mitigation Grant Program)

This program provides funding on a nationally competitive basis for plans and for natural hazards mitigation projects. Eligible activities include Local Hazard Mitigation Plans, property acquisition and demolition, elevation or relocation, minor localized flood reduction projects (i.e., detention ponds, improved culverts, channel stabilization), structural retrofitting of existing buildings, infrastructure retrofits, construction of tornado safe rooms, and wildfire defensible space or fuels reduction projects.

FEMA Flood Mitigation Assistance Program

The Flood Mitigation Assistance (FMA) program provides funding for flood risk reduction activities. Communities eligible for FMA funding must be participants in the National Flood Insurance Program (NFIP). Eligible activities include property acquisition and demolition, elevation or relocation, and minor localized flood reduction projects.

FEMA Hazard Mitigation Funding Under Public Assistance, Section 406

FEMA can fund cost-effective mitigation measures under the Public Assistance (PA) program in conjunction with the repair of disaster-damaged public facilities. These opportunities usually become apparent during the immediate repair phase following disaster events. Eligible projects include Disaster recovery, storm-proofing retrofits, emergency aid, stormwater management, disaster preparedness, infrastructure upgrades. The program is administered by the Colorado Department of Public Safety, Division of Homeland Security & Emergency Management and awards funds from FEMA on a cost reimbursement basis. Eligible hazard mitigation measures must be identified and approved with an eligible PA project.

FEMA Hazard Mitigation Grant Program

The Hazard Mitigation Grant Program (HMGP) provides Post-Disaster Mitigation (PDM) funding in the event of a presidential disaster declaration. Potential activities funded through HMGP include all eligible PDM activities, in addition to post-disaster code enforcement activities. Eligible projects include property acquisition/easement, disaster preparedness, disaster recovery, vulnerability assessment, planning, stormwater management, storm-proofing retrofits.

FHWA Emergency Relief Program and Resilience

The Federal Highway Administration (FHWA) developed this document to clarify that program funds provided through the Emergency Relief (ER) Program may be used to rebuild more resiliently in ways that will prevent damage from future extreme weather events. The FHWA-ER program provides funding for the repair or reconstruction of Federal-aid highways that have experienced major damage from natural disasters or other externally-caused catastrophic failures.

FHWA Federal Lands Access Program

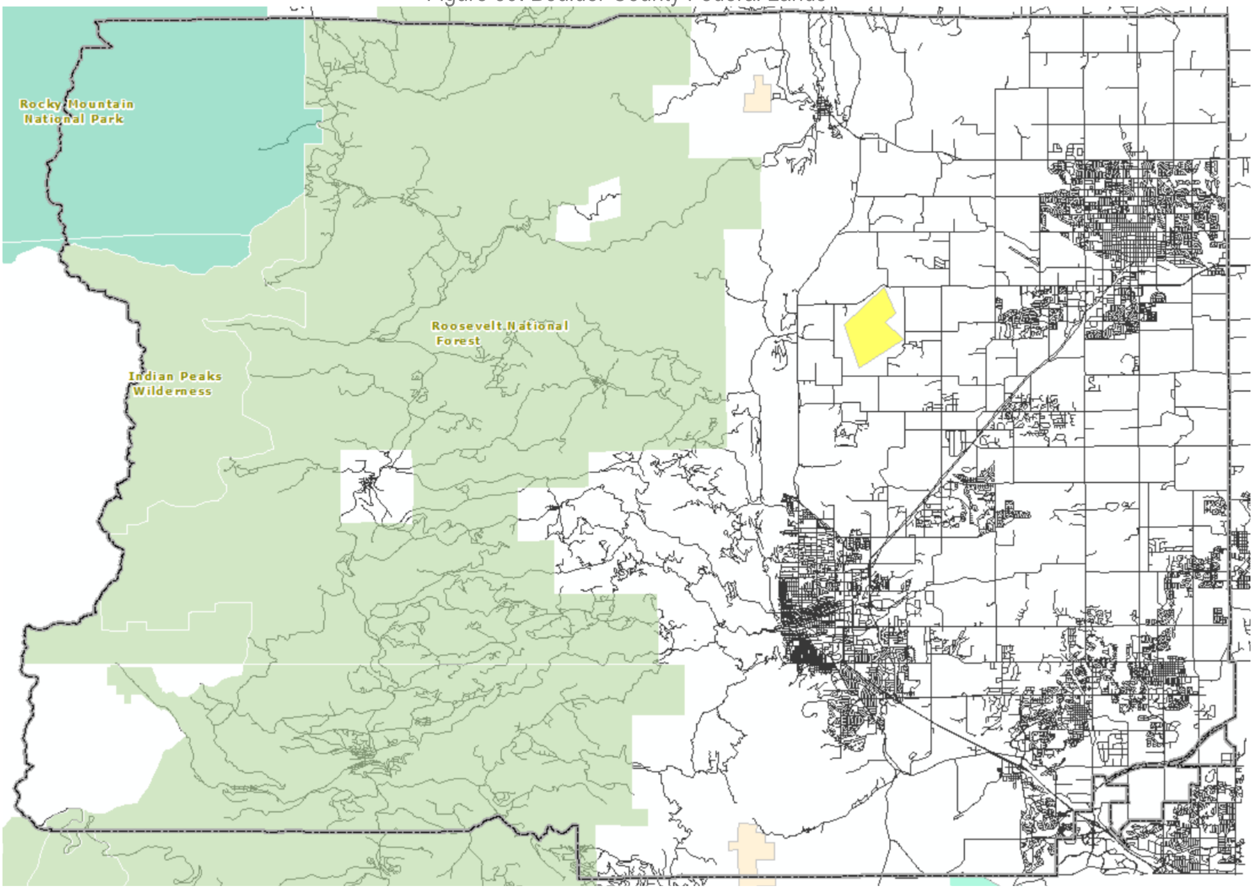
The Federal Lands Access Program (Access Program) is intended to improve transportation facilities and transit that provide access to, are adjacent to, or are located within Federal lands. The Access Program supplements State and local resources for public roads, transit systems, and other transportation facilities, with an emphasis on high-use federal land recreational sites and economic generators like Rocky Mountain National Park, Roosevelt National Forest, and Arapaho National Forest. Access Program funds are eligible for facilities owned and/or maintained by a state, county, or local agency. Colorado agencies receive about $16.7 million a year from the Program.

There are 227,026 acres of federal land in boulder county, including National Park Service's Rocky Mountain National Park. These areas are high-use public lands and popular destinations for both Coloradoans and out-of-state visitors alike. Rocky Mountain National Park received 4.6 million visitors in 2018 and was is deemed so vital to Colorado's economy that the State of Colorado paid to keep the park open during the 2013 government shutdown. The criticality of such federal lands to the Colorado economy make potential access disruptions due to flooding or other event especially unwelcome, and worthy of investment to prevent. Boulder County road, bridge, culvert, and transit projects that can prevent disruptions to access of federal lands would be highly competitive projects for the Program.

Access Program funds may be used for the costs of transportation planning, research, engineering, preventive maintenance, rehabilitation, restoration, construction, and reconstruction of transportation facilities located on or adjacent to, or that provide access to, federal lands. Applicable activities include parking areas; acquisition of scenic easements or historic sites; bicycle and pedestrian provisions; environmental mitigation; public safety; roadside rest areas; and other facilities determined by the Secretary of Transportation. Other eligible activities include the operation and maintenance of transit facilities, and any transportation project that is within, adjacent to, or provides access to federal land.

This funding source has broad applicability to recommended actions (Chapter 4.2). Those involving road, bridge, culvert upgrades, transit service, studies, and multi-use trails that in some way involve access to federal land (Figure 39) are eligible.

Figure 39. Boulder County Federal Lands



HUD Community Development Block Grant

The Department of Local Affairs administers the federal Community Development Block Grant (CDBG) program for non-entitlement municipalities and counties to carry out community development activities. Eligible uses of funds include acquisition, design/engineering, construction, reconstruction, rehabilitation or installation of public improvements or public facilities. Examples of projects include sewer and water systems, commercial streetscape improvements, community centers, food banks, shelters, health clinics etc. Because these funds must be used for activities that either benefit low- and moderate-income persons, Boulder County is limited in their ability to use them. or prevent or eliminate slums or blight.

HUD Community Development Block Grant - Disaster Recovery

The Colorado Department of Local Affairs (DOLA) administers the state's Community Development Block Grant - Disaster Recovery (CDBG-DR) grant dollars received from HUD for flood and fire recovery programs. The program addresses housing, infrastructure, planning, and economic development, including agricultural businesses.

Funding goes toward needs not addressed through other sources of public and private assistance such as the Federal Emergency Management Agency and Small Business Administration. This program reimburses local governments, communities, small business owners, farmers and homeowners for expenses associated with recovery projects and services. Funds reimburse grantees for costs incurred throughout the phases of ongoing, extensive reconstruction and rebuilding.

This program supports recovery efforts in 19 presidentially declared flood or fire-impacted counties, with a majority of the funds going to the most impacted counties: Boulder, Larimer and Weld. The grant stipulates 50 percent of the funds be distributed to low- and moderate-income households.

NFWF Resilient Communities Program

National Fish and Wildlife Foundation (NFWF) offers a category of grant that may be applicable to boulder County. NFWF is seeking applicants for high-impact resiliency adaptations that help communities prepare for fire, floods and droughts. The program is also interested in applications for community capacity-building projects that help communities understand environmental risks and opportunities and organize and take actions to improve local resiliency by enhancing natural buffers and system functions.

USDA Community Facilities Direct Loan and Grant Program

This program provides affordable funding to develop essential community facilities in rural areas. An essential community facility is defined as a facility that provides an essential service to the local community for the orderly development of the community in a primarily rural area, and does not include private, commercial or business undertakings. Project type include infrastructure upgrades, disaster preparedness, planning, property acquisition/easements. Grants can fund a maximum of 75 percent of eligible project costs.

USDA Conservation Innovation Grants

Conservation Innovation Grants (CIG) are competitive grants that drive public and private sector innovation in resource conservation to improve water quality, soil health, and wildlife habitat. The grants enables NRCS to work with other public and private entities to accelerate technology transfer and adoption of promising technologies and approaches to address some of the Nation's most pressing natural resource concerns. CIG will benefit agricultural producers by providing more options for environmental enhancement and compliance with federal, state, and local regulations.

This funding source shares a possible connection to Top Action 3.2.7 - *Flood risk tracking tool and climate vulnerability assessments.*

USDA Emergency Watershed Protection Program

This program, administered by the USDA, Natural Resource and Conservation Service (NRCS), provides federal funds to relieve imminent hazards caused by floods, fires, windstorms, and other natural occurrences. Eligibility is not limited to presidentially declared disasters and includes projects such as stream restoration, correcting damaged drainage facilities, establishing cover on critically eroding lands, repairing flood control structures, and the purchase of floodplain easements.

USDA Tree Assistance Program

The Agricultural Act of 2014 (the 2014 Farm Bill) authorized the Tree Assistance Program (TAP) to provide financial assistance to qualifying orchardists and nursery tree growers to replant or rehabilitate eligible trees, bushes and vines damaged by natural disasters. The 2014 Farm Bill makes TAP a permanent disaster program and provides retroactive authority to cover eligible losses back to Oct. 1, 2011.

The Budget Act of 2018 made several changes to TAP, including removing the per person and legal entity program year payment limitation ceiling of $125,000. It also increased the acreage cap, and growers are eligible to be partly reimbursed for losses on up to 1,000 acres per program year, double the previous acreage.

This funding source shares a connection to Top Action 3.2.4.

USDA Watershed Rehabilitation Program

This program, administered by the US Department of Agriculture, NRCS, provides funds to help rehabilitate aging dams that are reaching the end of their design lives to address critical public health and safety concerns. Eligible activities include the planning, design, and construction of entire projects. NRCS selects projects based on recent rehabilitation investments and the risks to lives and property if a dam failure were to occur.

USDA Watershed Protection and Flood Prevention (WFPO) Program

The WFPO is a cooperative program between the federal government, states, and locals to prevent erosion; floodwater and sediment damage; to further the conservation development, use and disposal of water; and to further the conservation and proper use of land in authorized watersheds. Of particular relevance to the Study, is the Program's commitment to financial and technical assistance for erosion and sediment control, watershed protection, and flood prevention projects.

USDOT Better Utilizing Investments to Leverage Development Grant Program

U.S. Department of Transportation offers the Better Utilizing Investments to Leverage Development (BUILD) transportation grant program. BUILD is a discretionary grant program that makes federal funding available on a competitive basis. Selection criteria encompass safety, economic competitiveness, quality of life, state of good repair, innovation and partnerships with a broad range of stakeholders.

Appendix 8. Transit Analysis

Transit Access Equity Analysis
Boulder County Resiliency Study

August 2019

1. Analysis Objective

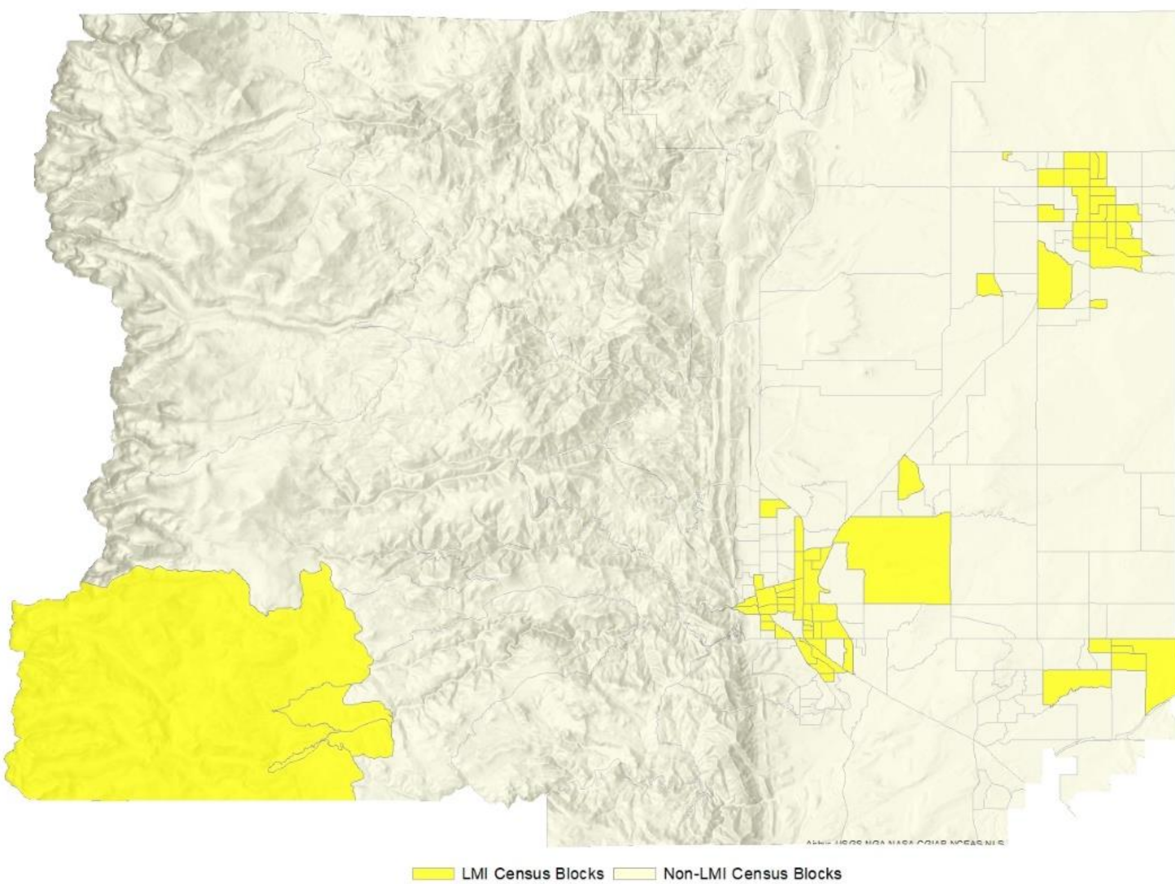
The objective of this analysis was to measure the level of low and medium income community transit accessibility to jobs, education, and health care across Boulder County. The underpinning of this objective was to determine the degree to which low and medium income communities are served by existing transit service, and compare that level of access to areas that are not low or medium income. This comparison is used to determine if low and medium income communities are underserved by transit service in contrast to other communities.

2. Approach

This analysis involved the calculations of employment, education, health care accessibility, indices for each census block group (area of land with households containing 600-3,000 people), where the index is the weighted sum of factors that reflect:

- Proximity to target establishments,
- Approximate travel times,
- Ability of residents to make use of transit,
- Level of low to moderate income community transit access compared to other communities' access.

Figure 2-1 Boulder County Census Blocks



2.1. Accessibility Index Formulation

The analysis is based on the following formula and variables.

$$Accessibility_{Establishment\ Type,\ Area} = \sum_{mode} \frac{Share_{Mode,\ Area}}{Travel\ Time_{Mode,\ Area}}$$

Establishment Types (Destinations)

See Table 2-1, below.

Table 2-1. Community Facilities: Establishment Types

Education	Health	Emergency	Employment
Day care	Later life/living care: Adult day care, assisted living, nursing homes, hospice	EMS	Commercial buildings
Public preschool to 12th grade	Clinics/Outpatient: Birth center, clinic, FQHC, disability care, end stage renal disease	Fire stations	
Private preschool to 12th grade	Home Health: Home health, home and community-based services		
University/trade schools: Colleges, universities, barber schools, fine arts, junior colleges, other technical and trade schools)	Hospital/Surgery: Hospital, surgery or transplant Rehab: Mental health facility, rehabilitation or recovery		

Area

Census Block Group. Analysis results are compared among Census blocks, are broken into two categories: low to moderate income (LMI) blocks, and all others. To assess the impacts of flooding on economically disadvantaged populations in the county, the study used the low-to-moderate income dataset developed by the US Department of Housing and Urban Development (HUD), which provides estimates at the census block group level. There are 203 census block groups in the county. Defining economically disadvantaged as those census block groups with 50% or higher low-to-mid income, the analysis found 66 census block groups that met the criterion.

Share

Is published in ACS for the selected Area Type

Travel Time

Was determined through the following steps:

- Find collection of establishments of target type across community.
- For each residential building unit in the target area (census tract or census block group), find the average distance to each establishment.
- Rank by distance (shortest to longest) and take the average of the top 10.
- Assume an SOV driving speed of 35 mph and multiply by average distance to get average SOV drive time.
- Multiply by mode impedance factor if not SOV
- Multiple by land use impedance factor (urbanized areas assumed to increase travel time).

- Analysis assumes a 15-minute wait time for transit
- Analysis assumes 4 mph walk speed to bus stops

Ridership

The analysis used travel time multiplied by census block population to create ridership indicators.

3. Results

The transit access equity analysis results in a 1 though 10 index score for each Boulder County Census block. The score represents access to the community facilities, or destinations, summarized in Table 2-1, with a factor for population levels. Higher index scores mean less transit accessibility for more people. Lower scores indicate greater transit accessibility for more people. Maps on the following pages depict the geographic distribution of these scores for each community facility type.

Comparisons of low to moderate income community transit access compared to other communities' access is summarized in Table 3-1. As summarized in the table, the transit access equity analysis shows that on average, low to moderate income communities have greater access to all community facility types studied, except for rehab.

Table 3-1. Transit Access Equity Comparison

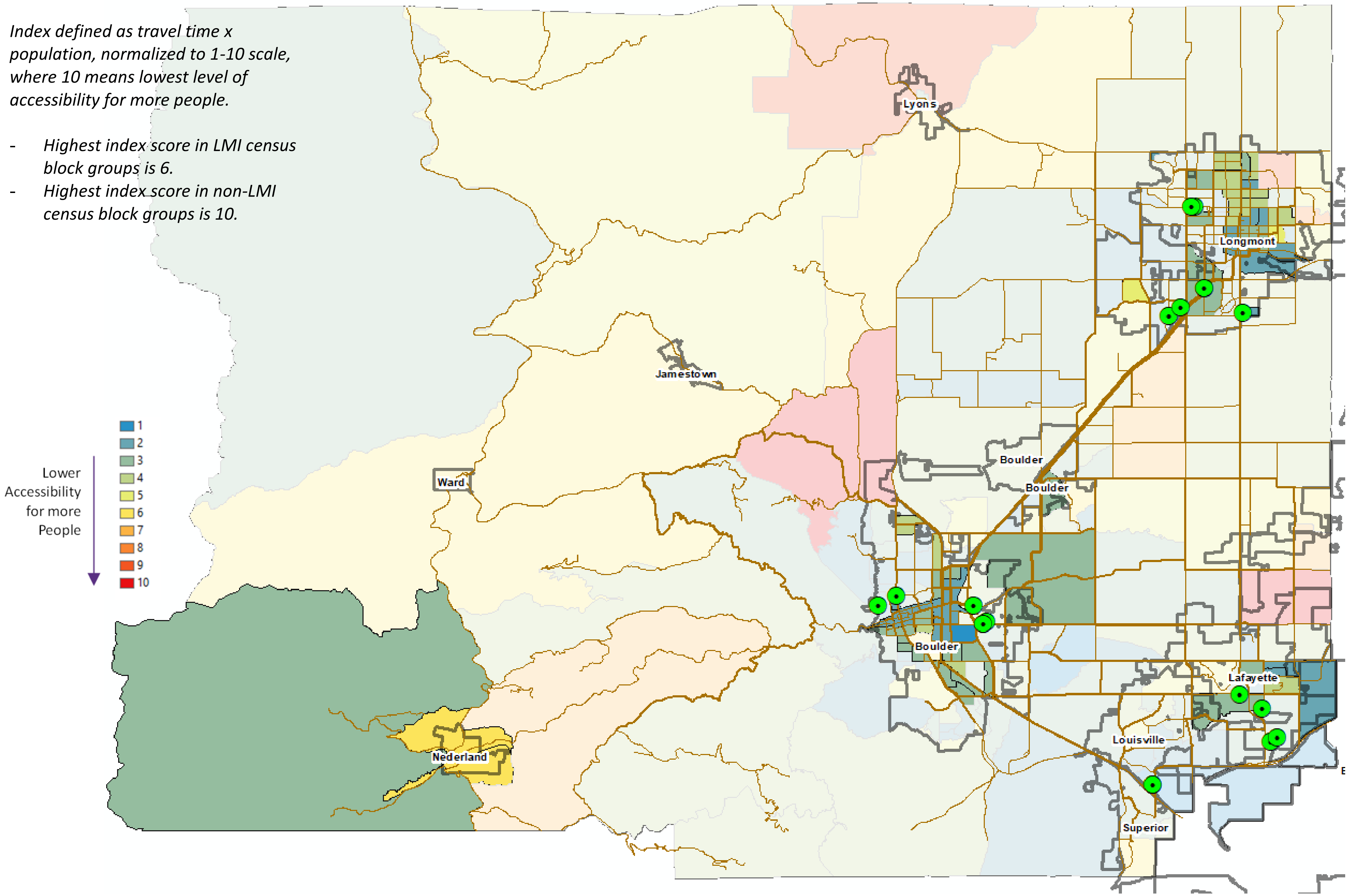
	Transit Access to…							
	Emergency Care (Map 1)	**Higher Education** (Map 2)	**Rehab** (Map 3)	**Childcare** (Map 4)	**EMS** (Map 5)	**Clinics / Outpatient** (Map 6)	**Schools PreK to 12** (Map 7)	**Later in Life Care** (Map 8)
Non-Low to Medium Income Communities	3.4	3.2	2.9	3.1	3.3	3.2	2.8	3.0
Low to Medium Income Communities	3.0	2.9	3.0	2.6	3.0	2.5	2.2	2.4
Equity Ratio*	1.14	1.11	0.95	1.16	1.08	1.28	1.30	1.26
Equity Difference (%)	14.2%	11.3%	-4.6%	16.3%	8.0%	28.4%	29.6%	25.7%

*****_A ratio of less than 1.0 indicates that non-low to medium income communities receive less transit access than other communities_

Map 1: Accessibility to Emergency Care or Hospitals

Index defined as travel time x population, normalized to 1-10 scale, where 10 means lowest level of accessibility for more people.

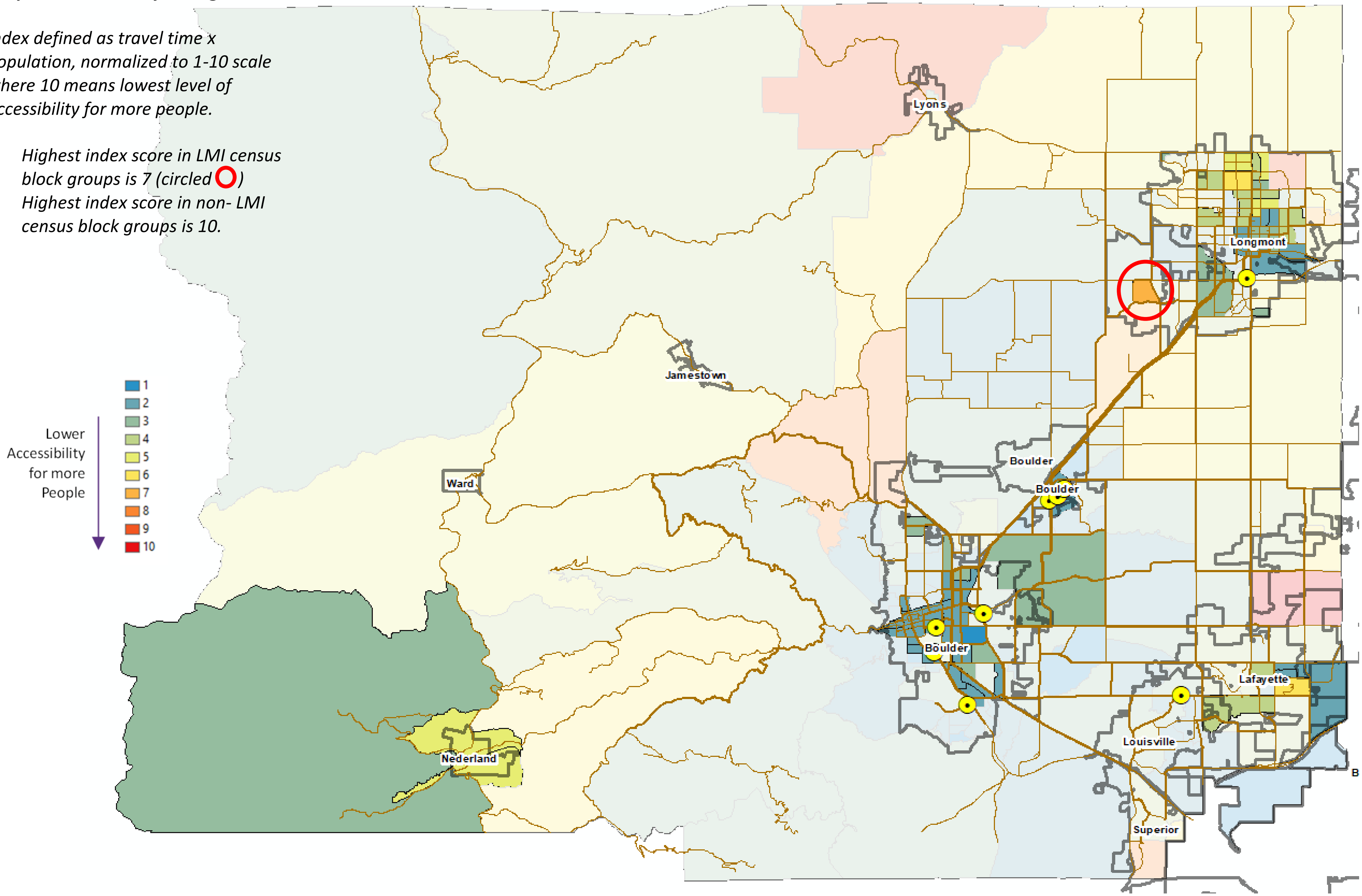
- *Highest index score in LMI census block groups is 6.*
- *Highest index score in non-LMI census block groups is 10.*



Map 2: Accessibility to Higher Education

Index defined as travel time x population, normalized to 1-10 scale where 10 means lowest level of accessibility for more people.

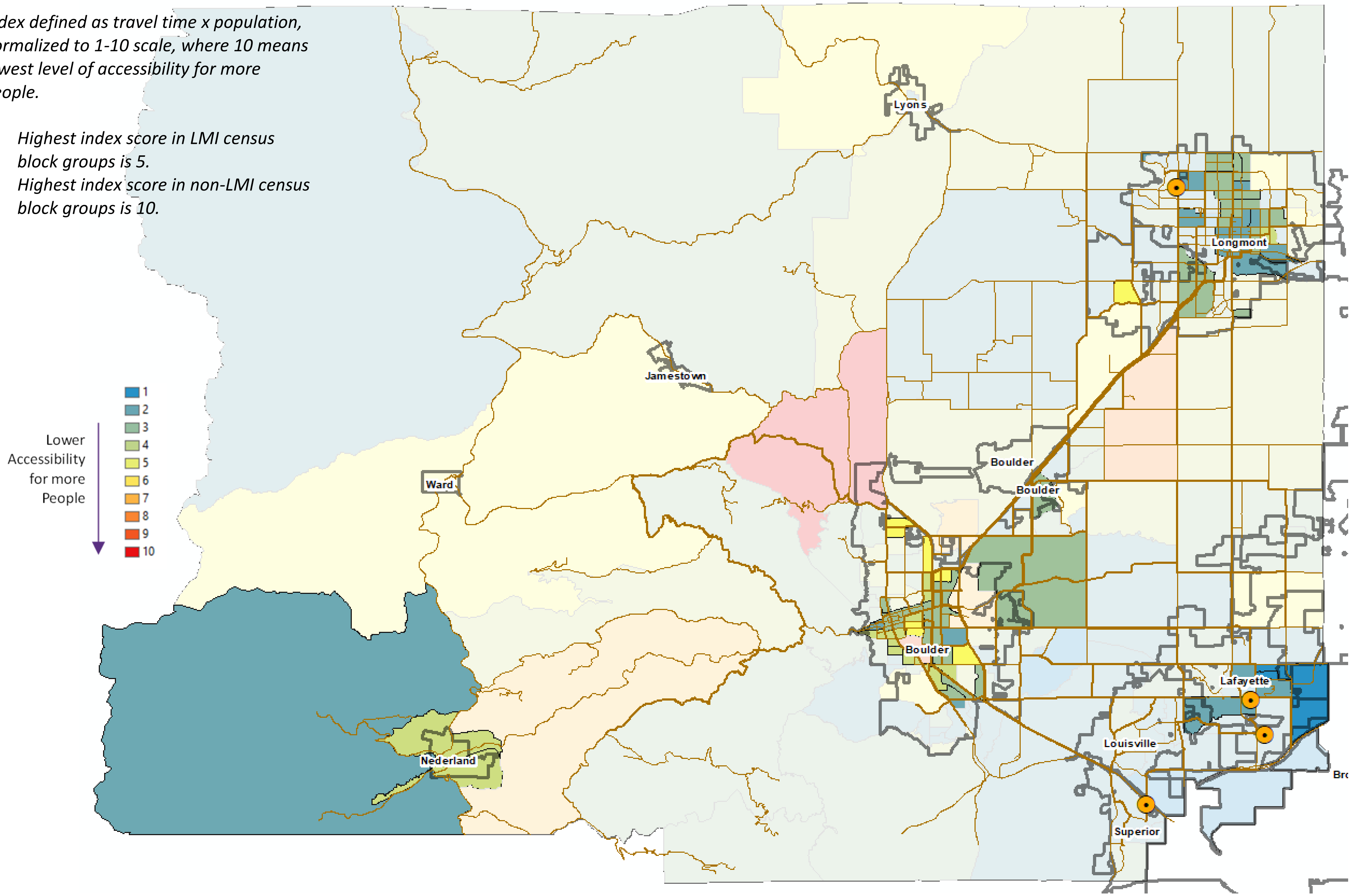
- *Highest index score in LMI census block groups is 7 (circled)*
- *Highest index score in non- LMI census block groups is 10.*



Map 3: Accessibility to Rehab and Mental Health Facilities

Index defined as travel time x population, normalized to 1-10 scale, where 10 means lowest level of accessibility for more people.

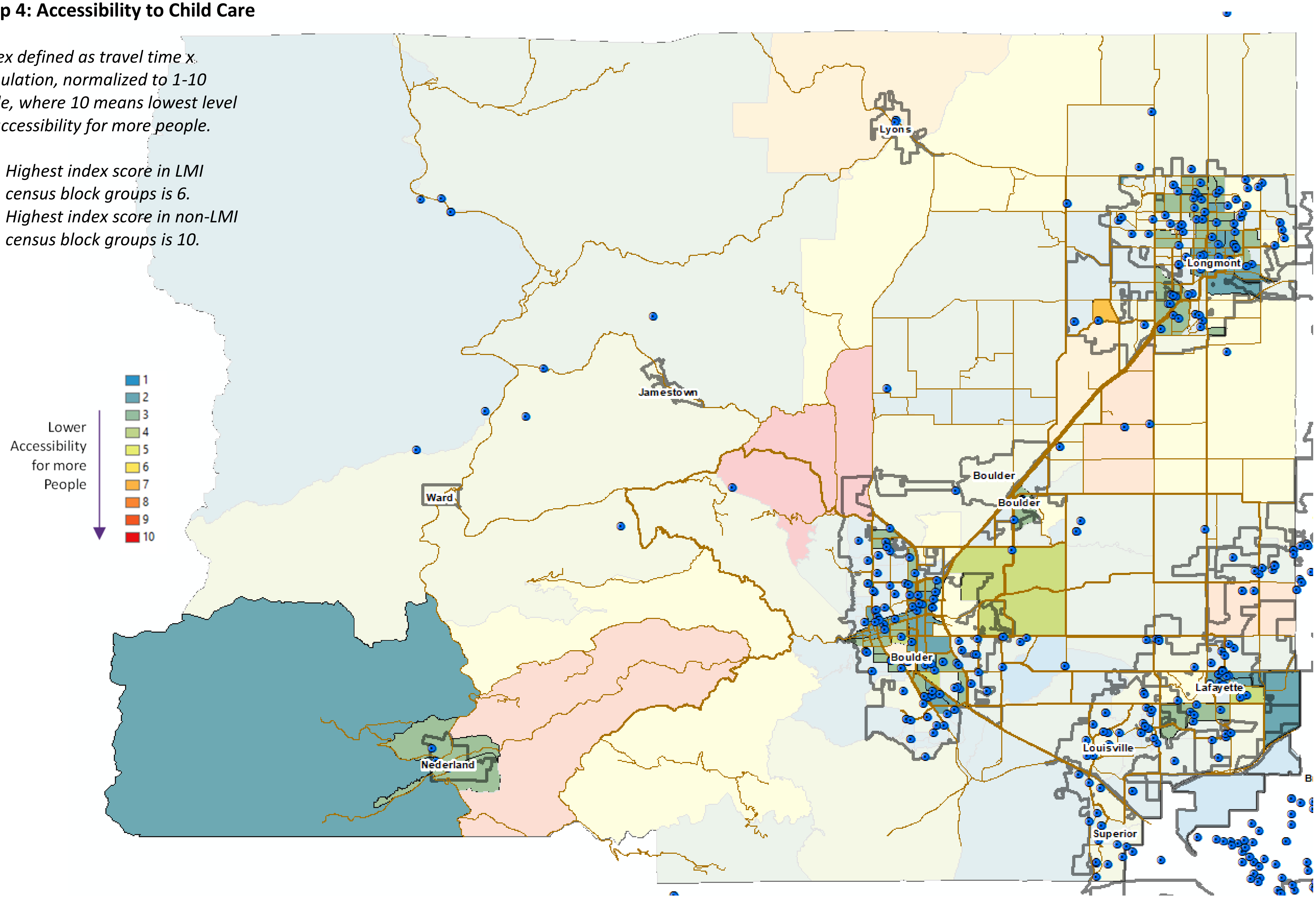
- *Highest index score in LMI census block groups is 5.*
- *Highest index score in non-LMI census block groups is 10.*



Map 4: Accessibility to Child Care

Index defined as travel time x population, normalized to 1-10 scale, where 10 means lowest level of accessibility for more people.

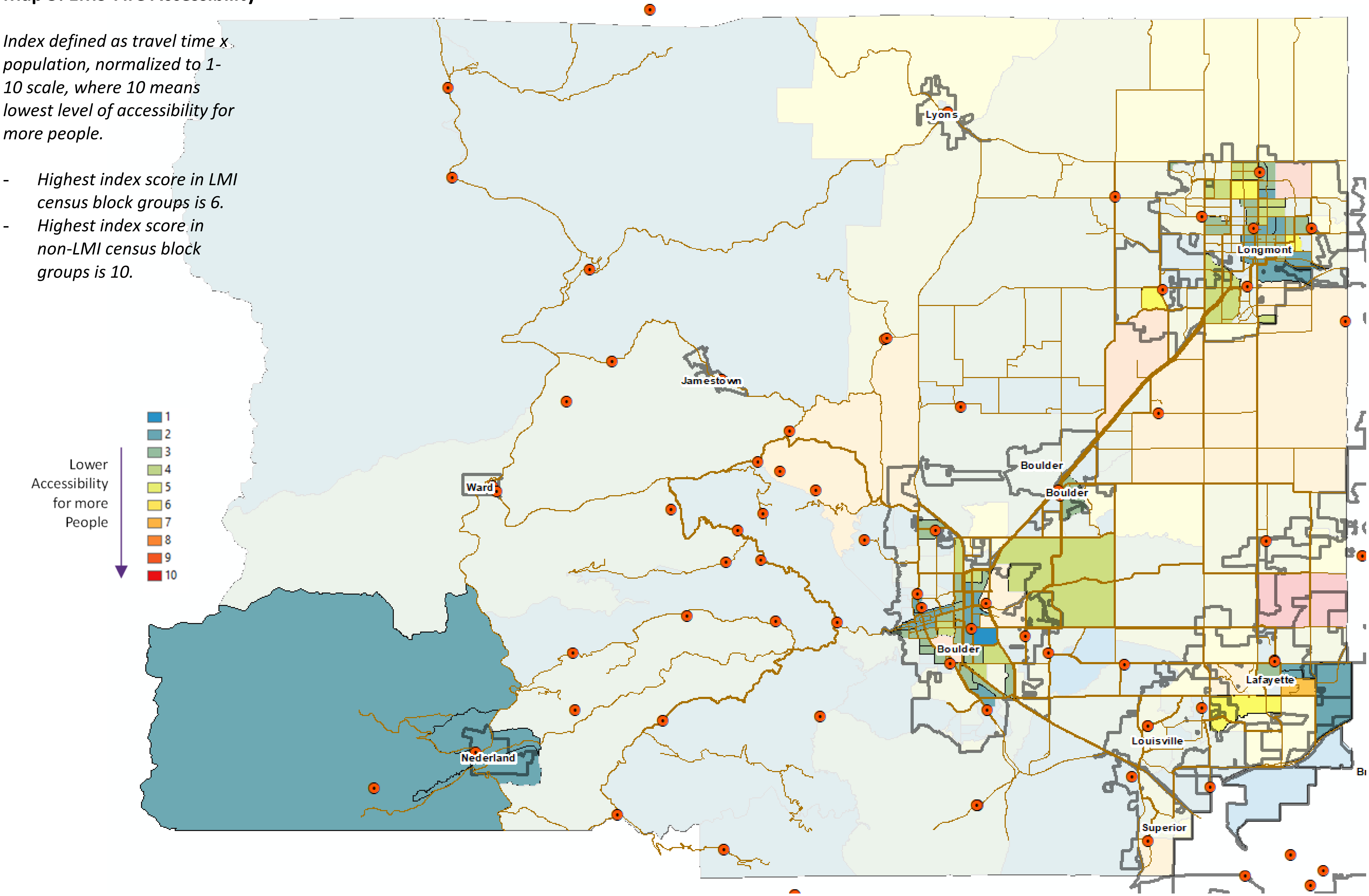
- *Highest index score in LMI census block groups is 6.*
- *Highest index in non-LMI census block groups is 10.*



Map 5: EMS-Fire Accessibility

Index defined as travel time x population, normalized to 1-10 scale, where 10 means lowest level of accessibility for more people.

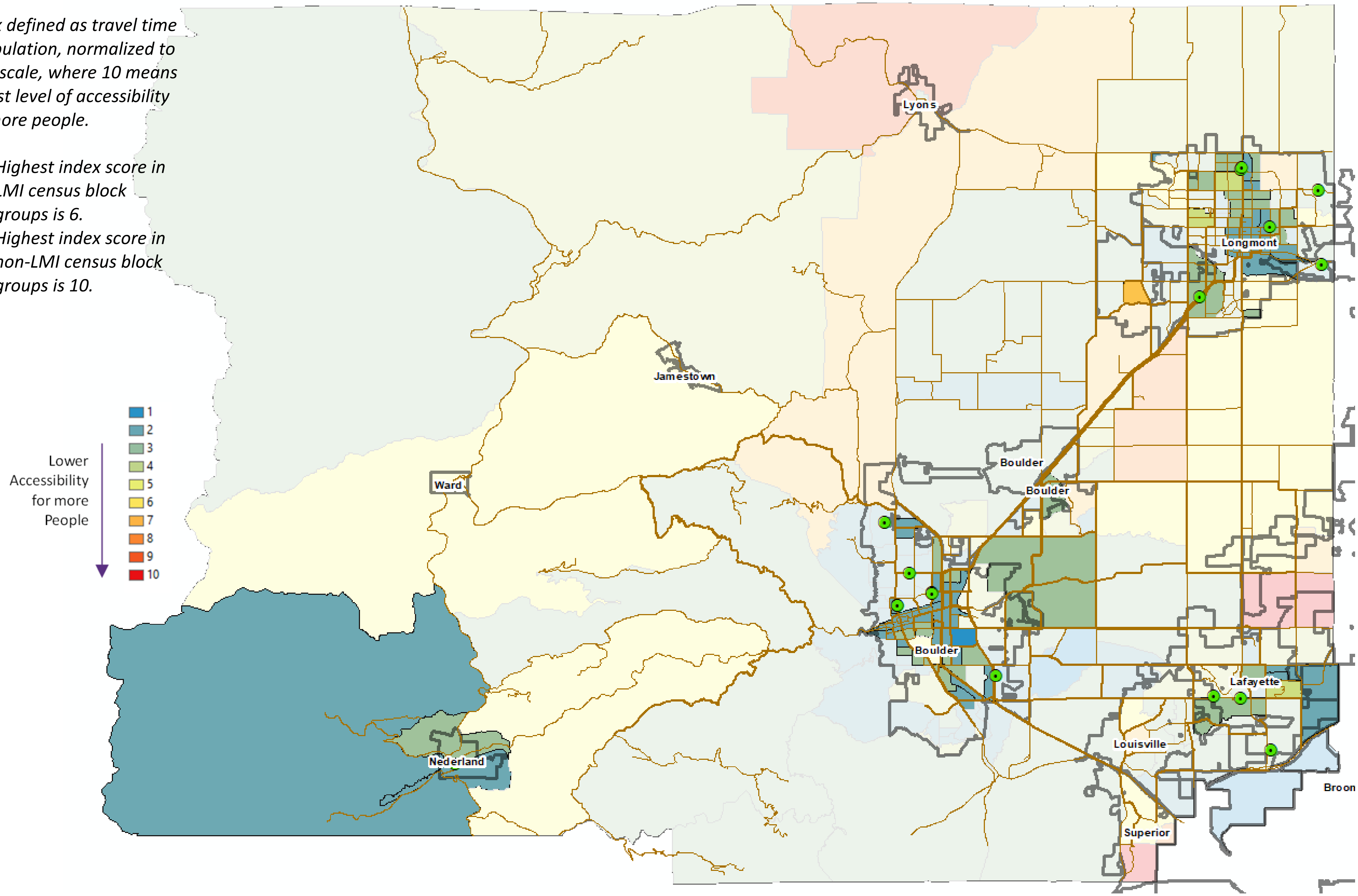
- *Highest index score in LMI census block groups is 6.*
- *Highest index score in non-LMI census block groups is 10.*



Map 6: Accessibility to Clinic/Outpatient Care

Index defined as travel time x population, normalized to 1-10 scale, where 10 means lowest level of accessibility for more people.

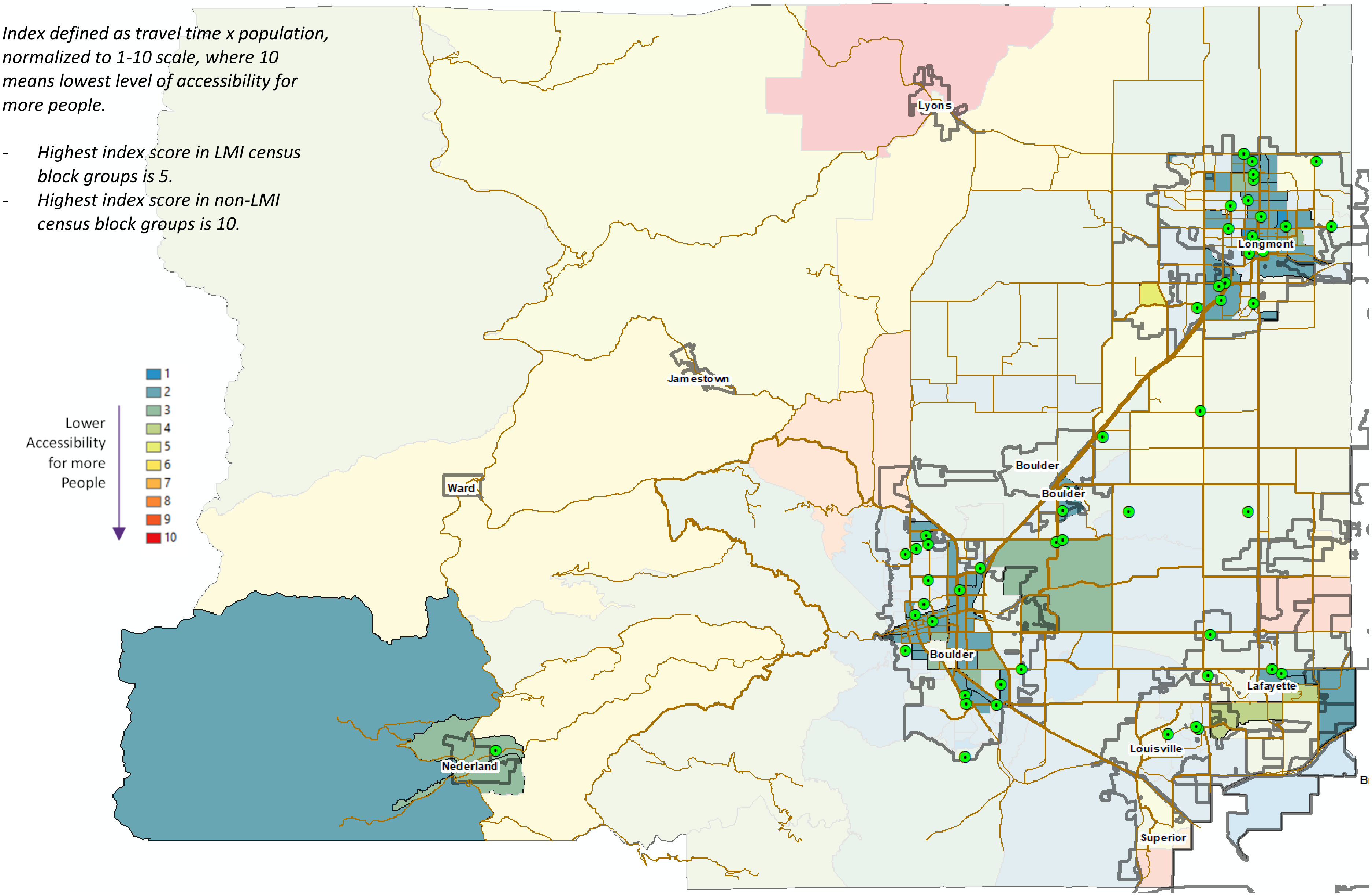
- *Highest index score in LMI census block groups is 6.*
- *Highest index score in non-LMI census block groups is 10.*



Map 7: Accessibility to PreK-12 Schools

Index defined as travel time x population, normalized to 1-10 scale, where 10 means lowest level of accessibility for more people.

- *Highest index score in LMI census block groups is 5.*
- *Highest index score in non-LMI census block groups is 10.*



Map 8: Accessibility to Later in Life Care

Index defined as travel time x population, normalized to 1-10 scale, where 10 means lowest level of accessibility for more people.

- *Highest index score in LMI census block groups is 7.*
- *Highest index score in non-LMI census block groups is 10.*