Social Vulnerability and Dam Risk

A methodology for understanding the relationship between demographic characteristics and hazard threat

https://upload.wikimedia.org/wikipedia/commons/thumb/7/79/USACE_Cherry_Creek_dam_and_reservoir.jpg/220px-USACE_Cherry_Creek_dam_and_reservoir.jpg

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Chapter 1- Introduction

Because vulnerable populations have fewer resources and face barriers to effectively respond to a disaster, it is essential that emergency managers understand community demographics. The objective of this analysis is to provide a methodology for which emergency managers can quantify and geospatially evaluate risk and social vulnerability. This research looks specifically at the potential for dam failure and provides a strategy to address the communities that are located in the inundation areas, and categorized as socially vulnerable based on economic and demographic characteristics. I will evaluate the efficacy of this methodology and discuss how this analytical tool might be replicated in other jurisdictions that are dealing with potential dam failure.

1.1 Field of Study

There are over 80,000 dams three feet high or greater in the US, according to the US Army Corps of Engineers' National Inventory of Dams, and at least a quarter of the dams listed are more than 50 years old (Bowles et.al. 1999). Many aging dams can no longer manage the waters they were built to control because of changes in river flows and weather patterns. Many dams built across the country were originally constructed in rural locations; however, with increasing growth, development downstream of high hazard dams puts people and property at risk. These dams were not designed to protect the surrounding dense clusters of homes and businesses. Failing to repair and modernize the country's aging dams leaves Americans vulnerable, however, there is a limited understanding of the full risk that old and deteriorating dams create.

1.2 Need for Proposed Research

Dam failure poses a significant threat to communities throughout the City and County of Denver. Though probability of the event is low, the implications of failure are high. To better inform policy, as well as evacuation and hazard mitigation plans, it is essential that emergency managers have a clear understanding of the demographics of potentially inundated communities, their barriers to evacuation, and what can be done to improve these conditions. With limited time and resources, assessment of dam risk allows emergency managers to prioritize actions for the highest threat dams.

1.2.1 Social Vulnerability

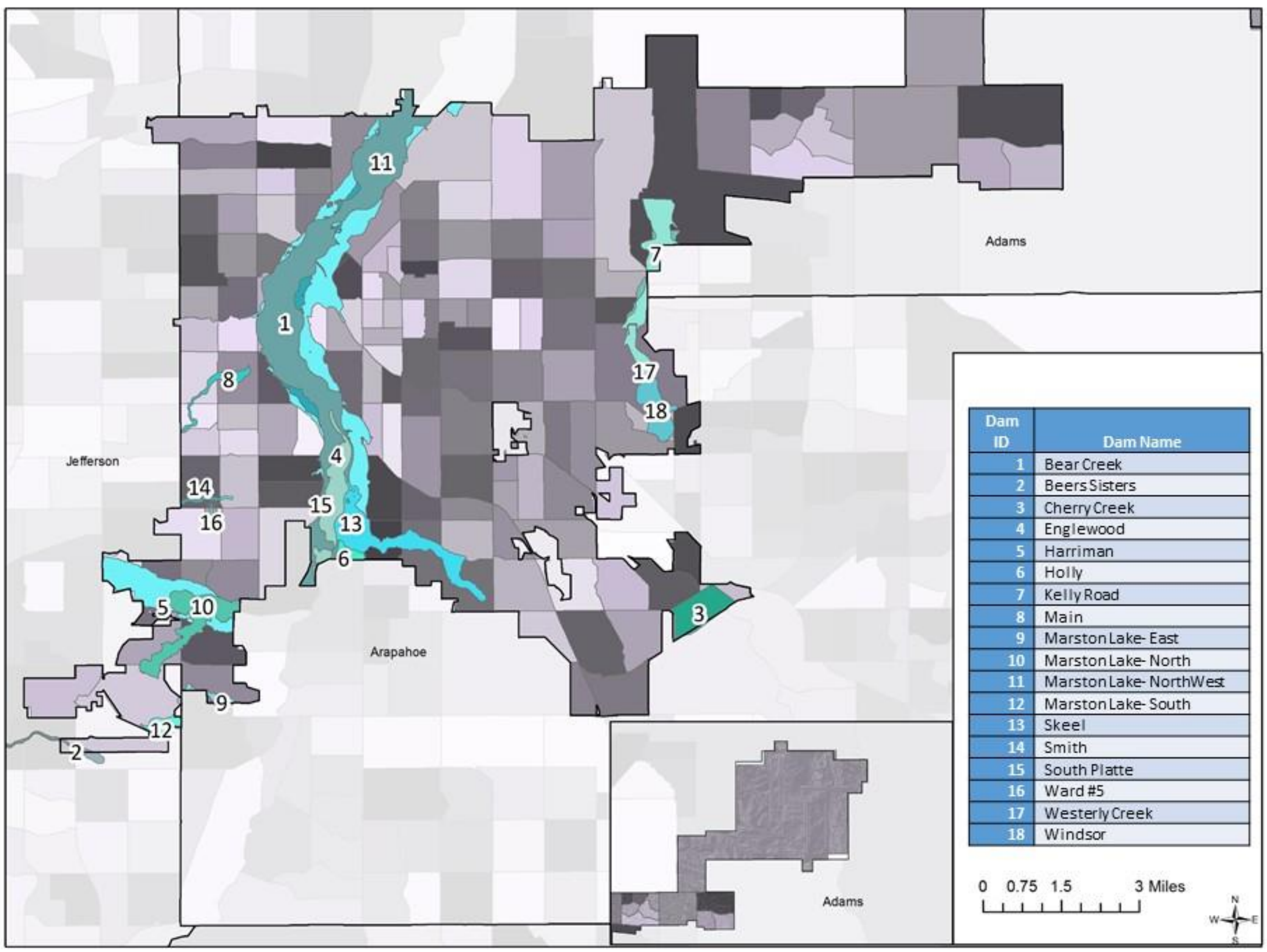
Emergency management often looks to the following equation as a way to quantify disaster potential: Risk = Hazard * (Vulnerability – Resources). Risk is the likelihood of loss; Hazard is the degree of threat of harm; Vulnerability is the extent to which persons or things are likely to be affected; and Resources are the means to decrease the effects of hazards (Dwyer et al. 2004; UCLA Center for Public Health and Disasters 2006). This equation can be very helpful, providing a straightforward unit of analysis for management, however, it only encompasses the physical hazard component, and the social vulnerability component is ignored.

The hazards and vulnerability literature reveals that different groups of people living in a disaster-stricken area are not affected equally. Racial minorities, children, elders, disabled people, individuals living in poverty, and residents of certain types of housing are disproportionately affected. Furthermore, such vulnerability factors often occur in combination (Morrow 1999). Population characteristics "are an important indicator of everything from evacuation compliance during an event to successful long-term recovery after one "with the socially vulnerable "more likely to die in a disaster event and less likely to recover after one" (Juntunen 2005). The most vulnerable people are likely those whose needs are not sufficiently considered or addressed in response and recovery planning. For example, after a disaster, evacuation information is often not provided to people with limited English proficiency, the hearing and visually impaired, and other special needs groups (U.S. Department of Transportation 2006).

1.2.2 Dam Impact in Denver County

There are ten dams located within the boundaries of Denver County, and eight additional dams with inundation polygons that impact census tracts in the County, illustrated in figure below. In total, there are 311,026 people living in dam inundation polygons, 137,466 households, and 150,283 individual housing units. The purpose of this study is to outline an effective methodology for looking more closely at the individuals, the infrastructure, and critical facilities that could potentially be impacted in the event of dam failure.

Figure 1: Dam Inundation in Denver County



Context and a rudimentary understanding of the hydro-fluvial characteristics of the area indicates that the Cherry Creek River and the Platte River run North → South and North-West → South-East (respectively), which is why the dam flow patterns generally follow along these two corridors.

1.3 Research Objectives

- Identify dams in the City and County of Denver with high vulnerability AND high risk.
  - Evaluate social vulnerability within dam inundation areas using SoVI method to quantify vulnerability. Rank the dams based on findings.
  - Evaluate risk using Andersen and Torrey's Condition Indexing Method for Embankment Dams. Rank the dams based on findings.
- Analyze response and evacuation strategies for communities located within the dam inundation areas of the identified top three high vulnerability/high risk dams.
- Evaluate efficacy of this methodology and feasibility for implementation in other jurisdictions.

Chapter 2- Existing Literature

Existing research focuses on either social vulnerability or dam risk. There is also additional information regarding the use of GIS for hazard modeling/prediction. The primary gap exists in the evaluation of the interface between sociology and dam safety. The literature is either highly technical, focused on hydrological engineering, or, the research revolves around a sociological evaluation of equity related to hazards.

In terms of social vulnerability, the research of many sociologists has led to increased awareness of social vulnerability in terms of risk and hazard resilience. As highlighted in my review of existing literature, the work done by Susan Cutter and her team at the University of South Carolina and Lori Peek at Colorado State University has highlighted many issues related to equity. Most saliently, the research focuses on how a community's ability to respond to a hazard is significantly impacted by economic resources. Additionally, they note that low income or cost-burdened populations often live in high risk buildings, or cannot afford mitigation actions, ultimately making them more susceptible in a hazard event. The research is comprehensive, evaluating a variety of demographic and social characteristics that may impact vulnerability, however, the research is largely focused on sociology and general hazard analysis, with no discussion on dam safety. Dam failure is a 'less popular' hazard topic, compared to floods or hurricanes, and my research will aim to fill the gap in the literature and integrate sociological implications into the dam safety conversation

On the other hand, dam safely is highly technical and existing analysis is dominated by either hydrological engineering reports that focus on improving dam construction, or the research is focused on the environmental impacts of dams and the interface with fragile ecosystems. The U.S. Army Corps of Engineers, as well as David Bowles, are the prevailing leaders in the study of dam risk. There are a variety of dam assessment models that quantify risk based on different weighted variables. Various multi attribute decision modeling and analysis methodologies are summarized by Herrald et. al. (2004), and my chosen methodology is modeled after the described Andersen and Torrey's method.

In my research, I have identified five key themes that have generated substantial attention: dam engineering/management, risk assessment, dam failure, GIS and technology, and social vulnerability to hazards. These themes represent the spectrum of analysis, ranging from highly technical to sociological, and my paper will aim to provide a methodology that will connect each of these themes.

2.1 Dam Engineering/Management

The dam construction process is highly variable and different choices (construction material, spillway design, and location of the dam) are based on both functionality, as well as safety concerns. There has been extensive progress made in technology and production standards related to dams, however, the majority of dams in the United States are very old and have not been retrofitted to the current standards. I will use this high level understanding of dam engineering to shape the lens in which I evaluate the dams in the City and County of Denver. Before evaluating the risk to community, it is important to understand the very basic fundamentals of dam construction and dam engineering, primarily in terms of safety. Using the detailed specifications outlined in the dams' Emergency Action Plans, I will be able to establish an initial assessment and predict the risk of dams that will later be informed by GIS analysis.

J.E Costa (1985) provides a summary of conditions that may catalyze the failure of dams. The report outlines the history of dams, as well as providing a high level description dam characteristics based on construction, purpose, and size. Bowles et. all (1999) outlines the risks and hazards associated with aging dams across the country.

There are many important features and variables that impact the susceptibility of dam failure/dam breach, and before embarking on an assessment of social vulnerability and exposure. When evaluating the likelihood and implications of a dam failure, it is important to understand that are different characteristics of a dam such as construction (arch, buttress, gravity), materials used (i.e. earth, rock fill, concrete), age, size, location, as well as the influential environmental conditions such as landslides or flooding. Additionally, there are different types of dam failure- over topping, foundation defects, and piping seepage. The report assesses notable dam failures across the US, providing information on the number of lives lost and associated damages. There are many benefits that are associated with the risk-enhanced approach, and the methodology is easily repeatable, ultimately increasing safety, efficiency, and furthering a better understanding of dam risk.

2.2 Dam Risk Assessment

Generally, risk is associated with the degree of hazard and the level of threat the event poses to people and property. Analysis of existing literature presents different approaches and models that can be utilized to accurately assess risk, however, each method involves different variables and alternative perspectives based on what is valued.

There are a variety of dam risk assessment tools and models that assess variables related to the type of dam and the most probable type of dam failure. There are many different types of dams (gravity, arch, barrages), however, the dams evaluated in the City and County of Denver are all embankment dams. Andersen and Torrey (1995), propose a total-systems approach for aging civil engineering facilities particularly embankment dams. Developed for embankment dams, the methodology has the objective of developing a rating procedure that describes the current condition of embankment dams in a uniform manner. The "risk indexing tool" is based upon identifying potential deficiencies to the safety of the structure, and produces an outcome that prioritizes maintenance, repair, and evaluation tasks on embankment dams that are less than 100 ft. with little information concerning performance history (Andersen et al 2001).

Baecher et. al. (1980) questions the practice of locating high volume dams above large population concentrations. He suggests incorporating a cost-benefit analysis in project evaluation. The authors distinguish cost in lives lost from dollar values, using previous events as a reference baseline for structural or economic costs associated with dam failure. This framework is a viable option, however, we cannot assume that dam failure will completely destroy every building, and it is highly unlikely that there will be loss of the total economic value of structures exposed to inundation. Additionally, it is challenging to quantify loss of life and make a comparison to economic loss.

2.3 GIS and Modeling Technology

A chapter from the comprehensive textbook "GIS and Emergency Management" (1999) outlines the roles and uses of GIS. This literature will be a valuable asset in establishing the fundamental utility of GIS for emergency management. It is imperative that I acknowledge perceptions of GIS in emergency management/hazard risk assessment, and identify the value of GIS for dam safety managers.

Approaching the topic from a highly technical background, the research breaks down the disaster cycle and pinpoints when and how GIS can be integrated into the process of action and decision-making. With the use of clear diagrams, the authors outline the functions and tools provided by GIS, and then praises the value and efficiency of the process. Various GIS applications are cited (such as CAMEO and SLOSH) in the response phase of disaster planning, and most relevant to my work, is the discussion of GIS tools for evacuation. I plan on using the USGS Evacuation tool to recommend future actions for Denver dam safety managers and policy makers, and the critical analysis provided by this article will help me formulate my personal assessment of the tool's accuracy and efficacy.

2.4 Social Vulnerability and Hazards

A significant focus of my project will be aimed at evaluating the demographics of populations exposed to dam risk. I will need to establish a list of vulnerability indicators and characteristics that reflect social vulnerability. Existing research examines a variety of factors, ranging from financial indicators such as income and cost-burden, social features such as and race, age, mobility/health conditions such as ambulatory and cognitive disability. Creating a community profile for the inundation polygons will highlight concentrations of populations that will be more disadvantaged in the event of dam failure. The literature broadly addresses social vulnerability in terms of hazards, however, there is no existing research that specifically targets vulnerability and threat associated with dams.

In the paper "Poverty and Disasters in the United States" (2004) Alice Fothergill and Lori Peek evaluates twenty years of research related to poverty and disasters in the United States. The findings are organized into eight categories that are determined by stage of a disaster event. The most salient conclusion relates to how different socioeconomic classes perceive, prepare for, and respond to hazard risks. The cause for inequity in disaster impact and risk may be due to type and location of residence, infrastructure, and social exclusion. Past articles have reviewed the literature concerning how gender (Fothergill, 1996) and race and ethnicity (Fothergill et al., 1999) play a role in disaster vulnerability in the United States, but no such review has been done on the literature on poverty, inequality, and disasters. By examining what is known on the topic of poverty and disasters in the United States, this review can assist in identifying gaps and thus help direct future scholarship on the topic. The research shows that there is a relationship between socioeconomic status and preparedness, and it is recognized that those living in poverty, with different social and risk event histories, have differential and unequal access to resources that may be relevant in any particular risk situation. Those with lower socioeconomic status may be more likely to face barriers to disaster recovery, particularly in the areas of housing and relocation.

To quantify the impact of certain demographic characteristics and how they relate to hazard resilience, Susan Cutter and her team at the University of South Carolina constructed an index of social vulnerability, called the Social Vulnerability Index (SoVI). Described in the research that appeared in the Social Science Quarterly (Cutter et. al., 2003), the index was developed using a factor analytic approach, 42 variables were reduced to 11 independent factors that accounted for about 76 percent of the variance. These factors were placed in an additive model to compute a summary score. This progressive approach represents a shift in the field of environmental hazard analysis, offering the first example of quantification of demographic characteristics. The index has been applied at the state and county level throughout the country, and discussion has been guided in the fields of flood, hurricane, earthquake, and tsunami safety management, however, this tool has never been utilized for dam safety.

Chapter 3- Methodology

The methodology for this project revolves around social vulnerability and dam risk. The multi-step analysis process follows the steps outlined in Figure 2 and described below:

1) Preliminary assessment using census data and simple spatial analysis.
2) Quantitative assessment of…
    a. Social vulnerability
    b. Dam risk
3) Analysis of findings
    a. Quantitative and geospatial evaluation of impacted people, critical facilities, and transportation infrastructure
    b. Quantitative and geospatial evaluation of dam risk
4) Overlay of social vulnerability and hazard risk results identified through scatterplot
5) In-depth evaluation of the top 3 high vulnerability/high risk dams
6) Discussion of efficacy of methodology

Figure 2: Methodology

3.1 Assessment

1) For all results generated by this research, there is a discussion of quantitative data and geospatial information. The assessment process is outlined in the steps below:
1) Social vulnerability scores are measured using statistical analysis of demographic data, and the high SV scores are used to generate GIS maps.
2) Dam risk is measured using Andersen and Torrey's index, and the risk scores are used to generate GIS maps.
3) The research focuses on the overlay of social vulnerability and hazard, identified by scatterplot analysis.
4) The overlay analysis results lead to three in-depth studies of the infrastructure, built environment, and response capacities surrounding high vulnerability/high risk dams.

3.1.1 Social Vulnerability Assessment

The process of social vulnerability assessment involves quantitative measurement, followed by geospatial analysis. Evaluation is divided into three categories: impacted people, critical facilities, and transportation. Organizing analysis into three groups provides more detailed perspective on the distribution of high SV populations and the relationship between people, the built environment, and infrastructure. After identifying overall trends, the top 20% of each factor score are highlighted, in addition to the top 20% of total social vulnerability. These top 20% groups are labeled as "high social vulnerability" or abbreviated by "high SV".

3.1.1.1 Quantitative Evaluation (Factor Analysis)

The quantitative analysis of demographics and social vulnerability revolves around the input variables from 2010-2015 American Community Survey. The process used to determine social vulnerability for census tracts in Denver County has been designed using the "SoVi Recipe". Established by Dr. Susan Cutter and her team at the University of South Carolina. A statistical factor analysis of demographic characteristics develops vulnerability scores at the county and state level. The analysis involves 24 demographic variables related to social vulnerability. The SoVI method has been utilized at the county level, but never at a smaller scale.

Steps taken to identify social vulnerability and the top 20% most vulnerable neighborhoods include:

- Step 1. Compile all relevant socioeconomic variables. Show a summary table of the variables, data source, and how they are computed.
- Step 2. Factor analysis and factor identification. Provide some details, list the criteria used to assign a variable to a particular factor (or category).
- Step 3. Factor scores are computed and standardized (i.e., z values). Using the Z value to identify tracts within the top 20% factor scores.

Factor analysis is a statistical procedure that is used to examine variations within a dataset and identify strong patterns between possibly correlated variables. The factors typically are viewed as broad concepts that can be used to describe an observed trend. Factor analysis models the observed variables as linear functions of the "factors." The process searches for joint variations among the variables and generates "latent" factors what are unobserved in those variables alone.

The variables chosen to determine social vulnerability are chosen based on four different categories: economic status, physical disability, minority status, and housing/transportation. Individuals who are living below the poverty line or are included in the low income category are more vulnerable during an event because they lack resources or the economic support, which ultimately complicates evacuation, as well as the ability to recover and reconstruct their lives post-event. Disabled or elderly individuals experience greater physical difficulties in evacuation, face special health/safety issues, and experience higher potential for loss of life. Post-event, disabled or elderly populations do not have access to the specialized facilities and medical personnel, that make it difficult to recover. Minority status is significant because this group often lacks influence and connections to centers of power. Specific census datasets chosen are reflective of the process used by Susan Cutter to develop the SoVI index, as well as the process used by the Center for Disease Control to develop the SV index.

Data is from the 2000 U.S. Census of Population and Housing at the census tract level. The index works at census tract level because tracts are a small enough scale that anomalies and unique characteristics can be identified. Additionally, this unit of measurement is used to collect and analyze data for policy and planning in government and public health (Krieger 2006). Census tracts are designed to be demographically homogeneous, and generally have between 1,500 and 8,000 people, with an optimum size of 4,000 people (U.S. Census Bureau 2009a). The mapping of these data reveals geographic patterns of potential population vulnerability to disaster that can be used in mitigation, preparedness, response, and recovery (Morrow 1999). The data sources are outlined below:

Table 1: Census Tract Data Sources

Variable	2015 ACS 5-year estimates	Vulnerability Category	Additional Description
Poverty	S1701	Economic status	% of total population
Families in poverty	S1701		% of total population
Unemployment Rate	S0201		% of total population
Age 65 and older	S0101	Household composition/disability	% of total population
Median Age (years)	S0201		
Female	S0201		% of total population
Family Households	S1101		% of total number of households
Female-headed households (families) no husband present	S1101		% of total number of households
Under 5 years old	S0101		% of total population
Less than 12 years education	S1501		% of population over 25 years old
Disability- Ambulatory difficulty	S1810		Those who responded "yes" when asked if they have serious difficulty walking or climbing stairs

Disability- Independent living difficulty	S1810		Those who responded "yes" when asked if they difficulty doing errands alone such as visiting a doctor's office or shopping
Households with no vehicles	S2504	Housing and transportation	% of total number of households
Average Household Size	DP04		
Renter occupied housing units	S2502		% total occupied housing units
Housing Density			
African American	DP05	Minority status and language	% of total population
Hispanic	DP05		% of total population
Speaks English less than very well	S1601		% of total population

Once the variables are normalized, SPSS software is used to calculate z-scores, which are detailed in Appendix A. In addition to the z-scores, descriptive statistics such as mean, minimum, maximum, and standard deviation are presented in Appendix B. The factor analysis utilizes a varimax rotation and Kaiser criterion for component selection. This rotation reduces the tendency for a variable to load highly on more than one factor. Through the SPSS software, the next step is to set parameters for the extraction of factors. The factor analysis process first applies a component value to each individual z-score, which is show in Appendix C.

The factor loading process is highly iterative, and the inclusion or removal of a single variable can have significant implications for identification of trends in the data. After various trials, the dataset was finalized and factors identified. Trends in the dataset are used to determine the broad representation and influence on (i.e. increase or decrease) social vulnerability for each factor by scrutinizing the factor loadings (i.e. correlation between the individual variable and the entire factor) for each variable in each factor. The grouped factors reflect a strong correlation between variables and how the variables are distributed throughout Denver County. Factors are named and grouped based on loading scores greater than 0.500 or less that -0.500. The grouping of variables is displayed in Appendix D.

Factor analysis is an exploratory/descriptive method that requires many subjective judgments by the user. It can be controversial because the models, methods, and subjectivity are so flexible and varying interpretations can occur. One of the biggest challenges in the factor analysis process is the decision of how to appropriately group the different datasets and choosing which variables to include. Removing one variable can dramatically alter the story told by the factor loading results, and it is challenging to accurately represent the socioeconomic conditions, without trying to manipulate the data to fit expectations.

The Factor Analysis process presents some challenges for use in a public planning context. First, the method is complex and uses a statistical procedure that is not easily communicated to a nonspecialized audience. The use of SPSS software was integral for this specific research scenario, and requires rudimentary understanding of statistical procedures. Additionally, the nature of the values can be difficult to understand, and results can be misinterpreted or misrepresented. Members of the public may expect definitive answers and might be averse to data that relies on comparisons among areas.

The next step is to weigh the variables and combine the results, resulting in an overall weighted score for each inundation area. This score is used to rank the dams in terms of community exposure and social vulnerability. The results of the score illustrate the degree of social vulnerability for the exposed communities in dam inundation polygons.

After identifying the top 20% of high social vulnerability scores (high SV census tracts), analysis focuses on the number of impacted people, critical facilities, and length of effected transportation infrastructure.

3.1.1.2 Geospatial Analysis

There are multiple layers of quantitative spatial analysis are described below and depicted in Figure 3. The process is complex and layered, with iterative evaluations for both specialized and cumulative vulnerability assessment.

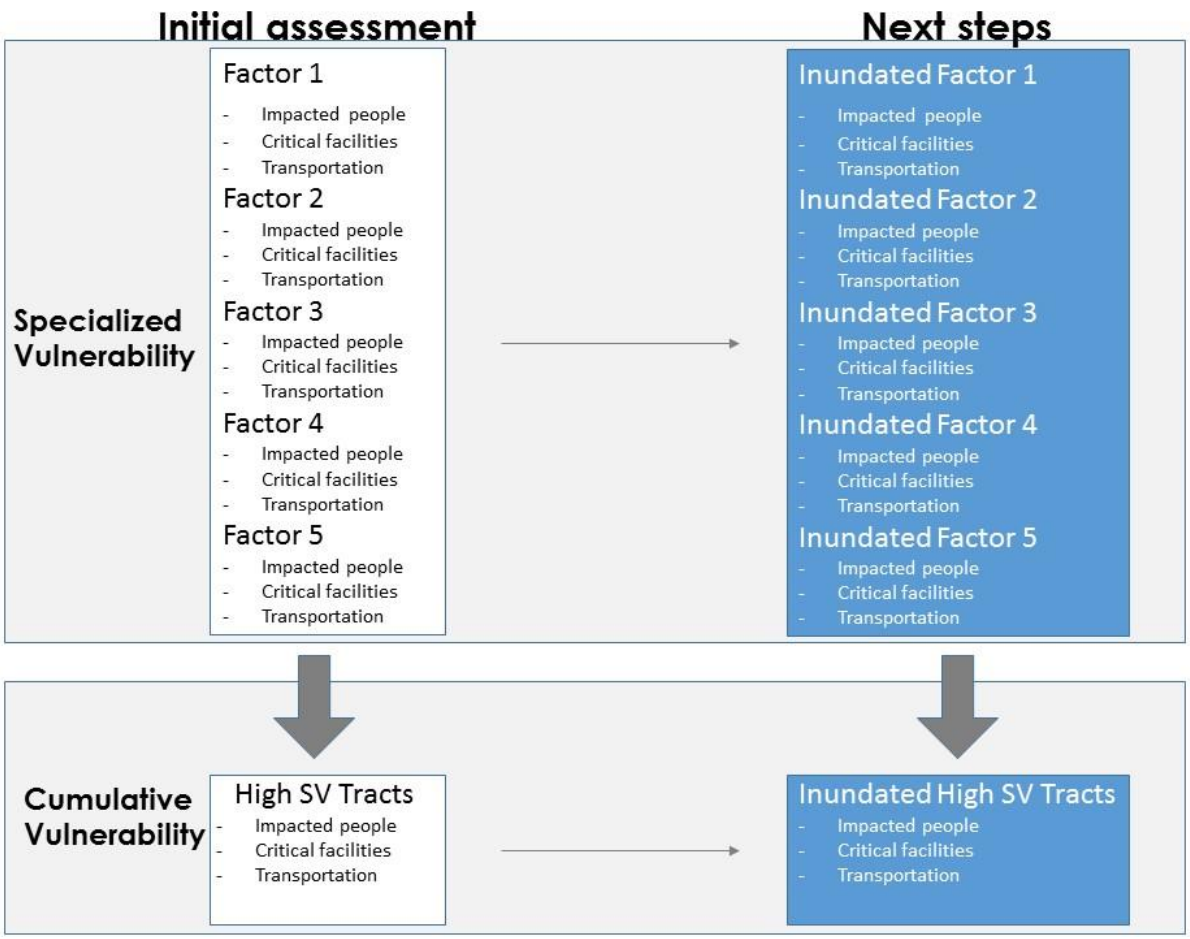
Specialized vulnerability geospatial process

- Step 1: Individual factor scores are mapped for census tracts using GIS. Tracts with top 20% factor scores (the socially vulnerable tracts) for each factor are highlighted.
- Step 2: The population and territory of the socially vulnerable tracts are used to estimate the vulnerable population and area size.
- Step 3: Critical facilities (schools, police stations, fire stations, and hospitals) are located and mapped for the entire county. Transportation infrastructure is mapped and assessed. Analysis focuses on the accessibility of these facilities for each factor group.
- Step 4: The factor groups are overlaid with inundation areas
- Step 5: Calculation of the population and the geographic extent of each factor group tracts within inundation area.
- Step 6: Evaluation of the critical facilities within inundation areas.

Cumulative vulnerability geospatial process

- Step 1: Adding the factor analysis scores for each group leads to cumulative social vulnerability scores for census tracts. Tracts included in the top 20% are highlighted.
- Step 2: The population and territory of the high socially vulnerable tracts are used to estimate the vulnerable population and area size.
- Step 3: Step 3: Critical facilities (schools, police stations, fire stations, and hospitals) are located and mapped for the entire county. Transportation infrastructure is mapped and assessed. Analysis focuses on the accessibility of these facilities for individuals included within the cumulatively high social vulnerability category.
- Step 4: The cumulative vulnerable census tracts are overlaid with inundation areas
- Step 5: Calculation of the population and the geographic extent of each factor group tracts within inundation area.
- Step 6: Evaluation of the quantity of critical facilities and transportation infrastructure within inundation areas

Figure 3: In-Depth Analysis Methodology



To inform quantitative assessment, geospatial analysis is used to measure impacted people, critical facilities, and transportation infrastructure. The census data provides the number of people, households, and housing units within each census tract. To calculate the number of highly vulnerable individuals located in the inundation area within the high SV census tracts, the area of each tract is calculated (square miles) and the area of the clipped inundation area within that tract is measured. The proportion of inundated area to total tract area is applied to calculate the number of high SV people, households, and housing units in the inundation area. It is important to note that this calculation assumes that people are distributed evenly throughout the inundation area.

Geospatial analysis is also used to calculate the number of critical facilities in each social vulnerability factor area, as well as within the inundation area as a whole. It is valuable to understand accessibility of critical facilities to each socially vulnerable sector, in addition to how a dam failure event will impact critical facilities as a whole. This same process is applied for transportation networks and calculation of miles of highway and arterial roads in the inundation area.

3.1.2 Dam Risk Assessment

3.1.2.1 Quantitative Evaluation

There are a variety of dam risk assessment tools and models that assess variables related to the type of dam and the most probable type of dam failure. There are many different types of dams (gravity, arch, barrages), however, the dams evaluated in the City and County of Denver are all embankment dams. Andersen and Torrey (1995), propose a total-systems approach for aging civil engineering facilities particularly embankment dams. Developed for embankment dams, the methodology has the objective of developing a rating procedure that describes the current condition of embankment dams in a uniform manner. The "risk indexing tool" is based upon identifying potential deficiencies to the safety of the structure, and produces an outcome that prioritizes maintenance, repair, and evaluation tasks on embankment dams that are less than 100 ft. with little information concerning performance history (Andersen et al 2001).

Dam index calculation process:

- Step 1: Compile all the relevant dam characteristic variables. Create a summary table of the variables and data source.
- Step 2: Assign a score to each characteristic based on the numbers outlined in the Andersen and Torrey method.
- Step 3: Calculate the combined score from each variable to establish a 'vulnerability' number for each dam.
- Step 4: Calculate the total dam risk for each score by multiplying the vulnerability score by the hazard score, which is "10" for all dams in this scenario

As previously mentioned, dam risk is determined by eight different factors, split into three categories; intrinsic characteristics, external time characteristics, and design characteristics. Data was gathered from each dam's Emergency Action Plan (EAP). The specific sources of data are described in Table 2.

Table 2: Dam Characteristic Data Sources

Dam ID	Name	Owner	Date of last EAP Update
1	Bear Creek	U.S. Army Corps of Engineers	3/1/2014
2	Beers Sisters	FOOTHILLS PARK & RECREATION DISTRICT	4/19/2007
3	Cherry Creek	U.S. Army Corps of Engineers	3/1/2014
4	Englewood	Urban Drainage & Flood Control District	5/11/2015
5	Harriman	Denver Board of Water Commissioners	1/1/2013
6	Holly	Urban Drainage & Flood Control District	5/11/2015
7	Kelly Road	City of Aurora, Stormwater Division	5/11/2015
8	Main	Agricultural Ditch & Reservoir Company	6/23/1997
9	Marston Lake- South	Denver Board of Water Commissioners	5/31/2012
10	Marston Lake- East	Denver Board of Water Commissioners	5/31/2012
11	Marston Lake- NorthWest	Denver Board of Water Commissioners	5/31/2012
12	Marston Lake- North	Denver Board of Water Commissioners	5/31/2012
13	Skeel	Wellshire Golf Course/City of Denver	11/9/1998
14	Smith	Agricultural Ditch & Reservoir Company	6/23/1997
15	South Platte	Centennial Water & Sanitation District	6/12/2013
16	Ward #5	Riviera Circle Lake Club	9/24/1998
17	Westerly Creek	Urban Drainage & Flood Control District	5/11/2015
18	Windsor	Consolidated Mutual Water Co	2/28/2014

The primary variation in risk is related to the intrinsic characteristics of dam height (I1) and storage capacity (I2). All of the dams are earth fill dams with concrete foundations. The dams also share the same external time characteristics because they were built in the same time from (30-59 years ago) and the seismicity for the Denver area is relatively low (Mercalli scale V). Design characteristics are challenging to evaluate without an official hydrologic report, so it should be noted that in this case the conservative assumption is that 1) the spillway capacity is greater than required for all dams (D1) and 2) the factor against mass movement is greater than required for all dams (D2). The eight characteristics for each dam is outlined in Appendix E.

The assessment of a dam (IDam) is determined as its overall dam vulnerability score multiplied by its hazard potential score in accordance with the following equation:

$$I_{\text{Dam}} = V \times H$$

Measure of vulnerability (V) utilizes the following variables:

Intrinsic Characteristics	
I1	Height
I2	Dam Type
I3	Foundation Type
I4	Storage Capacity
External Time-Variant Factors	
E1	Age
E2	Seismicity
Design Characteristics	
D1	Spillway Adequacy
D2	Mass Movement Factor

Each of the factors in the vulnerability function are treated on a scale from 1 to 10 with the overall vulnerability being expressed as the product of the mean value of the intrinsic time-invariant characteristics, the mean value of the external time-variant factors, and the mean value of the design characteristics according to the following equation:

$$V = \frac{(I_1 + I_2 + I_3 + I_4)}{4} \cdot \frac{(E_1 + E_2)}{2} \cdot \frac{(D_1 + D_2)}{2}$$

The suggested scores that determine the 1-10 value for each characteristic are outlined in the Table 2 below.

Table 3: Andersen Torrey Embankment Dam Scoring

Height of Dam (I1)	
Height (ft)	Score
<9	1
Sep-40	3
40-100	6
>100	10
Type of Dam (I2)	
Type of Fill	Score
Rockfill	4
Earthfill	10
Foundation Type	
Type	Score
Concrete	3
Storage Capacity (I4)	
Capacity (acre-ft)	Score
<50	1
50 - 999	3
1,000 - 50,000	6
>50,000	10
Age of Dam (E1)	

Spillway Adequacy (D1)	
Conditions	Score
Known*	
Spillway capcity is less than half the require capcity	10
Spillway capcity is greater than half the required capacity	5
Spillway capacity is greater than required	1
Suspected	
Spillway capacity is less than required	5
Spillway capcity is greater than required	2
* Known conditions only if a hydrologic and hydraulic analysis has been	
Mass Movement Factor of Safety (D2)	
Conditions	Score
Known*	
Factor of safety against mass movement is less than required	10
Factor of safety against mass movement is greater than required	1
Suspected	
Factor of safety against mass movement is less than required	7
Factor of safety against mass movement is greater than required	2

The dam characteristic data is primarily outlined in the Emergency Action Plans of the dams. Once the data is collected, scores will be assigned to each variable, and the “V” (vulnerability) score is calculated based on the aforementioned equation.

The hazard potential of the dam is determined in accordance with specific types of damage that could occur downstream as a result of a dam breach following the recommendations by FEMA (1998) and is quantified in terms of a number (H) on a scale from 1 to 10. Three hazard potential ranges include high, medium, and low. The dam hazard classification has already been conducted for all dams in the City and County of Denver, and the 18 dams identified in the scope of my research project are all included in the high hazard category. High hazard dams have a score of 10.

3.1.2.2 Geospatial Analysis

Once determining the quantitative dam risk, the results are displayed geospatially. GIS is used to classify the dam inundation polygons based on the risk scores. The map will centralize around hazard risk and only the susceptibility of individual dam failure. Presentation of dam risk scores will highlight which dams should attract attention, and where resources should be focused.

Dam index geospatial analysis

- Step 1: Using polygons digitized from the Emergency Action plans, display and define the geographic extent of dam inundation areas.
- Step 2: Integrate the results of the dam index calculations and display dam risk index scores using different colors for each category.

3.1.3 Combining Social Vulnerability and Hazard Risk

The final step in the process is to overlay the results from the social vulnerability assessment with the results of the dam risk evaluation. The data is outlined in a table that informs a scatter plot diagram, as depicted in Figure 3 below:

Figure 4: Scatterplot Analysis Format

Each individual dam is charted. The top left quadrant of the scatterplot will locate the dams those pose the greatest risk to the greatest number of highly socially vulnerable people, in addition to the highest susceptibility for failure. Further case study analysis will focus on the top three dams with both the greatest number of High SV tracts and the highest dam risk index score. These case studies will examine specific transit patterns, access to resources, critical facilities, and community capacity.

3.3 Ethical Considerations

There are minimal ethical considerations related to this research. It is important for me to be sensitive and respectful of the communities that I am evaluating, and not make any inaccurate assumptions based on my preconceived ideas formed when living in Denver.

Chapter 4- Findings

Findings are first evaluated by examining the results of the social vulnerability assessment and then dam risk. Each category of analysis is thoroughly analyzed, through quantitative analysis of people, critical facilities, and transportation infrastructure. After completing evaluation of the social and physical conditions, discussion of findings will focus on the overlay of results. Three in-depth case studies identify areas that should receive more attention and increased response planning based on the higher likelihood of dam failure combined with high concentrations of at-risk populations.

4.1 Social Vulnerability

There are 600,000 total people living in Denver County, of which 120,000 are considered socially vulnerable, which is equivalent of approximately 20% of the population. Of the total County area (155square miles), 10% of census tract area is home to individuals included in the high social vulnerability category. If there were complete dam failure across the county, 176,000 people in Denver County would be affected, of which 20,000 would be socially vulnerable individuals. Dam failure would impact 84,000 households, of which 9,000 would be the homes of socially vulnerable, and 77,000 housing units, of which 9,700 would be socially vulnerable. Proportionally, approximately 10% of people effected by dam failure would be highly vulnerable, without adequate access to support, resources, or aid.

4.1.2 Specialized Vulnerability

Beyond the spatial analysis of social vulnerability, the factor analysis provides quantitative measurements that present (1) the number of people who are considered socially vulnerable, and when overlaid by inundation area information, (2) the number of socially vulnerable people who are also living in an inundation area.

The Eiger scores generated by the factor analysis process are the key indicators used to establish the factor groups. These scores reflect the degree to which different variables are correlated, and any values between 0.5 and -0.5 indicate a relationship that ultimately leads to the grouping of variables. Appendix C displays the analysis results. The cells highlighted in red reflect a strong correlation between variables, later used to define the factor groups.

The results of the factor analysis produced five different groups, reflecting strong relationships and trends found within the 24 assessed census variables. Factor group 1 is comprised of Hispanic, single, women, limited English proficiency, and low educational attainment. Factor group 2 represents unemployed renters, living below the poverty line, with no access to a vehicle. Factor group 3 is the anomaly, in that the group is considered “less vulnerable”. Group 3 is made up of families with children living in high density. Factor group 4 encompasses the elderly and disabled individuals, and Factor group 5 reflects Denver’s African American women. Each group is further described later in this chapter.

In terms of number of people, households, and housing units, the most populated factor-loading group is Fact 1 (Hispanic, families, low income, non-English speaking, single mothers), which represents close to 25% of the total population of Denver County. The smallest factor-loading group is Factor 4, which includes the disabled and elderly individuals. Though approximately 20% of the total population, households, and housing units, are considered socially vulnerable, the combined number of high SV individuals covers only 10% of the area, translating to a disproportionate distribution of vulnerable populations.

Table 4 evaluates land coverage, both in terms of the area covered by the high SV census tracts, but also integrating the area covered by dam inundation polygons. Denver County encompasses close to 155 square miles, of which approximately 1/3rd is covered by inundation area. Factor 2 has the largest proportion of land inundated when compared to total square mileage (36%), and Factor 4 also has a significantly proportion (27%). Factor 5 barely covers land in inundation areas (5%), which is reasonable since the majority of Factor 5 individuals live in the Northeast, and the majority of inundation land is located in the central/western portion of the County.

Table 4: Land Coverage Analysis

	Total	Inundation	
	Tract Total Area (Sq. Mi)	**Inundation Area (Sq. Mi)**	**% of Total Area**
Denver County	154	45	29%
Cumulative Social Vulnerability	16	3	17%
Factor 1	23	3	13%
Factor 2	20	7	36%
Factor 3	78	9	12%
Factor 4	20	5	27%
Factor 5	63	3	5%

Despite having a large number of people considered socially vulnerable (25%), the number of Factor 1 individuals living in inundation areas is significantly lower (11%). Factor 2 has the highest proportion of people living in inundation areas (24%). Factor 3 and Factor 5 have lower rates of people included in inundation areas, dropping from 18% to 7% and 21% to 4%, while the rates are not impacted for Factor 4 (17% to 16%).

Factor 1 is the largest group, with 25% of the total population of Denver County considered socially vulnerable under the Factor 1 conditions; however, when it comes to number of households and number of housing units, this proportion drops significantly (16% and 18% respectively), which indicates that many of these individuals are living together. Factor 2 is comprised of the most households (18% of the total number of households) and the most housing units (21% of total units). These results are reiterated by the Census data, which indicates that Factor 2 individuals live downtown and are unemployed, without a car, living in high density units, and primarily single/unmarried individuals.

As previously described, the results of the factor analysis created five factor groups based on trends found in the census tract data. Table 5 describes the geospatial distribution of each factor group.

Table 5: Spatial Distribution of Factor Groups

Factor Group	Characteristics	Location
1	Large families Hispanic Non-English speaking Low educational attainment	West, North
2	Renters Poverty Unemployment No vehicle	Central(Downtown), North
3	Families Children Low density	East
4	Elderly Unemployed Disabled	No specific pattern (Southwest, Northwest, Southeast)
5	African American Females	Northeast

4.1.2.1 Factor 1

Factor Group 1 is comprised of Hispanic, women (who are largely single-parents), with many children, who, when surveyed, noted that they "speak English less than well". This group is considered more vulnerable to natural disasters based on limitations associated with race, gender, and children. Hispanic origin is correlated with higher vulnerability rates (Cutter et al. 2003; Elliot and Pais 2006), as the social and economic marginalization of certain racial and ethnic groups, including real estate discrimination, has rendered these populations more vulnerable at all stages of disaster (Morrow 1999; Cutter et al. 2003). Additionally, limited English proficiency makes disaster communication and response techniques increasingly difficult. Children, especially in the youngest age groups, cannot protect themselves during a disaster because they lack the necessary resources, knowledge, or life experiences to effectively cope with the situation. Children are rarely incorporated into disaster-scenario exercises (Martin et al. 2006), and in a single-parent circumstance, both the child and adult are at increased risk because all daily caretaker responsibility falls to the one parent, and there is one less adult available to share post-disaster responsibilities.

Figure 5: Factor 1 Population Distribution

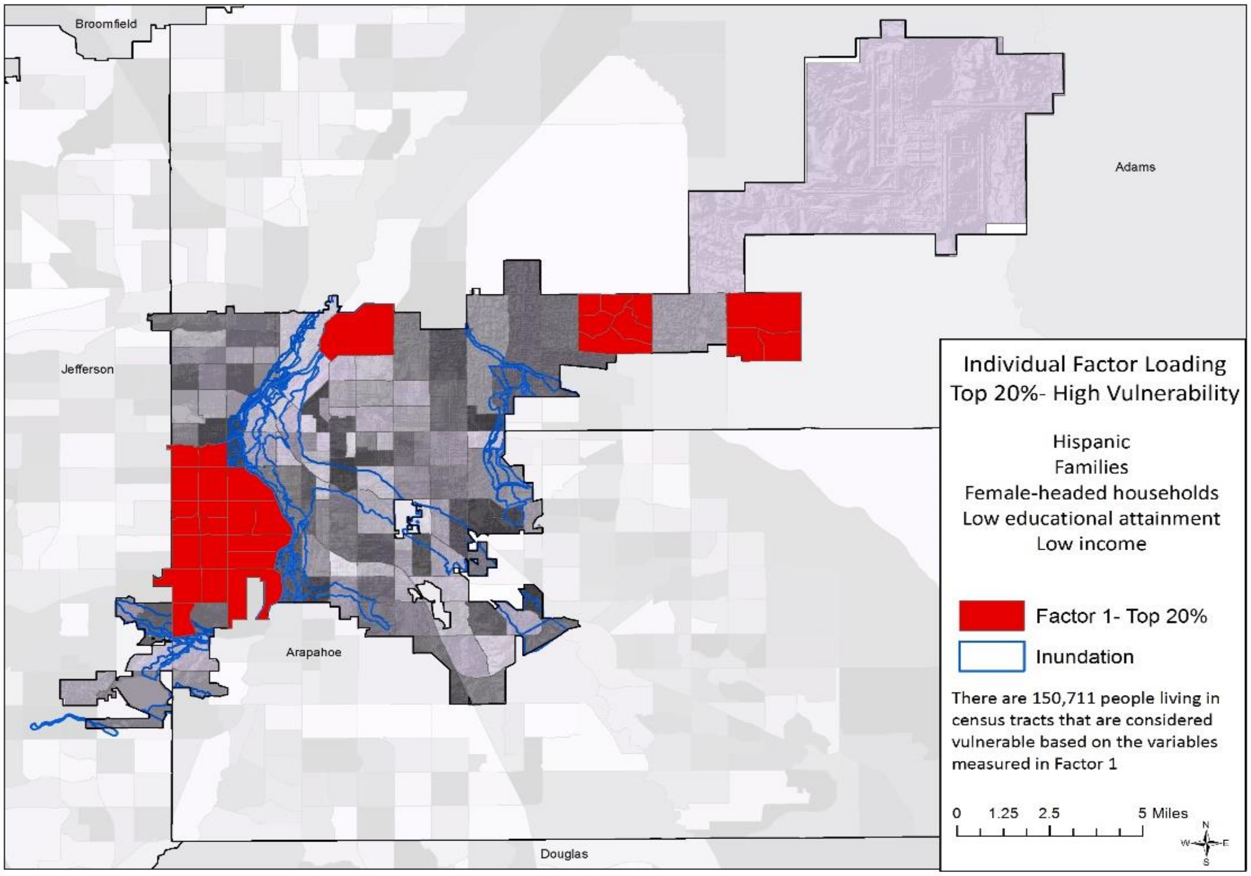
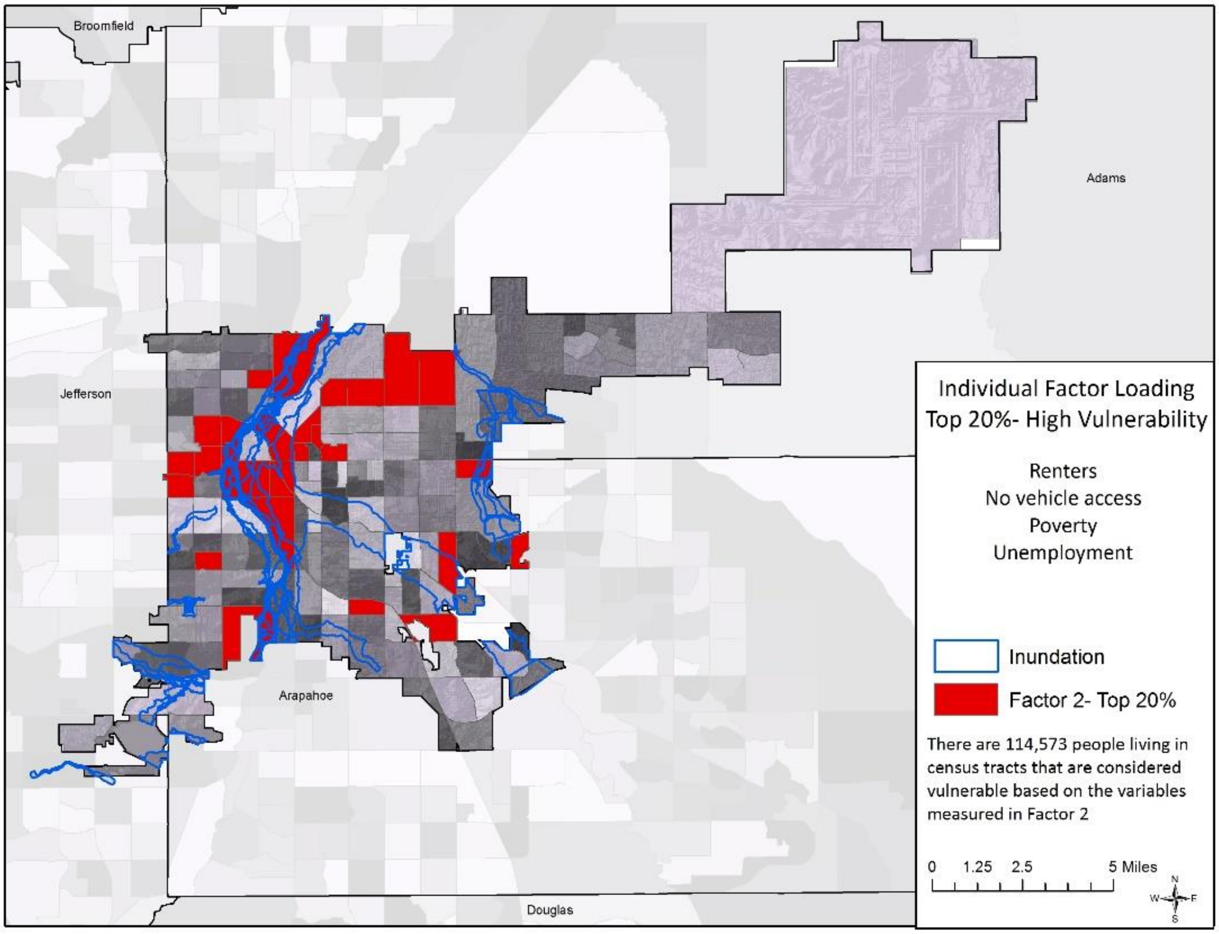


Figure 6 shows that the highest proportion of Factor 1 individuals are located in the western portion of the county, in addition to some tracts along the northern boundary. There is a strong clustering of highly vulnerable factor 1 individuals, which is especially significant for this factor group because these tracts are home to a large number of Hispanic people who do not speak English well. There are approximately 150,000 individuals included in the highly vulnerable top 20% category.

4.1.1.2 Factor 2

Evacuation can be significantly problematic for people who do not have access to a vehicle (Morrow 1997). Rates of automobile ownership are generally lower in urban areas, especially among inner city poor populations (Pucher and Renne 2004). For many, the cost of buying, insuring, and maintaining a car may prevent vehicle use (Brodie et al. 2006). In addition to obstacles for vehicle ownership, the poor are less likely to have the income or assets needed to prepare for a possible disaster or to recover after a disaster (Morrow 1999; Cutter et al. 2003). Although the monetary value of their property may be less, it likely represents a larger proportion of total assets and total income. High-income populations, on the other hand, may suffer higher household losses in absolute terms, yet find their overall position mitigated by insurance policies, financial investments, and stable employment (Bolin and Stanford 1998; Tierney 2006). For the households of individuals living below the poverty line, the damaged or lost property is more expensive to replace, especially without homeowner's or renter's insurance (Tierney 2006). Moreover, unemployed persons do not have employee benefits plans that provide income and health cost assistance in the event of personal injury or death (Brodie et al. 2006).

Figure 6: Factor 2 Population Distribution



Factor 2 individuals tend to be located in the northern/central region of the County. This group is comprised of individuals who rent and are without vehicle access, so it would make sense that they are living in close proximity to the downtown central business district area.

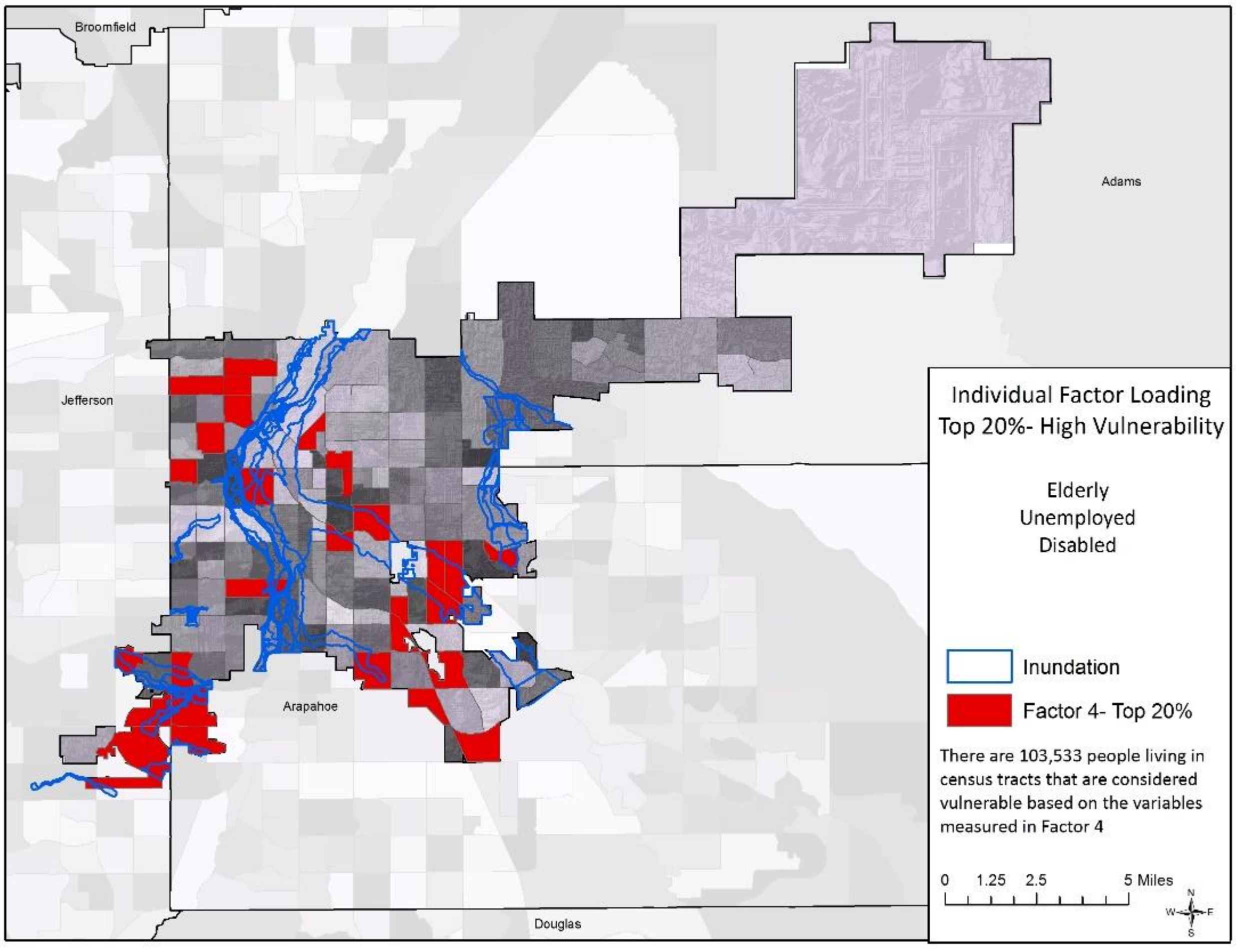
4.1.1.3 Factor 3

Unlike the other factor loading groups, Factor 3 individuals are considered <u>less vulnerable</u>. When calculating the cumulative vulnerability scores, the census tracts with this factor group receive a positive value, while the other factor groups are negative (See Appendix D). Factor 3 reflects areas with low density housing for families with children. These individuals are not limited financially or physically, and tend to have increased access to resources and support. The top 20% of people in the Factor 3 group are located along a corridor in the eastern/central portion of the county. These tracts are home to affluent neighborhoods, with some distance from the city to create a semi-suburban atmosphere, in addition to access to major highways (I25 and I70).

4.1.1.4 Factor 4

Elders living alone and people of any age having physical, sensory, or cognitive challenges are also likely to be more vulnerable to disasters (Eidson et al. 1990; Schmidlin and King 1995; Morrow 1999; Peek-Asa et al. 2003; White et al. 2006; McGuire et al. 2007; Rosenkoetter et al. 2007). Older or disabled people have needs that require specialized assistance from others.

Figure 7: Factor 4 Population Distribution

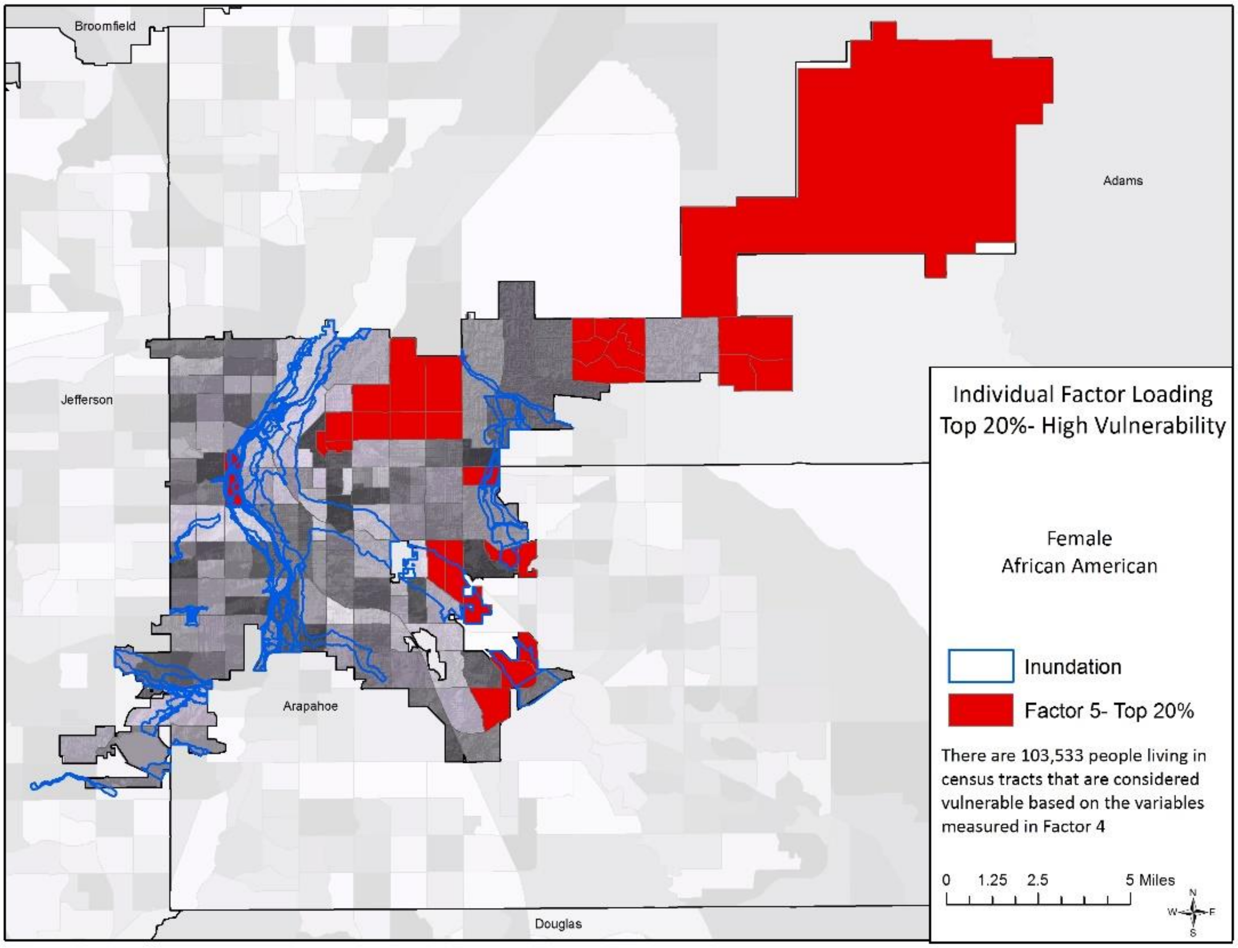


Factor 4 is the most highly dispersed grouping, and it is difficult to discern a clear trend in the clustering of individuals. This dispersal might be a result of the distribution of nursing homes and elderly living facilities and health care centers. As depicted in Figure 9, there is a small cluster in southwest Denver, as well as along a diagonal corridor running from the northwest to the southwest.

4.1.1.5 Factor 5

Factor 5 is the most anomalous of the Factor groups, with a significant gap between high and low population concentrations. The majority of Factor 5 individuals, meaning African American women, live in the large census tract in the northeast, in addition to a few tracts also in the northeast. Though being African American and a woman does not intrinsically mean that an individual is vulnerable, there are limitations associated with race and gender that can lead to disproportionate availability of resources. The wage gap for both African Americans and women generally results in increased rates of poverty.

Figure 8: Factor 5 Population Distribution

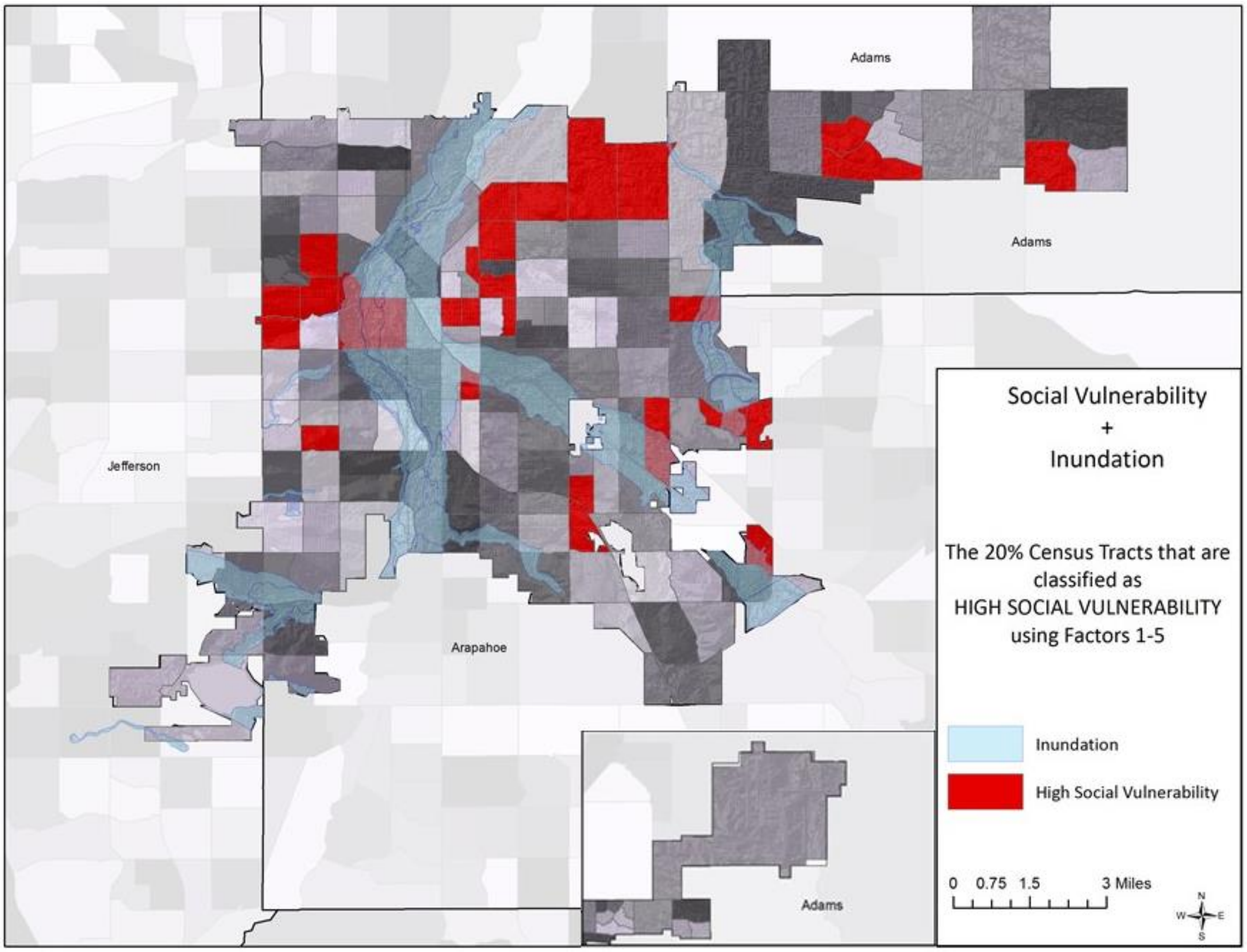


4.1.4 Cumulative Vulnerability

Using the results of the factor loading score analysis, the top 20% of the scores equate to the most socially vulnerable census tracts, depicted by red polygons in the map below. The overlay of each factor group produces a cumulative vulnerability score, demonstrated in 28 "high social vulnerability tracts" in Denver County.

Geospatial analysis was performed on the census tracts in the top 20% category, and an assessment measured the area of the tracts that are covered by the inundation polygon. To determine the number of socially vulnerable individuals living in inundation areas, it was essential to first measure the area of the census tracts in the top 20% of each factor group, then determine the area of the factor group within the inundation polygon.

Figure 9: Cumulative High Social Vulnerability



Overlaying the inundation polygon on top of the social vulnerability data illuminates areas that are at risk based on access to resources/socioeconomic conditions, as well as risk in the event of a dam failure. It should be noted that the inundation area polygon is an aggregate of all dams in the area, and individual dam risk will be further discussed later in this paper.

There is not a strong pattern that dictates how socially vulnerable populations cluster in Denver County, however, the trend locates these individuals in the Northern/Central region. As depicted in the previously mentioned quantitative analysis, there are 120,000 individuals that are included in the High SV category.

The downtown business area is also located in the proximity of the high SV cluster, which translates to higher density populations surrounded by essential infrastructure, government buildings, and valuable businesses/economic assets.

4.1.3 Critical Facilities

Critical facilities, meaning schools, police stations, fire stations, and hospitals are vital when evaluating response and recovery abilities post disaster. The table in Appendix H outlines the critical facilities in total, and within the inundation area, for both cumulative and specialized vulnerability groups. Facility availability for each individual factor group highlights any disproportionate access to resources and aids. In Denver County, there are 287 total critical facilities, most of which are K-12 schools. Local planning aims to distribute these facilities equally across the County, based on population density and community needs. Factor 1 has the most schools, while Factor 4 and 3 have the least, which is appropriate because Factor 1 represents the largest number of people (and children), while Factor 3 is low density and Factor 4 is elderly. Police stations and fire stations are distributed relatively evenly across the all loading groups, though it should be noted that there are more fire stations in Factor 3 and Factor 5 census tracts, which are also the least dense areas. Factor 4 does include a large number of hospitals, which is essential for the elderly/disabled, but there are no hospitals in the Factor 1 census tracts. Factor 2 has the most hospitals, which is likely a result of the centralized/downtown location of the census tracts included in this loading group.

The total distribution of critical facilities has already been described; however, the following analysis examines how and which of these facilities will be impacted in the event of dam failure. When integrating social vulnerability and dam failure, none of the critical facilities are located in cumulatively high social vulnerable census tracts. Hospitals are the only type of facility that are located in both dam failure polygons and socially vulnerable census tracts.

There are 33 schools located within dam inundation areas. Amongst these schools, there are four charter schools, sixteen elementary schools, five middle schools, and eight high schools. None of these schools are located in high vulnerability census tracts, which means that students are having to travel from their homes, disproportionately when compared to the less vulnerable students. If a natural disaster occurs while the students are at school, the distance poses further challenges for the vulnerable students, and it might be more difficult to reconnect with their families, especially if the family has limited access to a vehicle.

There are eight structures related to police activity that would be impacted by total dam failure. Of these buildings, there is the Denver police headquarters, the police academy, three cop shops, the Webb Municipal Building/Courthouse, bicycle impound, and traffic investigations. Within the dam inundation polygons there are four fire stations. These stations serve two districts; district 2 and district 7. As mentioned, these critical facilities are not located in census tracts with highly vulnerable communities. The lack of critical facilities in these areas means that in the event of dam failure, the vulnerable populations will have limited access to police and fire fighters, which inevitably translates to longer response times, and inherently more damage faced by the communities. Understanding the geospatial distribution of critical facilities highlights the gaps and the disproportionate access that affects communities that already lack resources and support.

The two at-risk hospitals located in central Denver, near the downtown, Denver Health Center, and La Mariposa Health Center. As mentioned, hospitals are the only type of critical facility that are located in both dam inundation areas and socially vulnerable census tracts; however, it is the same two hospitals that will be effected.

4.1.4 Transportation

The table in Appendix H details Denver's transportation infrastructure, for both the total County and within the inundation area, and for cumulative and specialized vulnerability groups. There are 421 miles of arterial streets and 75 miles of highway in Denver County. The majority of streets and highway are located in factor 3, which is includes the lowest density of housing and people. This disproportionate distribution of roadways to people reflects a suburban urban form, providing access for commuters who want to live farther from the city. Factors 2, 4, and 5 cover equal amounts of arterial streets (around 75-80 miles). In terms of highway mileage, factor 2 has more highway access because this group includes census tracts in the north, which borders I70. Factor 1 has the lowest number of transportation miles within its census tracts, further isolating the heavily clustered non-English speaking communities.

In this research, arterial streets and highways will be the primary forms of assessed transportation infrastructure. In Denver County, there are 421 miles of arterial streets that follow a grid format. There are two main highways that run through the county, I-70 serving the east/west traffic, and I-25 running north/south.

In the event of total dam failure, over 20% of streets and highways will be effected and likely unusable. The majority of the inoperative roads are located in the Factor 2 census tracts, which is especially concerning because these individuals do not have access to cars and are at a greater risk of being stranded. As displayed in figure, I-25 is more heavily effected by dam inundation. Using this information, evacuation planning should consider focusing efforts on getting people to I-70.

4.2 Dam Risk

Using the indexing tool and assigning the appropriate values for the variables the dams receive a score and ranked based on degree of anticipated risk. Table 6 outlines the results of the Andersen and Torrey's method.

Table 6: Dam Risk Scores

Risk Rank	Dam ID	Dam Name	Risk
1	1	Bear Creek	320.625
2	3	Cherry Creek	320.625
3	4	Englewood	280.125
4	15	South Platte	280.125
5	17	Westerly Creek	280.125
6	8	Main	240.75
7	9	Marston Lake- East	240.75
8	10	Marston Lake- North	240.75
9	11	Marston Lake- Northwest	240.75

10	12	Marston Lake- South	240.75
11	5	Harriman	210.375
12	7	Kelly Road	210.375
13	13	Skeel	210.375
14	14	Smith	210.375
15	16	Ward #5	210.375
16	18	Windsor	210.375
17	2	Beers Sisters	190.125
18	6	Holly	180

Dams 1 and 3 pose the greatest risk because they contain the largest volume of water, posing a greater threat in the event of failure. The inundation area for each of these dams covers a significant portion of highly populated areas. These dams will be further investigated in the case studies later in this paper.

As previously described, dam 1 and 3 have the highest risk index scores (both 320), and figure displays the large land area covered by these two inundation polygons. The north-south corridor covered by dam 1 and the northwest/southeast corridor covered by dam 3 follow the flow patterns of the Cherry Creek and Platte waterways. The other dams with lower scores are associated with smaller hydrologic features, which minimizes their impact and limits the coverage of inundation.

4.3 Overlaying Social Vulnerability and Dam Risk

Of the 28 high social vulnerability census tracts, 11 are located within the inundation area. This means that roughly 8% of all census tracts in Denver are comprised of 48,000 highly vulnerable individuals at risk to dam failure. The probability of all the dams failing at once is extremely unlikely, and examination of each individual dam inundation polygon provides a more accurate assessment of different disaster scenarios. To further evaluate the relationship between social vulnerability and dam risk, each dam is individually assessed based on the census tracts included within the inundation polygon.

The figure below displays the high SV tracts (crosshatched), in addition to the dam risk scores. Using the cumulative vulnerability results (top 20% of total social vulnerability), the number of high SV tracts for each dam is calculated, and each dam is grouped into one of three categories (low, moderate, and high). The lower SV categories (green) includes dams with one or no “high SV” tracts, the moderate category (orange) includes dams with two “high SV” tracts, and the high category (red) includes dams with five “high SV” tracts.

Figure 10: Social Vulnerability and Dam Risk Overlay

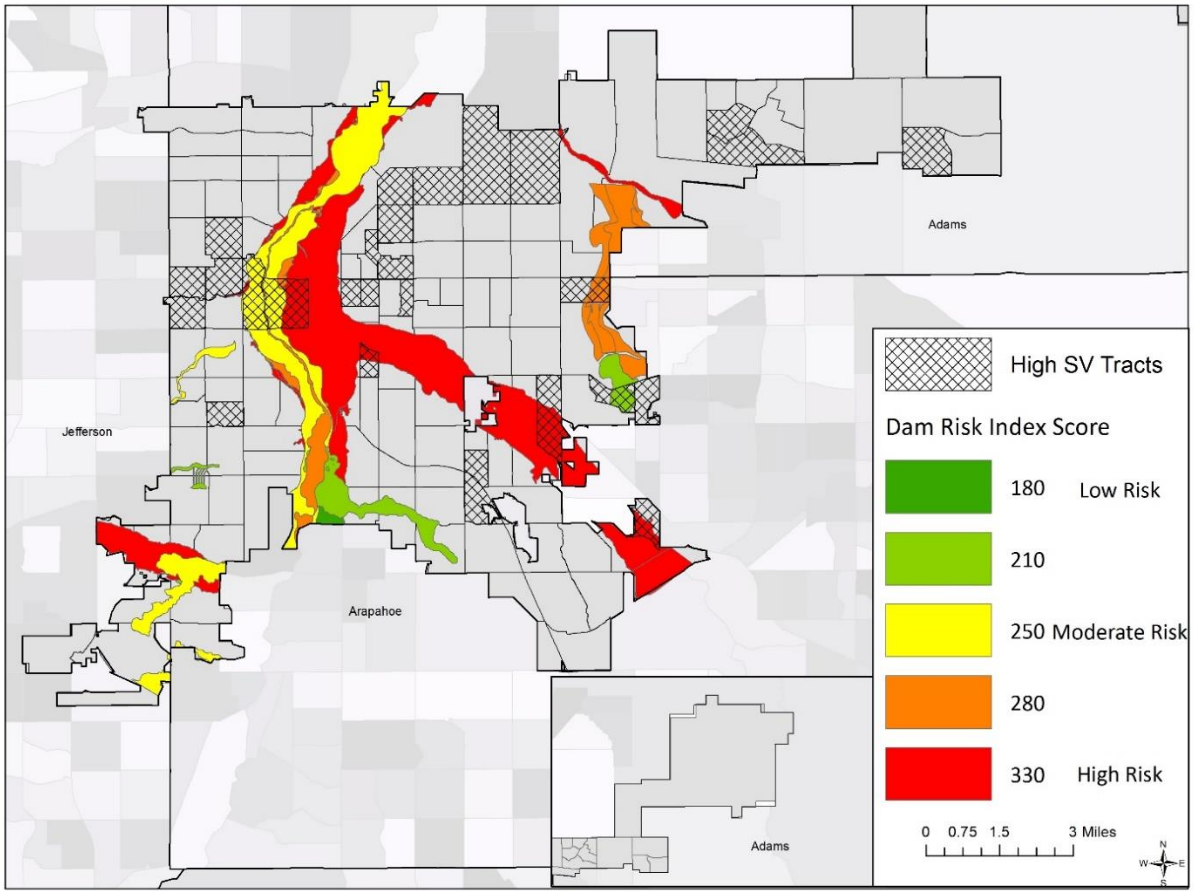


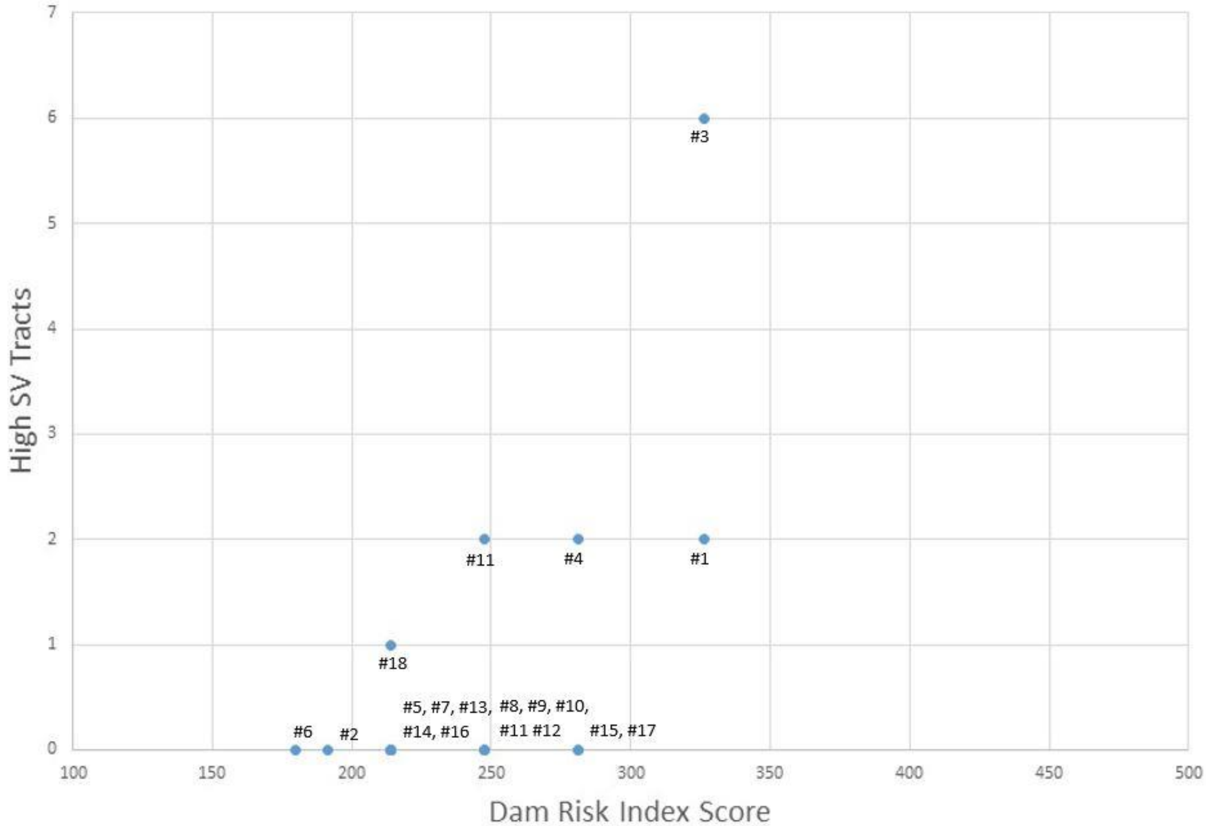
Table 7 identifies both the risk ranking, as well as the social vulnerability ranking for each dam. There are nine dams identified (half of the dams) that should receive attention. The cells highlighted in red depict the dams with equally high dam risk and social vulnerability ranking, emphasizing the dams that have the greatest potential to cause the most damage to the most number of socially vulnerable individuals. The dams in the red rows should be the focus of both increased mitigation efforts, and response planning for populations with limited access to resources and support. The cells highlighted in yellow depict the dams that have a high risk, but low social vulnerability ranking, and therefore warrant more specialized engineering attention. These dams should provoke either hydrologic mitigation efforts, or response planning, based on whether there is a higher risk ranking, or a higher social vulnerability ranking. The dams highlighted in yellow have high risk scores, but low social vulnerability, which indicates a need for increased hydrologic engineering attention and mitigation efforts, however, there is

Table 7: Social Vulnerability and Dam Risk Overlay

Dam ID	Dam Name	Risk	SV Tracts	Risk Rank	SV Rank
3	Cherry Creek	326.25	6	2	1
1	Bear Creek	326.25	2	1	2
4	Englewood	281.25	2	3	2
6	Holly	180	0	18	-
7	Kelly Road	213.75	0	12	--
8	Main	247.5	0	6	--
15	South Platte	281.25	0	4	--
13	Skeel	213.75	0	13	--
18	Windsor	213.75	1	16	3
5	Harriman	213.75	0	11	--
14	Smith	213.75	0	14	--
16	Ward #5	213.75	0	15	--
17	Westerly Creek	281.25	0	5	--
9	Marston Lake- East	247.5	0	7	--
10	Marston Lake- North	247.5	0	8	--
11	Marston Lake- Northwest	247.5	2	9	2
2	Beers Sisters	191.25	0	17	--
12	Marston Lake- South	2475		10	--

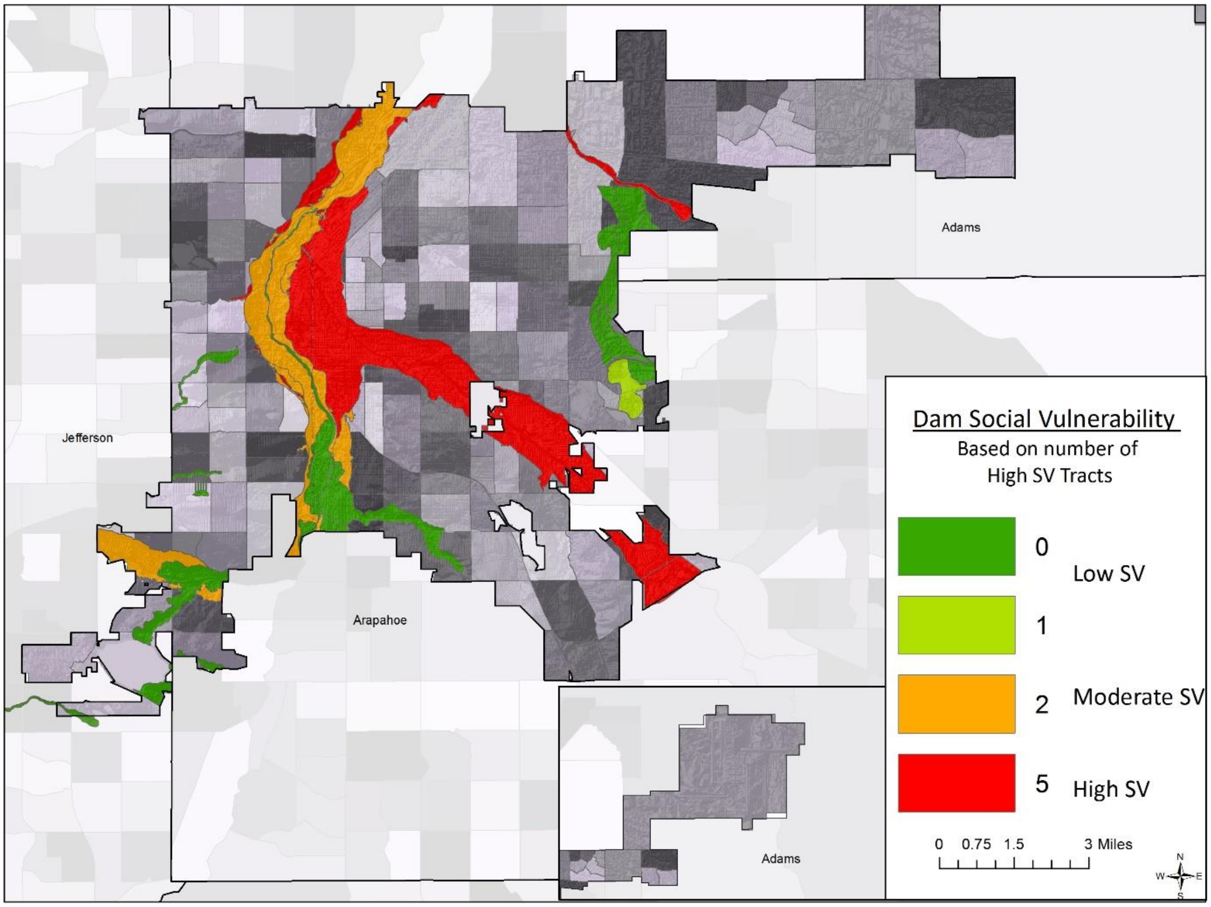
Dam 3, 1, and 4 (highlighted in red) are all the most significant when assessing both cumulative social vulnerability and risk. The results of the two index processes are largely in part to the fact that these three inundation areas cover the largest surface area. Scatterplot diagram is also used to display this overlay.

Figure 12: Scatterplot Results



The scatterplot diagram is a useful tool to accompany geospatial and statistical processes. The spread of data based on two different variables identifies and highlights specific dams that should be further analyzed. 14 out of 18 dams (78%) do not have any cumulative social vulnerability tracts, which is why the data is clustered in the lower portion of the plot. Dams #18, #11, #4, and #1 all include one or two high social vulnerability tracts, but vary in their risk ranking. Dam #3 is anomalous, both in terms of social vulnerability and dam risk index score, which makes it stand out in the upper right corner. The dams identified in the aforementioned table and scatterplot are more closely examined in the case studies in the following chapter.

Figure 13: Dam Risk based on Social Vulnerability



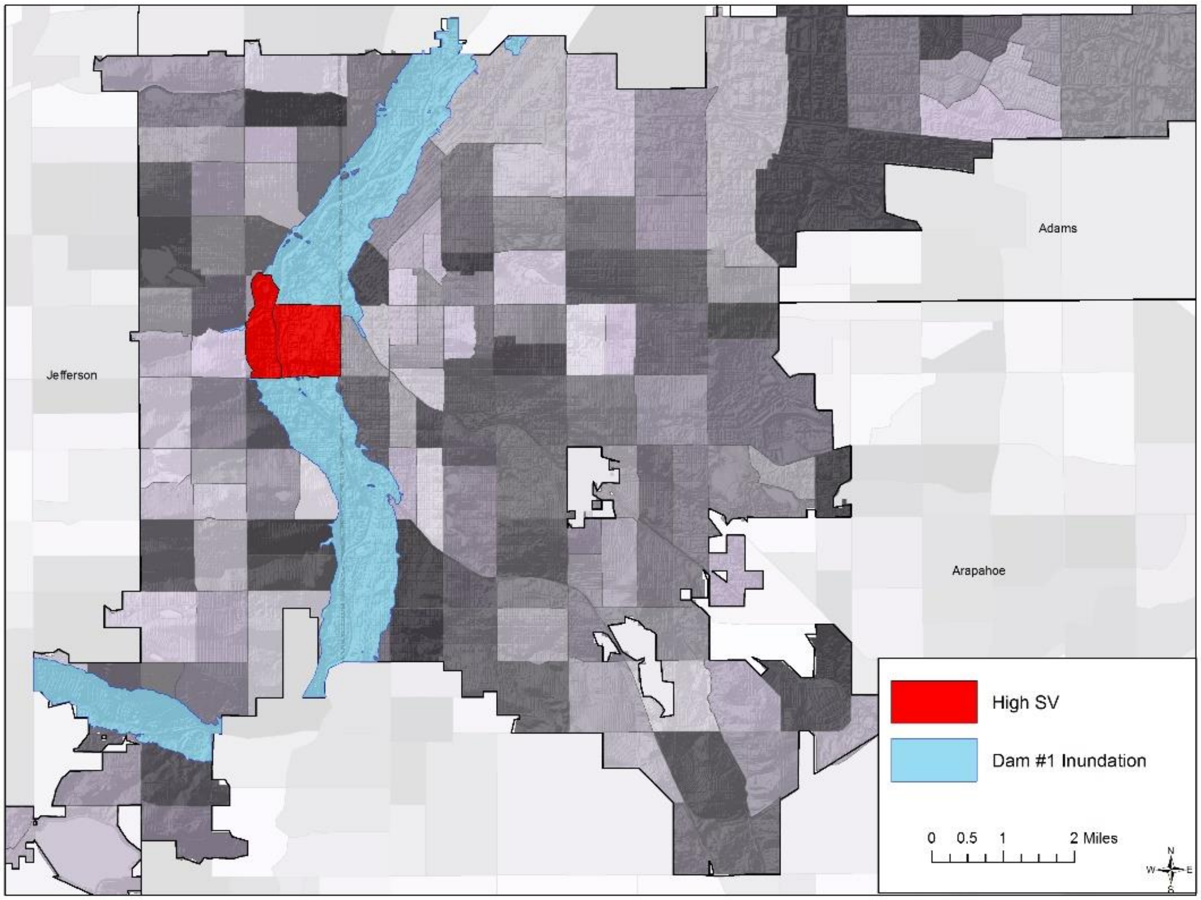
Another way to measure dam risk is to apply the social vulnerability index results to each specific dam, and evaluate the dam purely on the number of at-risk individuals located within the inundation area. Figure 13 presents all 18 dam inundation polygons, and the color of the inundation area is determined by the number of cumulatively high social vulnerability tracts. This analysis is based purely on the number of tracts, not the number of individuals or density within those tracts. Using the visualization of data, it becomes evident that the highest vulnerability is concentrated in the central region of the County.

4.4 Three In-Depth Assessments

Three dams are assessed based on high dam risk index scores, and high concentrations of cumulatively vulnerable populations. Additionally, emergency managers can use the results of geospatial analysis to inform evacuation plans and integrate more specialized action items that address the disproportional impacts facing the disadvantaged populations within the target census tracts.

4.4.1 Dam #1

Figure 14: Dam #1

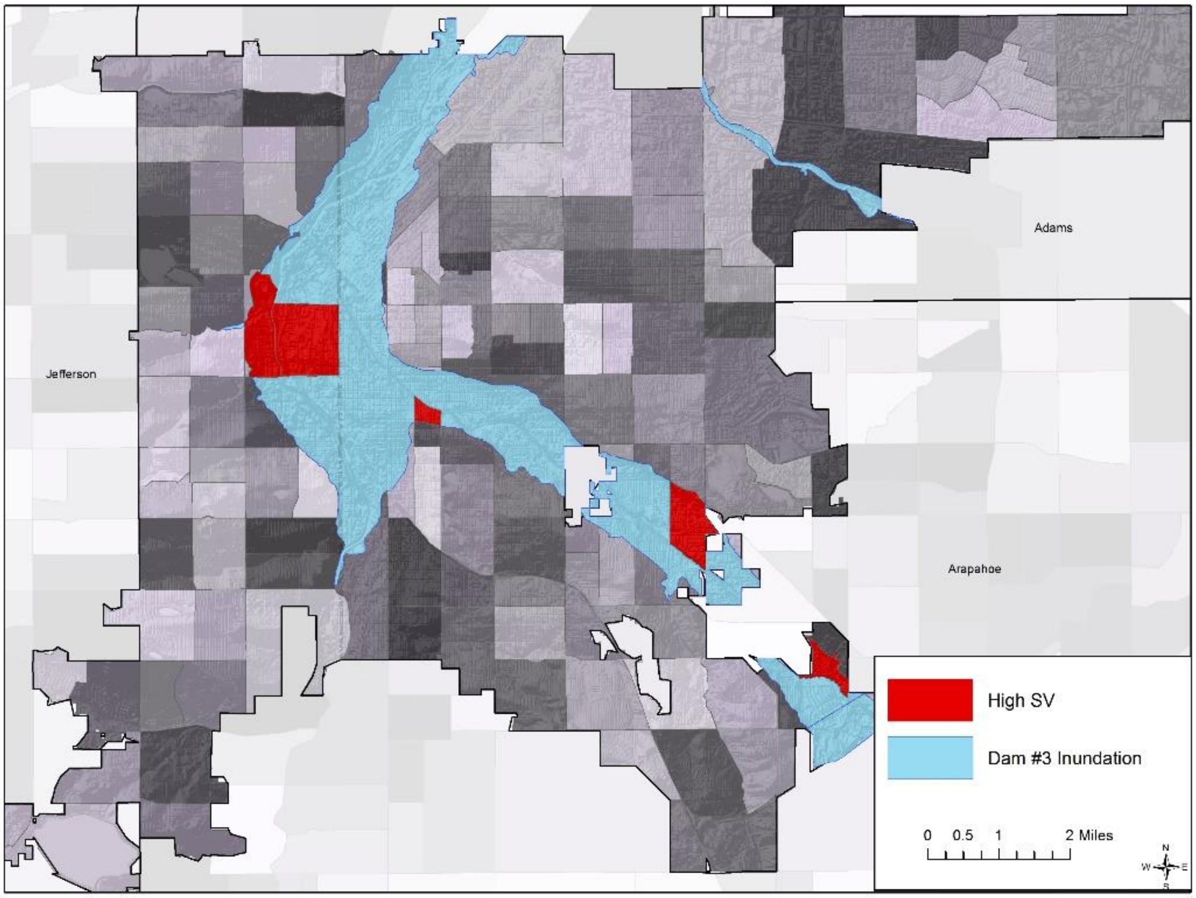


Dam #1 scored 326 for dam risk, covers 10 square miles, and includes two high social vulnerability tracts. As previously mentioned, it is tied for the number one ranking terms of hazard and it is number two in terms of social vulnerability.

There are close to 125,000 individuals living within the inundation area, of which 4,000 are included in the high social vulnerability category. The population is 51-49 percent male-female, 46% Hispanic, 44% White, 4% Black, 3% Asian, and 1% other, with a median age of 32 years old. Dam failure will effect 25,000 families, 17,000 children under ten years old, 300 people in assisted living, and 4,400 in group quarters. In terms of critical facilities, there are seven schools, of which there are five elementary, one middle school, and one high school. There are four police stations, two fire stations, and no hospitals located within the inundation area. The exact location of these critical facilities is displayed in Appendix N.

4.4.2 Dam #3

Figure 15: Dam #3

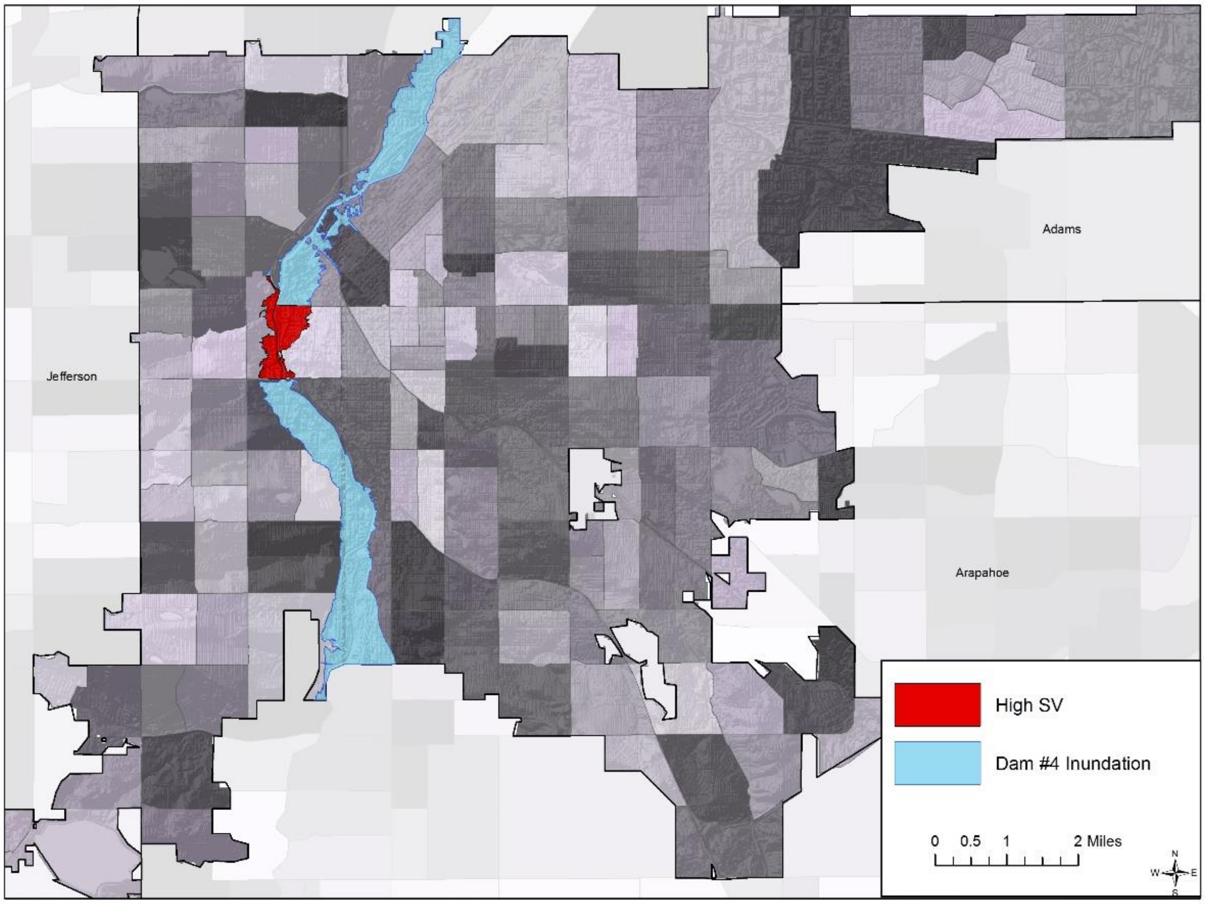


Dam #3 scored 326 for dam risk, covers 16 square miles (the largest inundation area), and includes five high social vulnerability tracts. As previously mentioned, it is tied for the number one ranking in terms of hazard and is ranked number one in terms of social vulnerability.

There are close to 187,000 individuals living within the inundation area, of which 19,000 are included in the high social vulnerability category. The population is 52-48 percent male-female, 30% Hispanic, 56% White, 8% Black, 3% Asian, and 1% other, with a median age of 34 years old. Dam failure will effect 36,000 families, 23,000 children under ten years old, 360 people in assisted living, and 7,800 in group quarters. In terms of critical facilities, there are 24 schools, of which there are three charter, nine elementary, four middle schools, and eight high schools. There are six police stations, four fire stations, and two hospitals located within the inundation area. The exact location of these critical facilities is displayed in Appendix P.

4.4.3 Dam #4

Figure 16: Dam #4



Dam #4 scored 281 for dam risk, covers 5 square miles (the largest inundation area), and includes two high social vulnerability tracts. As previously mentioned, it is number two in terms of hazard and is tied for number two in terms of social vulnerability.

There are close to 67,000 individuals living within the inundation area, of which 4,400 are included in the high social vulnerability category. The population is 52-48 percent male-female, 52% Hispanic, 37% White, 5% Black, 3% Asian, and 1% other, with a median age of 30 years old. Dam failure will effect 13,000 families, 9,800 children under ten years old, 0 people in assisted living, and 2,900 in group quarters. In terms of critical facilities, there are 3 schools, all of which are elementary schools. There are two police stations, no fire stations, and no hospitals located within the inundation area. The exact location of these critical facilities is displayed in Appendix R.

Chapter 5- Limitations, Application, and Recommendations

5.1 Challenges and Limitations

- Challenge 1: No collaboration with dam owners/dam safety managers

My analysis of dam risk can be significantly improved and more accurate if I could collaborate with dam owners, engineers, and dam safety managers. Though my preliminary research provides me with a general understanding of dam functionality and construction, I make assumptions that impact the validity of my analysis. My results could be improved if I was able to consult with experts and receive feedback on my calculations. The disadvantages, as well as the opportunities associated with this challenge are further discussed later in this chapter.

- Challenge 2: Difficult to evaluate communities located in more than one inundation area.

Looking at the preliminary GIS maps I have created, it is inevitable that my results will include communities that are located in the inundation zones of two different dams. It will be challenging to assess whether or not these communities are at a greater risk, and to what degree. This determination will necessitate a variety of assumptions such as "cause of dam failure", which might make my results less accurate. Additionally, these assumptions make the methodology more specialized and difficult to repeat for other jurisdictions.

- Limitation 1: American Community Survey and Census data use

There are limitations related to the use of American Community Survey census data. Most saliently, the fact that the numbers are aggregated and generalized, which can lead to accuracy issues. Decennial census data is generally perceived as more accurate because the survey population size is larger, however, the census does not account for the rapidly changing composition of some small-area populations in the intercensal years. Also, the census counts people where they live, not necessarily the locations of work and recreation.

An inherent limitation of dealing with census data is that the information only reflects the populations that responded to the survey, and that the information does not account for future trends or changes. In this research, it is vital that all sub-groups of the community are accurately represented, and culture, language, literacy, and/or resource availability may impact an individual's inclination to respond to the survey. Additionally, the results of my analysis will only be useful for Denver Emergency Managers for a few years. As the communities change over time, the social vulnerability analysis must be repeated with more current data.

5.2 Value and Applicability

The most vulnerable people are likely those whose needs are not sufficiently considered in the planning of local response and relief organizations. Many low-income people in New Orleans were stranded in the wake of Hurricane Katrina because they had no personal transportation and public authorities did not provide emergency mass transit. In mitigating and planning for emergencies, state, local, and tribal officials must identify socially vulnerable communities to provide those residents increased assistance over the course of a disaster. (Flanagan et. al. 2011)

Although local authorities are in the best position to identify vulnerable communities, such agencies are frequently underfunded, understaffed, and stretched thin by a myriad of responsibilities. State agencies, even if sufficiently staffed and funded, may lack the systems in place to assess and allocate appropriate resources (APHA 2006; USGAO 2006).

While the primary motivation for social vulnerability assessment is to consider equity implications and better insure the safety of all represented populations, state and local officials should also consider cost savings when planning for emergencies. Effective mitigation and preparation decreases both human and economic loss related to providing social services and public assistance after a disaster (Flanagan et. al. 2011). Increasing recognition of the importance of identifying vulnerable populations has increased a demand for tools to do so. The methodology outlined in this paper is easily replicable and requires only census data and a fundamental understanding of statistical processes and geospatial analysis.

The value of my research is emphasized by recognizing the mistakes made by disaster management during Hurricane Katrina. The majority of Katrina fatalities in Orleans, St. Bernard, and Jefferson Parishes were elderly people, almost half of which were older than 75 years of age. Given that only 6% of the pre-Katrina residents in the affected area were older than age 75, the elderly was especially vulnerable to this catastrophic event (Brunkard et al. 2008). Many nursing home residents died in their facilities, and were allegedly abandoned by their caretakers. Facility evacuation problems during Katrina included transportation contracts that were not honored, lengthy transit times for patients, host facilities that were not ready or available, insufficient staffing, complicated patient medical needs, loss of facility emergency plans, and staff difficulties entering their own facilities due to flooding or damage (Department of Health and Human Services, Office of Inspector General, 2006). Applying the methodology outlined in this paper and recognizing the location of different vulnerable populations, emergency managers might have reduced the number of causalities and minimized the deficiencies of response. Evacuation challenges are not exclusive to the elderly, and many low-income people in New Orleans were stranded because they had no personal transportation and public authorities did not provide emergency mass transit. The mapping of different vulnerable groups can inform management of specific needs and limitations, so that in the event of a disaster, the jurisdiction will be able to send out the appropriate mass transit options to the specific locations of need, without wasting time or resources.

Another example of improved strategies relates to the populations that “speak English less than well”. In San Francisco, the NICOS Chinese Health Coalition is a coalition of nonprofit and private organizations representing and caring for Chinatown’s Chinese community. The Chinatown Disaster Response Project prepares Chinatown residents for the first 72 hours following a disaster through emergency response training, HAM radio operation classes, and drills. The committee has also developed multiple bilingual preparedness materials. *In 2007, NICOS and the committee developed the “San Francisco Chinatown Disaster Response Plan”; an* easy-to-read document that alternates between English and Chinese. The success of NICOS hinges on the understanding of the demographics and community profile, as informed by mapping and surveying the population. The methodology outlined in my research will help inform the location of communities needing bilingual services, the location of health centers associated with serving these individuals, and the roles of responders.

5.2.1 Specialized vs. Cumulative Vulnerability Assessment

This factor analysis process and development of a social vulnerability index scores can be used to survey and study the highly vulnerable populations in more detail. An in-depth understanding of the location and characteristics of individuals included within vulnerability categories can illuminate specific needs for those communities.

There are a variety of characteristics that contribute to an individual's ability to act, respond, and recover during/after a disaster event. The degree to which the individual is economically or physically obstructed can affect the impact of the natural hazard. Additionally, the type of hazard (i.e. dam failure, fire, flood, earthquake, hurricane) can have different effects on different disadvantaged groups. One of the key strengths of the factor analysis methodology is that the process identifies what can be categorized as "specialized vulnerability". For the purpose of this paper, specialized vulnerability refers to the distinct classes of at-risk individuals.

Planning for specialized vulnerability is especially valuable for large jurisdictions, multi-jurisdiction/regional circumstances, heavily populated areas, and/or highly diverse communities. If staffing and funding resources are available, identification of different vulnerable populations can inform specific action items that can be integrated into natural hazard mitigation plans, as well as response and evacuation plans. Mitigation and response strategies can be more appropriately designed based on the challenges faced by the targeted group.

Mapping of specialized vulnerable groups can better inform emergency management for all phases of the disaster cycle, but most saliently, this strategy can lead to more effective response planning. As previously mentioned, there are a variety of specific needs associated with each target population. Response, whether that be evacuation or distribution of aid, will be most efficient and appropriate if planners have an accurate understanding of the demographic profile of the community.

On the other hand, cumulative social vulnerability is also a valuable tool for achieving both a comprehensive assessment of the general community profile, as well as identifying individuals with aggregated vulnerability. This heightened level of susceptibility makes cumulatively vulnerable communities exponentially more exposed and in-need of extra assistance in a natural hazard event. For example, individuals who have minimal English language proficiency and are physically disabled are faced with communication barriers and issues related to mobility that can significantly impede their ability to evacuate.

Cumulative social vulnerability can be used by emergency management to determine how to prioritize aid and immediate response support in the early phases of response and recovery. Following a triage-like structure, priority should fall in areas with the highest concentration of cumulatively vulnerable individuals. Additionally, aggregated vulnerability characteristics can be applied for smaller jurisdictions with more limited funding and staff, or with smaller overall populations. Specialized mitigation and response assistance may not be an effective use of resources when there are only a few individuals in each category.

5.3 Future Analysis

The method of comparing social vulnerability to a risk index score can be applied to other natural hazard evaluations. Once a jurisdiction calculates social vulnerability scores, the emergency managers will have a fundamental understanding of the demographics and community profile, and then evaluating the conditions for different types of disasters. The social vulnerability index measurement should be repeated at a minimum, every five years to account for changes in population. In addition to the overlay of hazard and cumulative vulnerability, the results from the factor analysis can also be used to inform mitigation and evacuation strategies that may vary based on the impacts of the targeted hazard. Each type of natural hazard has a unique set of issues and obstacles for response and recovery, and have different implications for each individual factor group.

Taking this further, future research might consider looking at multiple hazards and creating a 'cumulative hazard' analysis. While this study has overlaid a variety of social vulnerability groups to establish an aggregated high social vulnerability rating, emergency managers could benefit by looking at areas that may be at-risk to more than one hazard.

Understanding geospatial trends and distribution of social vulnerability assists planners and emergency managers concerned with all phases of the disaster and aid in their efforts to ensure the safety and well-being of the community. With this knowledge, planners can more effectively target efforts to mitigate and prepare for disaster events. Responders can plan more effectively design evacuation plans for those people who might need special assistance (i.e. without vehicles, the elderly, limited English proficiency). The information can also be used to identify neighborhoods that may need additional human services support in the recovery phase.

Future research could also benefit from facilitated discussion with hydrologic experts, geotechnical engineers, representatives from the Army Corps of Engineers, in addition to local emergency management and FEMA. My research is based on rudimentary understanding of dam function, but integrating a higher level of science and engineering would insure more accurate results. addition, something that this research does not take into account is the different causes for dam failure, and there may be underlying seismic conditions or hydro fluvial features that I am not aware of, which could ultimately catalyze a dam failure.

Though the lack of collaboration with dam engineers initially seems like a limitation, this methodology presents a unique strategy that empowers planners and emergency managers to independently process hazard risk conditions. Coordination with multiple entities and stakeholders requires effort, resources, and time, and frequently, an emergency manager may just want a fundamental understanding of the natural disaster potential. Utilizing a comprehensive risk index (such as the Andersen Torreys Embankment Dam Index) provides individuals without an advanced scientific/engineering background, with the opportunity to quantify a threat using readily available data.

It is important to note, that while this research centralizes around the City and County of Denver, the primary purpose of this study reflects an effort to establish a methodology that can be replicated in a variety of other situations. The use of the factor analysis for social vulnerability assessment, combined with an overlay of hazard risk index, reflects a tool that can lead to more effective emergency management, especially in the realm of response and evacuation planning. The process outlined in this paper is highly involved and requires advanced understanding of statistical analysis, as well as extensive GIS capabilities, and therefore, a more streamlined approach is presented below.

Specialized Vulnerability (Streamlined)

Step 1: Collect fundamental census variables (See table below)

Step 2: Quantify hazard risk

Step 3: Overlay individual census variables with hazard risk to determine the impacts for different demographic groups.

Table 8 Streamlined Social Vulnerability Assessment Data

Variable	2015 ACS 5-year estimates	Vulnerability Category	Additional Description
Poverty	S1701	Economic status	% of total population
Age 65 and older	S0101	Household composition/disability	% of total population
Under 5 years old	S0101		% of total population
Disability- Ambulatory difficulty	S1810		Those who responded "yes" when asked if they have serious difficulty walking or climbing stairs
Households with no vehicles	S2504	Housing and transportation	% of total number of households
Speaks English less than very well	S1601	Minority status and language	% of total population

The streamlined approach described above stipulates the creation of individual specialized vulnerability maps based on a single census variable, and therefore it is essential that the analyzed dataset be condensed. From the large dataset used to inform my research, I omitted 18 variables and condensed the analysis to six demographic characteristics, with at least one represented variable from each vulnerability category. Table 8 presents each variable and the source of data. The variables were chosen based on the degree to which they encompass a range of issues and obstacles, as well as the relevancy of targeted response strategies. For example, “Speaks English less than well” is chosen represent the “Minority status and language category”, while “African American” or “Hispanic” was omitted from the dataset, because inability to communicate or understand evacuation language is a more objective limitation than the trending vulnerability associated with race. “Ambulatory difficulty” is included in the “Household composition/disability” category, while “Self-care difficulty” is omitted, because there are more direct issues related to physical immobility than the limitations associated with an individual who faces challenges living alone. However, the most comprehensive understanding of a community profile is derived from the extensive list of 24 variables outlined in the earlier proposed methodology.

Cumulative Vulnerability (Streamlined)

Step 1: Use GIS to identify the tracts within the top 20% of each specialized category.

Step 2: Identify tracts that are included in the top 20% for multiple categories.

Step 3: Quantify hazard risk

Step 3: Overlay results from Step 2 with hazard risk results

Moving away from the aforementioned streamlined approach and taking this research in a more advanced and involved direction, GIS can be utilized to determine more specific evacuation strategies. Running the network analysis tool for individual inundated census tracts might highlight arterial roads or unaffected highway miles that can be used to either move individuals out of impacted areas, or be used to transport resources and aid to stranded or injured people. It would be highly effective to integrate the geospatial social vulnerability component into FEMA's HAZUS software. HAZUS is a GIS tool, centralized around the ArcGIS platform, which can be used to model Hurricane, Flood, Earthquake, and Tsunami events. The model runs a variety of scenarios with varying degrees of impact and severity, and measures the effects on site-specific infrastructure. To bridge the research gap between hazard analysis and social vulnerability assessment, the Hazus software could overlay different scenarios on top of the census data and provide a more thorough evaluation of the impacted populations.

5.4 Final Thoughts

Ultimately, this research serves to inspire increased dialogue in regards to hazard analysis and the implications for vulnerable populations. Though this methodology was applied to dam failure, the process can be reiterated in a myriad of conditions with different hazards. It is imperative that emergency managers and planners integrate sociology into the discussion of natural disaster potential and response approach. Every community is unique, with a dynamic demographic profile, and there is no 'one-size fits all' strategy. Effective utilization of geospatial analysis can identify target areas and help communities customize planning to most appropriately and efficiently utilize resources and time.

Appendices

Appendix A: Z-Scores for Census Variables

ID	GeoID	ZAge65an	ZMedianA	ZAverageI	ZRenteroc	ZHispanicp	ZFemalep	ZAfricanA	ZFamilyHo	ZFemaleh	ZUnder5y	ZSpeaksEr	ZHouseho	ZLessthan	Zbelowpo	Zbelowpo	ZCivilianla	ZPopulatio	ZMedianH	ZMedianH	ZPercapita	ZAmbulat	ZIndepen	ZPopulatio	ZHousingD
1	8.03E+09	0.2115	0.60089	-0.54262	-0.95705	-0.25759	-0.70496	-0.77745	0.09935	-0.6938	0.90481	-0.83614	-0.82009	-0.78453	-0.57936	-0.69842	-0.5138	0.6258	0.15678	0.47459	0.35989	-0.22342	-0.26575	-0.76662	-0.48651
2	8.03E+09	0.05967	0.19922	0.22795	-1.05222	1.21988	0.12927	-0.74818	0.28734	-0.40296	-0.08312	0.62222	-0.04407	0.78855	-0.61376	-0.34554	-0.16594	-0.30272	-0.70477	-0.41229	-0.53431	-0.48346	0.75178	-0.6124	-0.57667
3	8.03E+09	0.40888	0.26101	-0.10645	-0.29085	1.0052	0.02723	-0.77745	0.40013	0.988	-0.26836	-0.1263	0.75546	0.13814	0.65026	0.76352	0.15708	-0.17817	-0.30459	-0.25059	-0.26374	0.77962	0.88451	-0.44396	-0.39728
4	8.03E+09	0.3026	0.61634	-0.5717	-0.4812	-0.06817	1.21093	-0.88478	-0.1531	-0.55471	0.22561	-0.43964	-0.02056	-0.45177	-0.81153	-0.79924	0.13223	0.32006	0.52742	0.12111	0.34653	1.00252	0.88451	-0.09076	-0.03427
5	8.03E+09	0.19632	0.07562	-0.33907	-0.71912	-0.73746	0.63261	-0.22128	-0.40554	-0.16271	0.62696	-0.83614	-1.18458	-0.67865	-0.82013	-0.58079	-0.73743	0.75035	0.39168	0.95372	0.65374	-1.44935	-1.01785	0.05369	-0.04206
6	8.03E+09	-0.3199	0.26101	-0.36815	-0.24327	-0.42597	-0.70621	-0.86527	-0.20144	-0.6938	-0.51534	-0.66013	-0.46735	-0.37614	-0.67395	-0.85806	0.10738	0.9655	0.76724	1.38896	1.33907	-0.00052	-0.66392	0.19125	0.16693
7	8.03E+09	-0.07698	0.09107	-0.19368	-0.38603	0.25173	0.30386	-0.60182	0.30882	0.55807	-0.57708	-0.24235	-0.52614	0.45578	-0.38159	-0.44636	-0.0914	-0.54051	0.28337	-0.22047	-0.25483	1.00252	0.84026	0.20325	0.02208
8	8.03E+09	0.3026	0.15287	-0.93517	0.08983	-0.29127	0.24635	-0.64085	-1.16288	-0.59264	-0.6697	-0.54408	0.08526	-0.40639	-0.16662	-0.14389	-0.5635	0.29742	0.34385	0.22956	0.91453	0.37098	1.6366	0.12488	0.35463
9	8.03E+09	-0.12252	0.50819	-0.46992	-0.90947	-0.38387	0.15843	-0.68964	-0.13161	-0.89612	0.31823	-0.84581	-1.07876	-0.6484	-0.73414	-0.90007	-0.63804	0.89756	0.64838	1.21252	0.76574	-0.52061	-1.15057	-1.19542	-0.78455
10	8.03E+09	0.40888	0.15287	-0.41177	-0.00534	0.16334	0.99376	0.09096	-0.22292	0.17871	-0.02137	-0.4377	0.7437	-0.46689	0.70185	0.57028	0.30616	-0.01964	0.33682	-0.32809	0.29178	1.41116	2.03477	0.42822	0.25049
11	8.03E+09	-1.18533	-0.52688	-0.58624	1.08913	0.94627	-2.14156	-0.41643	-0.79227	-0.6938	-0.08312	0.85238	1.24929	1.42384	0.87383	0.93156	-0.06655	0.78432	-0.00569	-0.69201	0.07627	-0.14912	0.08817	-0.43265	-0.20495
12	8.03E+09	1.00101	0.4773	-0.36815	1.37464	0.84525	-0.05865	-0.13346	-0.68484	0.14078	0.04037	-0.07408	2.14288	1.66585	0.82223	0.6627	1.94609	-1.09536	-0.27575	-1.42302	-0.70188	1.63406	0.92875	0.14377	0.14518
13	8.03E+09	-0.62356	-0.9749	0.47511	1.37464	1.0052	0.44192	0.24707	-0.13161	0.92477	1.831	1.34946	1.90772	0.74318	2.65377	2.67917	0.35586	-0.49522	-0.36226	-1.28922	-1.00192	1.26256	1.19419	0.51436	0.03181
14	8.03E+09	-0.86649	-2.67429	0.82405	2.27877	0.70213	0.20599	1.85704	1.02856	5.56553	3.68337	-0.56536	3.63612	3.0423	5.93849	5.71228	6.89072	-3.23548	-1.10635	-1.90364	-1.61756	0.14808	1.90204	-1.24904	-0.94427
15	8.03E+09	-0.13771	-0.23335	1.46376	-0.67154	1.80076	-1.02509	-0.76769	1.18432	0.64658	0.62696	1.31078	-0.65548	1.71123	0.86523	0.72151	0.20677	-0.9708	-0.97554	-0.3376	-0.9288	1.33686	0.39786	0.11651	-0.38371
16	8.03E+09	-0.51728	-0.74317	1.4056	-0.1481	2.02807	0.78778	-0.78721	1.32935	1.56967	-0.39185	1.53514	-0.44384	1.39359	1.32956	1.5113	1.67277	-0.78963	-1.05501	-0.74252	-1.15097	-0.03767	0.57482	0.21465	-0.37444
17	8.03E+09	-0.53246	-0.92856	0.66412	0.99396	1.80918	-0.40502	-0.5823	0.36254	0.88684	0.81219	1.20827	1.68432	2.58853	1.7423	1.46929	1.05158	-0.92551	-0.98679	-1.26086	-1.14478	1.78266	0.97299	0.67724	0.0595
18	8.03E+09	-0.57801	-0.52688	1.63823	-0.33844	1.85549	-0.08937	-0.62133	0.79223	0.10284	1.39878	1.13283	-0.25571	1.33308	0.48688	0.55347	0.33101	-0.78963	-1.10846	-0.72405	-1.09116	0.44527	-0.30999	0.07841	-0.41959
19	8.03E+09	-0.71466	-0.52688	1.20206	0.42293	2.04491	-0.08634	-0.4457	0.94799	1.48116	1.61489	1.12123	0.42624	2.49777	1.08879	1.73815	-0.53865	-1.48036	-0.96288	-1.22576	-1.20531	0.59387	0.30938	-0.86446	-0.77733
20	8.03E+09	-0.44137	-0.52688	0.53327	0.13742	1.46823	-1.02959	-0.35788	0.8728	1.41793	0.65783	-0.04507	0.438	1.2272	0.54707	0.82233	0.95219	-0.33669	-0.35241	-0.57734	-0.81941	2.2656	0.4421	0.02273	-0.26518
21	8.03E+09	-1.04868	-0.78952	-0.13553	0.56569	0.2349	0.32813	-0.3774	-0.3196	-0.13742	0.44172	-0.22688	-0.46735	-0.37614	-0.26121	0.09136	-0.68773	1.1127	0.8446	0.49446	0.30652	-1.11501	-0.7524	-0.06156	-0.0675
22	8.03E+09	-0.2288	0.21466	0.86766	-0.33844	1.86811	-1.10316	-0.81648	0.64721	1.38	-0.57708	1.56222	-0.37329	1.55997	-0.01185	0.2258	0.50494	-0.38199	-0.92912	-0.41796	-0.76277	0.03663	0.08817	-0.29793	-0.47387
23	8.03E+09	-0.82094	-0.9749	0.72227	-0.52878	1.81339	-1.07847	-0.78721	0.78149	0.12813	1.30616	0.83884	-0.79657	1.15157	0.01395	0.20899	-0.86167	0.4333	-1.05009	-0.43717	-0.92133	0.37098	-0.30999	-0.63273	-0.65612
24	8.03E+09	0.24186	-0.29515	1.17298	0.08983	1.6829	-0.41773	-0.78721	0.70629	0.05226	0.44172	2.18502	1.34335	1.92299	0.18593	0.19219	-0.36472	-1.06139	-0.89606	-0.79545	-0.99583	0.70532	-0.00031	0.03968	-0.36274
25	8.03E+09	-0.44137	-0.3106	1.1439	-0.10051	1.39667	-0.77563	0.1495	0.67943	1.2409	0.81219	1.23148	0.2146	1.84736	1.14899	1.0828	0.18192	-0.55184	-0.92209	-0.85445	-1.12032	0.22238	0.92875	-0.16991	-0.481
26	8.03E+09	-0.8513	-0.32605	-0.60078	1.1843	-0.07238	-0.94676	0.15926	-0.85135	-0.23858	-0.17574	-0.6582	-0.27923	-0.13412	0.26331	0.28461	-0.83682	1.24858	-0.80463	-0.29159	-0.21932	-0.29772	-0.61968	-1.10505	-0.71425
27	8.03E+09	-0.66911	-0.71227	0.73681	0.75603	1.363	-1.96272	-0.54327	0.18529	0.36839	0.13299	0.28181	0.14405	1.1667	1.47574	1.02398	1.17582	-0.98213	-1.14574	-1.12941	-1.10026	1.29971	1.90204	-1.3722	-1.00811
28	8.03E+09	-1.21569	-0.85131	-0.70255	1.27947	-0.26601	-2.20008	-0.15298	-1.29716	-0.9467	-0.76232	0.03617	-0.34977	-0.04337	0.44389	0.20899	-0.5635	1.12403	-0.08657	0.40421	0.35339	-0.00052	-0.92937	0.05666	0.04163
29	8.03E+09	-0.00106	1.00256	-1.34226	0.75603	-0.85111	-1.98121	-0.77745	-1.50663	-1.31341	-1.44152	-0.4377	1.13171	-0.5879	0.15153	0.36863	0.15708	-0.22346	1.42131	0.91757	2.41961	0.14808	0.22089	0.89654	1.67274
30	8.03E+09	-0.82094	-0.46509	-1.38588	0.8512	-0.79639	-1.5156	-0.17249	-1.89336	-1.3387	-1.96636	-0.84968	2.94241	-0.55765	0.30631	-0.69842	-0.5635	0.84094	-0.18784	-0.01038	1.24942	-0.96641	-0.79664	0.41256	1.29541
31	8.03E+09	-0.56283	-0.49599	-0.5717	1.04154	0.48325	0.27669	-0.47497	-1.12528	0.10284	-0.3301	0.00909	1.75487	-0.13412	0.65026	-0.01786	-0.0417	0.08227	-0.54582	-0.5117	-0.35942	0.85392	0.35362	0.3112	0.3418
32	8.03E+09	0.01412	-0.55778	0.22795	1.32706	0.70634	-0.32352	0.92033	-0.08327	1.55703	-0.73145	-0.17852	2.15464	1.33308	2.4044	2.32629	4.40598	-1.52565	-0.42204	-1.57376	-1.15655	2.45135	1.45964	-1.09355	-0.80918
33	8.03E+09	-1.62563	-2.36531	-1.13872	1.1843	-0.47227	1.57536	-0.61158	-1.20047	-1.43986	-2.05898	-0.81873	-1.26688	-1.1173	-0.77713	-1.10171	0.60433	-1.91065	1.09146	0.94993	-1.29557	-1.7837	-1.76994	-1.47562	-1.15668
34	8.03E+09	-0.36545	1.1725	-1.4295	1.1843	-1.00264	-3.04704	-0.27983	-1.22733	-1.19961	-1.59589	-0.91157	0.97886	-0.49714	-0.3386	-1.10171	-0.0417	0.56918	0.54359	0.43547	2.45921	1.00252	-1.15057	-0.40316	0.28226
35	8.03E+09	-0.30472	-0.14066	-0.29546	0.70844	0.21385	-0.27386	-0.5823	-0.78689	-0.32709	0.16386	0.13094	0.72019	0.51629	0.73625	0.38543	-0.53865	0.35403	0.12161	-0.35951	-0.08583	1.00252	1.06147	-0.86777	-0.60858
36	8.03E+09	-0.86649	-0.74317	0.51873	-0.19568	-0.2618	2.28837	1.50578	0.19066	1.30413	0.31823	-0.21334	0.33218	-0.13412	0.75344	0.61229	0.33101	1.05609	0.21867	0.01384	-0.4527	-0.48346	0.75178	0.70883	0.03474
37	8.03E+09	-0.13771	0.21466	-0.61531	0.42293	-0.68273	-0.22671	1.66189	-0.31423	0.10284	0.0095	-0.84001	1.22577	-0.54252	0.50408	0.64589	0.75341	0.19551	0.41348	-0.12571	0.26251	0.55672	0.57482	0.72507	0.48404
38	8.03E+09	-0.13771	0.18377	-1.19687	0.75603	-0.35862	-0.72513	0.10071	-1.49052	-0.55471	-1.71938	-0.68914	1.54323	-0.08875	0.63306	0.59548	0.55464	0.36536	0.1624	-0.57734	0.37309	1.85696	1.10571	0.26844	0.72682
39	8.03E+09	-0.35027	-0.55778	-1.47311	-2.24495	-0.97318	-3.78089	-0.18225	-2.11894	-1.06051	-1.56502	-0.48606	3.09526	-0.52739	0.79644	1.15841	0.20677	0.52389	0.1202	-0.65262	0.32212	0.51957	0.84026	1.79356	2.70529
40	8.03E+09	-0.98795	-0.54233	-1.24049	1.27947	-0.81743	0.06581	-0.46522	-1.64091	-1.04786	-1.37978	-0.82647	0.72019	-0.79966	-0.23541	-0.14389	-1.18468	1.56564	0.19124	0.20206	0.68546	-1.3379	-1.50449	2.63061	2.55303
41	8.03E+09	-0.83612	-0.58868	-1.51673	1.99326	-0.55225	-1.17016	-0.49449	-2.24785	-1.30077	-2.05898	-0.54988	2.63671	-0.90554	-0.00325	-0.81605	-0.21563	1.50902	-0.24973	-0.85699	-0.05262	0.55672	-0.35424	3.30265	4.17777
42	8.03E+09	-0.65393	-0.32605	-1.29865	0.89879	-0.9816	-1.6745	-0.66036	-1.94707	-1.43986	-1.4724	-0.76457	0.23812	-1.10218	-0.48478	-1.10171	-0.66289	1.67887	-0.49448	-0.27211	0.63127	-0.89211	-1.41601	3.56724	3.87406
43	8.03E+09	-0.91203	-0.66593	-1.31319	1.56499	-0.83427	-2.15655	0.03241	-1.89873	-1.25019	-1.59589	-0.80326	1.09643	-0.67865	0.05694	-0.04307	-0.66289	1.4977	-0.74696	-0.71255	-0.03144	-1.37505	-0.48696	4.17723	4.64853
44	8.03E+09	-0.5021	-0.38784	-0.84794	0.42293	-0.96476	-0.04044	-0.81648	-1.22196	-0.99728	-0.42272	-0.82647	-0.66723	-1.1173	-0.62236	-0.78244	-0.48896	1.73549	0.81999	0.23089	1.20301	-0.37201	-1.46025	0.53505	0.71079
45	8.03E+09	-0.83612	-0.20246	-1.21141	1.23189	-0.6238	-1.46538	-0.75794	-1.9417	-1.35135	-1.4724	-0.70848	0.97886	-0.81479	0.05694	-0.37074	-0.16594	1.39579	0.3952	-0.49558	0.31394	0.14808	0.61906	1.17973	1.55233
46	8.03E+09	0.04449	-0.14066	-1.32772	1.61257	-1.03211	0.19512	-0.66036	-2.00615	-0.99728	-1.71938	-0.80906	-0.12638	-0.84504	-0.49338	-0.606	-0.16594	1.33917	0.10684	-0.23502	0.60068	-0.18627	-0.44272	3.02137	3.55704
47	8.03E+09	-0.35027	-0.17156	-0.54262	-0.19568	-0.87215	-0.64483	-0.66036	-0.70096	-0.61793	-0.05225	-0.87289	-0.60845	-0.81479	-0.33	-0.48837	0.30616	1.44108	0.4824	0.26317	0.53626	-0.81781	-1.19481	0.13799	0.12287
48	8.03E+09	-0.35027	0.4773	-0.42631	-0.76671	-0.93529	0.38909	-0.75794	-0.45388	-0.88348	0.04037	-0.86902	-0.98469	-0.79966	-1.20707	-0.81605	-1.25922	1.41843	1.49867	1.6951	1.4523	-1.2636	-1.10633	0.18885	0.11859
49	8.03E+09	-0.39582	0.27646	-0.46992	-0.8143	-0.99422	0.39357	-0.75794	-0.05104	-0.41561	-0.36097	-0.85161	-0.63196	-0.84504	-0.85452	-0.79084	0.03284	1.58829	0.90509	1.56701	0.99737	-0.81781	-0.84088	-0.14603	-0.08262

50	8.03E+09	0.28741	0.02928	-0.68801	0.23259	-0.91846	-0.92458	-0.72866	-0.57742	-0.73174	-0.48447	-0.84774	0.04999	-0.7089	-0.74274	-1.0177	-0.81197	0.89756	0.33682	0.24326	0.26021	0.33383	1.01723	-0.76658	-0.40533
51	8.03E+09	-1.10941	-1.80915	-0.71709	0.66086	-0.83848	-0.0451	-0.76769	-0.69021	-0.90877	-0.88581	-0.70268	0.06175	-1.1173	0.15153	-0.77404	0.10738	-1.32183	0.36566	-0.52144	-0.67957	-1.74655	-1.50449	-0.01391	-0.30106
52	8.03E+09	-0.54765	-1.02125	-0.46992	0.28017	-0.96055	-0.10112	-0.5823	-0.73318	-1.07315	-0.60796	-0.19787	-0.30274	-0.96604	0.3751	-0.50518	0.13223	-0.90286	0.42825	-0.38619	-0.35384	-0.55776	-1.10633	-0.03547	-0.20299
53	8.03E+09	-0.57801	-0.2797	-0.64439	-0.10051	-0.43859	0.66655	0.87155	-0.65799	-0.09948	-0.45359	-0.82453	0.93183	-0.24	-0.19242	-0.14389	0.82796	0.67109	0.2693	-0.13178	0.23468	-0.22342	0.04393	-0.08835	0.13105
54	8.03E+09	0.22668	-0.20246	-1.22595	1.46982	-0.59434	-1.32313	0.69591	-1.76445	-0.93406	-0.91669	-0.76071	3.16581	0.18352	1.44994	1.0912	0.08254	-0.66507	0.20952	-1.11919	-0.18044	3.64014	2.21173	0.42985	0.64223
55	8.03E+09	0.10522	-0.15611	-1.05148	0.42293	-0.89741	-1.72376	-0.54327	-1.35087	-0.99728	-1.19454	-0.67367	0.2969	-0.60302	-0.3472	-0.56399	0.00799	1.03344	-0.18503	0.00085	0.33092	-0.85496	0.08817	2.05921	2.2138
56	8.03E+09	1.9879	1.68232	-1.28411	0.89879	-0.96476	0.56366	-0.56279	-1.45829	-1.04786	-1.68851	-0.8284	0.73194	-0.78453	-0.33	-0.11028	-0.5138	0.34271	-0.02819	-0.2617	0.42287	-0.07482	-0.13303	1.81442	2.20614
57	8.03E+09	0.71253	1.48148	-0.07737	-1.33774	-1.0742	1.19044	-0.89454	0.51293	-1.17432	-0.36097	-0.78392	-0.92591	-0.98117	-1.25866	-1.10171	-0.9859	-0.13287	3.72532	2.96002	2.91818	-1.7094	-1.10633	-0.63343	-0.51529
58	8.03E+09	0.0293	0.46185	-0.06283	-0.95705	-0.86373	0.57784	-0.78721	0.36254	-0.51677	0.90481	-0.91157	-1.00821	-1.07192	-1.12968	-0.78244	-1.11014	0.81829	1.82711	2.27658	1.16761	-1.2636	-0.57544	-0.09924	-0.22024
59	8.03E+09	1.82088	1.45058	-0.60078	-0.95705	-1.14576	3.21581	-0.75794	-0.51834	-0.98464	-0.82407	-0.88836	-0.47911	-0.84504	-0.95771	-0.96728	-0.93621	0.13889	1.04012	0.897	1.51309	-0.66921	-0.92937	-0.48824	-0.14521
60	8.03E+09	0.07485	0.56999	-0.01922	-1.24257	-0.9395	0.23611	-0.89454	0.86742	-0.76967	0.53434	-0.83614	-1.17282	-0.92067	-1.06089	-0.81605	-0.93621	0.17286	2.4854	2.61632	1.86609	-1.7094	-1.59298	-0.7232	-0.57396
61	8.03E+09	-0.77539	-1.22209	2.0744	0.32776	2.27221	-0.67666	-0.46522	1.51197	0.93742	1.15179	2.69563	-0.30274	1.55997	1.18338	1.18362	0.97704	-0.95948	-1.15207	-0.74624	-1.17932	0.48242	0.48634	-1.17696	-0.96038
62	8.03E+09	-0.74502	-0.3106	0.48965	0.04225	1.00941	-0.1044	0.36416	0.4807	0.58336	-0.20661	0.63189	1.08468	0.59192	0.62446	0.93156	0.82796	0.11624	-0.62037	-0.79111	-0.64549	0.92822	1.28267	0.32062	-0.05457
63	8.03E+09	-0.15289	-0.3106	0.53327	-0.19568	0.56743	0.18534	1.75947	0.32494	1.10181	0.13299	0.52744	0.50855	0.95494	0.63306	0.83914	1.42429	-0.51787	-0.88481	-0.75809	-0.53313	0.70532	0.70754	-0.49057	-0.51184
64	8.03E+09	0.51516	0.18377	-0.2373	-0.62395	-0.50594	-1.17604	2.80351	-0.22829	0.26723	-0.91669	-0.73556	-0.0911	-0.16437	-0.42459	-0.54719	-0.48896	0.87491	-0.17166	0.20679	0.04163	1.00252	0.53058	-0.8101	-0.57232
65	8.03E+09	0.04449	-0.04797	-0.8334	0.47052	-0.87215	1.3301	-0.20177	-1.05008	-0.80761	-0.23748	-0.86902	0.17933	-0.98117	-0.40739	-0.90847	-0.63804	1.23726	0.34315	-0.00079	0.28221	-0.85496	-0.79664	-0.80812	-0.43152
66	8.03E+09	-0.79057	-0.46509	-1.08056	1.08913	-0.89741	-0.24601	-0.2408	-1.60331	-1.17432	-1.56502	-0.84387	0.73194	-0.5879	-0.01185	-1.10171	-0.31502	1.10138	0.91001	-0.66713	0.10323	-0.89211	0.22089	2.29378	2.11423
67	8.03E+09	-1.01831	-0.23335	-0.81886	0.37535	-0.61959	0.76253	-0.3091	-1.01786	-0.93406	-0.85494	-0.67173	-0.22044	-0.98117	-0.55357	-0.90007	-0.91136	1.61093	0.6315	-0.02798	0.96263	-1.15216	-0.48696	0.81704	0.91189
68	8.03E+09	1.95753	2.17668	-1.22595	0.185	-0.96476	1.58864	-0.81648	-0.81375	-0.89612	-0.97843	-0.52861	-0.04407	-0.6484	-0.64815	-0.81605	-0.58834	-0.32537	2.46501	1.22919	3.20425	-0.26057	-0.04455	-0.04067	0.42472
69	8.03E+09	1.57796	1.60507	-0.44085	-1.38532	-1.02369	0.1018	-0.79697	0.42162	-1.06051	-0.70058	-0.91157	-0.96118	-0.69378	-1.23287	-1.10171	-0.53865	-0.24611	3.14932	2.84914	2.7	-0.85496	-0.17727	-0.82515	-0.52355
70	8.03E+09	0.07485	0.19922	0.14071	-1.00464	-0.8932	-0.56885	-0.76769	0.81908	0.10284	0.87394	-0.78778	-0.80833	-0.73916	-0.86312	-0.65641	-0.5635	0.55786	0.9086	1.41138	1.19385	-1.04071	-0.35424	-0.46805	-0.47783
71	8.03E+09	1.7146	1.8986	0.0244	-1.71842	-0.99001	0.91704	-0.80672	1.02319	-0.07419	0.75045	-0.79165	-1.067	-1.02655	-1.08669	-0.78244	-0.68773	-0.93683	1.6752	1.6122	1.08733	-0.40916	-0.39848	-0.94061	-0.71647
72	8.03E+09	-0.03143	0.27646	-0.13553	-1.05222	-0.74166	0.53612	-0.33837	0.42162	-0.35238	1.21354	-0.87675	-0.8436	-0.96604	-1.0265	-0.82445	-0.33987	-0.07625	-0.24832	0.53679	0.4153	0.25953	0.04393	-0.73419	-0.5534
73	8.03E+09	1.60832	1.60507	-0.25184	-1.95635	-1.10788	0.23357	-0.62133	0.21751	-0.41561	-0.63883	-0.80519	-1.03173	-0.79966	-1.18987	-1.10171	-1.08529	-0.25743	0.14271	0.68663	0.7838	-0.14912	-1.06209	-0.96577	-0.68104
74	8.03E+09	0.15077	-0.89766	-0.68801	1.32706	-0.94371	0.38335	-0.74818	-1.36698	-1.09845	-0.57708	-0.36227	0.34394	-0.76941	0.91682	-0.25312	-0.26533	-0.6764	0.51757	-0.85656	-0.19998	-0.00052	0.17665	-0.03891	0.16087
75	8.03E+09	-0.3199	0.35371	-0.38269	0.04225	-0.99001	-0.23613	-0.73842	-0.36257	-0.97199	-0.91669	-0.53441	-0.54966	-0.96604	-0.26981	-0.90847	-0.29018	-0.0989	3.48972	0.32925	1.42707	-1.07786	-1.41601	-0.37982	-0.24975
76	8.03E+09	0.05967	-0.48054	0.37334	0.89879	0.16334	0.37052	2.78399	0.29271	1.34206	0.99743	0.26246	1.1905	0.93981	0.89962	1.28444	1.20067	-1.40109	-0.77088	-0.98665	-0.96958	0.33383	0.92875	-1.19178	-0.90043
77	8.03E+09	0.09004	-0.07887	0.57688	-0.29085	-0.07659	0.00022	3.67191	0.30345	1.2409	0.6887	-0.0528	-0.26747	0.27427	0.79644	0.72991	1.39945	-1.27654	-0.69211	-0.87174	-0.87308	0.22238	1.28267	-1.07722	-0.86649
78	8.03E+09	0.48479	0.52364	0.2861	-1.76601	-0.8469	0.38139	1.60335	0.87817	0.25458	0.87394	-0.62725	-0.43208	0.00201	-0.51917	-0.74883	-0.96106	0.18418	0.67722	1.21761	0.2771	0.22238	1.01723	0.04517	-0.23409
79	8.03E+09	0.3026	0.12197	0.16979	-1.33774	-0.64906	0.25656	2.5986	0.14232	0.48219	0.53434	-0.4435	-0.70251	-0.40639	-0.49338	0.06616	-0.26533	0.02566	-0.30248	0.3402	-0.16335	0.29668	-0.04455	-0.32493	-0.39223
80	8.03E+09	-1.23087	-0.07887	0.63504	-1.43291	-0.63643	-0.1197	-0.22128	1.10376	-0.60529	1.73838	-0.03153	-1.09051	-0.01312	-1.34465	-0.96728	-0.73743	-1.3558	1.2068	3.07132	0.34479	-1.858	-1.81418	-1.27769	-0.99906
81	8.03E+09	-0.77539	0.04473	-0.22276	-0.38603	-0.88478	1.05272	0.0812	0.2014	-0.64322	1.831	-0.7491	-0.70251	-0.75428	-0.95771	-0.79084	-1.08529	0.53521	0.66386	1.5255	0.79419	-0.52061	-0.5312	-1.37022	-0.93989
82	8.03E+09	0.40888	1.03346	-0.06283	-1.09981	-0.69957	0.63918	-0.54327	0.65258	-0.31445	0.28735	-0.47058	-0.43208	-0.78453	-0.85452	-0.79084	-0.83682	0.32006	1.4396	1.53877	0.92328	-0.59491	-0.30999	-0.29934	-0.31427
83	8.03E+09	0.68217	0.30736	-0.10645	-1.81359	-0.78797	0.85578	0.12998	0.77612	-0.51677	0.53434	-0.52474	-1.26688	-0.98117	-1.17268	-1.0261	-0.26533	-0.11023	0.90368	2.16735	0.86552	-1.00356	-0.97361	-0.39311	-0.47327
84	8.03E+09	-0.30472	0.21466	-1.22595	0.8512	-0.69115	0.74548	-0.34813	-1.35087	-0.70645	-0.79319	-0.5905	0.63788	-0.63328	-0.25261	-0.33714	-0.73743	1.158	-0.38125	-0.56944	0.34597	-0.92926	-0.84088	0.09907	0.55814
85	8.03E+09	0.36333	0.81717	-0.67347	-0.71912	-0.7585	-0.78135	-0.42619	-0.16921	-0.51677	-0.20661	-0.87095	-0.54966	-0.76941	-1.0265	-0.92527	-0.19079	0.90888	0.47678	0.98228	0.76124	0.63102	-0.17727	-0.51233	-0.26841
86	8.03E+09	0.834	1.24974	0.19887	-1.76601	-1.13313	1.18495	-0.77745	1.17895	-0.4409	1.33703	-0.7375	-1.05524	-1.0568	-1.0093	-0.74043	-0.26533	-0.4839	4.04321	4.12439	4.24929	-0.70636	-0.04455	-0.79396	-0.63508
87	8.03E+09	-0.07698	0.80173	-0.45539	-0.71912	-0.61118	0.58615	-0.69939	0.02415	-0.16271	-0.76232	-0.6756	-0.44384	-0.67865	-0.77713	-0.606	-0.96106	0.15021	0.37832	0.75745	0.89888	-1.00356	-0.26575	-0.41409	-0.292
88	8.03E+09	1.07692	1.06436	-0.2373	-0.52878	-1.09525	0.27396	-0.41643	0.25511	-0.82025	0.28735	-0.72976	-1.13755	-0.90554	-1.11249	-1.0177	-0.83682	-0.31405	1.64496	1.44334	1.42917	-0.33487	-0.30999	-0.55993	-0.47238
89	8.03E+09	-0.24399	-0.15611	0.08256	0.37535	0.13808	-0.60907	1.03742	-0.21218	0.36839	-0.73145	-0.24622	-0.14989	-0.40639	0.83943	0.98197	0.77826	0.32006	-0.88622	-0.43063	-0.53523	-0.26057	-0.48696	-0.05596	-0.13103
90	8.03E+09	-0.88167	-0.91311	0.66412	1.08913	-0.36704	0.55031	1.90583	-0.05104	0.40632	1.92362	2.26625	1.29632	0.25915	2.12064	2.04062	1.22552	-0.13287	-0.87637	-0.87566	-0.94968	1.11397	2.30021	1.49389	0.4635
91	8.03E+09	-0.00106	0.32281	-0.36815	0.13742	-0.78376	1.17825	-0.36764	-0.06179	-0.56735	-0.36097	-0.47058	0.02648	-1.01142	-0.79433	-0.58079	-0.66289	0.48992	1.06333	0.70979	0.93812	0.29668	1.23843	-0.94768	-0.62151
92	8.03E+09	-1.09423	-1.45382	1.75454	0.47052	2.38586	-1.23147	-0.84575	0.66332	0.21665	1.09005	0.6667	0.01472	1.45409	1.12319	1.89779	-1.28407	-1.03874	-1.20059	-0.92511	-1.14222	-0.63206	-0.88512	0.86874	-0.13374
93	8.03E+09	-0.66911	-1.0676	2.04532	0.42293	2.01544	1.15002	-0.71891	1.47437	1.15239	1.52227	1.0574	-0.3145	2.05912	0.3407	0.47785	0.18192	-0.41596	-1.12956	-0.79361	-1.12595	-0.70636	-1.06209	1.02395	-0.13871
94	8.03E+09	-0.51728	-1.11395	1.66731	0.56569	2.31009	-0.03708	-0.88478	1.1145	0.97535	1.30616	1.47325	0.67315	2.21038	1.96587	1.72975	-1.06045	-1.15198	-1.19919	-1.24842	-1.31133	-0.00052	0.17665	0.83606	-0.14582
95	8.03E+09	-0.57801	-1.54652	1.65277	1.04154	1.80918	0.95367	0.15926	1.57105	2.58128	1.67663	0.7286	0.36745	2.45239	1.81109	1.9566	0.4304	-0.88022	-1.10916	-1.23347	-1.24502	0.29668	0.22089	0.43822	-0.27439
96	8.03E+09	0.0293	-0.48054	1.05667	-0.90947	1.5019	0.371	-0.85551	1.24341	1.10181	0.90481	0.67637	-0.50263	1.77173	0.08274	-0.07668	-0.33987	-0.91419	-0.9671	-0.47398	-0.86403	0.14808	0.57482	0.0154	-0.39305
97	8.03E+09	-0.36545	-0.78952	1.50738	0.56569	1.8639	-0.38613	-0.74818	1.18432	0.92477	0.78132	2.35329	0.47327	0.97006	-0.17522	0.09977	0.18192	-0.41596	-1.09932	-0.50325	-1.05856	-0.29772	-0.26575	0.64456	-0.19701
98	8.03E+09	-0.45655	-0.46509	0.79497	-0.24327	1.21988	0.22449	-0.5823	0.74389	0.65923	0.90481	0.5081	-0.52614	1.86249	0.71905	0.93996	0.60433	-0.13287	-0.84472	-0.56631	-0.94461	0.51957	0.57482	0.14548	-0.2952
99	8.03E+09	-0.2288	-0.57323	1.05667	-0.10051	1.33774	0.44444	-0.86527	1.24878	1.94903	0.93568	1.52934	-0.3968	0.47091	-0.01185	0.37703	-0.29018	0.21815	-0.58169	-0.37539	-0.86551	-0.70636	-1.15057	-0.17204	-0.47244

100	8.03E+09	1.06174	0.95621	0.9549	-1.81359	0.60532	0.40335	-0.89454	1.38843	0.24194	0.25648	-0.41449	-0.43208	1.01544	-0.75134	-0.29513	-0.41441	-0.72169	-0.5205	0.32737	-0.53047	0.11093	-0.08879	-0.38693	-0.55478
101	8.03E+09	0.66698	0.90987	0.06802	-1.00464	-0.77113	0.75528	0.62761	0.61498	-0.06155	0.56521	-0.42996	-0.97294	-0.5879	0.15153	-0.12709	-0.14109	-0.46125	-0.31936	-0.06832	-0.34576	-0.52061	1.01723	-0.64457	-0.59675
102	8.03E+09	0.7429	-0.29515	-0.35361	1.08913	-0.51015	0.23529	1.60335	0.01341	0.3431	0.56521	0.57773	0.61437	-0.52739	0.51268	0.57028	0.95219	-0.35934	0.24399	-0.87679	-0.51307	1.15112	1.99052	0.26775	0.1781
103	8.03E+09	-0.07698	0.09107	-0.01922	-0.76671	-0.45122	0.43496	-0.63109	0.24974	-0.07419	0.10212	-0.73169	-0.72602	-0.6484	-0.57076	-0.55559	-0.31502	0.25212	-0.16463	0.14064	-0.28497	-0.11197	-0.7524	-0.4686	-0.38826
104	8.03E+09	0.75808	0.26101	-0.31	1.5174	-0.29969	0.4766	-0.07492	-0.10476	-0.74438	0.84307	0.23345	0.49679	-0.55765	0.61586	0.54507	0.40555	-0.95948	-0.14213	-0.77421	-0.3434	0.81677	0.48634	1.1696	0.63718
105	8.03E+09	0.54552	1.34244	0.03894	-1.71842	-0.74166	0.48963	-0.27007	0.64184	-0.01096	0.0095	-0.68914	-1.12579	-0.52739	-0.80293	-0.67321	0.13223	-0.50654	-0.02889	0.95728	0.1217	0.63102	1.59236	-0.81097	-0.629
106	8.03E+09	3.35435	2.53201	-0.60078	0.28017	-0.89741	0.94086	0.27635	-0.32497	-0.03626	-0.76232	-0.72782	1.37862	0.2894	-0.33	-0.38755	0.18192	-2.00123	-0.24481	-0.87425	-0.28257	3.38009	2.96382	-1.01251	-0.65681
107	8.03E+09	0.2115	-0.15611	0.69319	-0.4812	0.36539	-0.10261	-0.3774	1.27026	0.01433	0.3491	-0.60404	-1.18458	0.7583	-0.3558	-0.86646	-1.0356	-1.48036	-0.38406	0.58996	-0.5668	0.66817	1.10571	-1.34276	-1.01985
108	8.03E+09	1.00101	0.89442	0.2861	-1.62325	0.0539	0.67752	-0.66036	1.22192	1.02593	-0.60796	-0.46865	-0.52614	-0.48202	-0.61376	-0.21111	0.3807	-0.4386	-0.42063	0.13688	-0.41627	0.74247	0.92875	-0.37594	-0.4529
109	8.03E+09	-0.44137	-0.91311	-1.19687	1.99326	-1.03211	-0.16918	-0.50425	-1.35624	-0.73174	-0.29923	-0.80906	-0.44384	-1.1173	-0.69975	-0.66481	-0.68773	1.71284	0.545	0.12788	0.51692	-0.14912	-0.57544	0.02089	0.53263
110	8.03E+09	1.86643	2.05309	-0.81886	-0.19568	-0.99001	-0.05961	-0.70915	-0.37869	-0.8329	-0.26836	-0.79552	-0.93766	-1.0568	-1.06949	-1.00089	-0.83682	0.07095	0.47256	0.96894	0.94165	-0.66921	-0.79664	-1.16251	-0.70015
111	8.03E+09	0.77326	0.58544	-0.499	-0.29085	-0.6659	-0.83567	-0.01638	-0.20681	-0.36503	-1.04018	-0.18433	-0.60845	-1.01142	-0.89752	-0.90847	-0.38957	0.16154	0.50702	-0.20427	0.58011	0.33383	-0.08879	-0.30403	-0.16125
112	8.03E+09	0.72772	0.81717	-0.51354	-0.24327	-0.66169	1.56971	0.44222	0.02952	-0.22593	-0.20661	-0.48219	-1.24337	-0.40639	-1.21567	-0.96728	-0.61319	0.84094	-0.7765	0.27373	0.04915	-0.22342	-0.79664	-0.35953	-0.20197
113	8.03E+09	0.72772	0.81717	-0.58624	0.28017	-0.60276	-0.10131	0.44222	-0.17458	-0.61793	-0.48447	-0.31972	0.07351	-0.96604	-0.89752	-0.82445	-0.0417	0.73903	0.02385	0.0611	0.09745	-1.00356	-1.28329	-0.05943	0.07305
114	8.03E+09	2.35228	2.08399	-0.65893	-1.29015	-0.91425	0.61136	-0.66036	-0.45388	-0.21329	-0.70058	-0.74717	-0.64372	-0.9963	-1.0093	-0.89167	0.33101	-0.78963	-0.77439	-0.15576	0.29639	0.74247	-0.48696	-0.67782	-0.40179
115	8.03E+09	0.34814	0.23011	-0.71709	1.61257	-0.78376	-0.13005	1.38869	-0.80838	-0.13742	0.22561	0.27213	0.35569	0.54654	-0.00325	0.07456	0.05769	0.48992	-0.7547	-0.70664	-0.48508	0.77962	1.01723	0.69462	0.73866
116	8.03E+09	0.51516	-0.3106	-0.13553	0.04225	-0.40492	-0.17316	1.17402	0.37328	0.53278	-0.94756	-0.48992	-0.34977	-0.31563	-0.26981	0.46105	-0.46411	0.65977	-0.18995	-0.3876	-0.33235	0.37098	1.54812	-0.47477	-0.36584
117	8.03E+09	0.77326	-0.15611	-0.77524	1.32706	-0.1271	-0.72232	0.09096	-0.63113	-0.15006	0.47259	-0.07021	0.61437	-0.49714	0.08274	-0.04307	1.3746	-0.08758	-0.1365	-1.05859	-0.59468	0.63102	0.08817	-0.18597	-0.02912
118	8.03E+09	-1.45862	-1.0058	-0.70255		0.0118	-0.99401	0.54955	-0.73318	-0.20064	0.62696	0.7286	0.23812	0.68267	0.22032	-0.22791	1.47399	1.25991		-1.06106	-0.7512	-1.6351	-1.46025	-0.24346	-0.00372
119	8.03E+09	0.54552	0.73993	-0.84794	-0.71912	-0.61118	0.9464	0.6081	-0.51834	-0.35238	0.0095	-0.54021	-0.71427	-0.72403	-0.86312	-0.76564	-0.31502	0.72771	-0.58521	-0.06132	0.19421	-0.37201	-1.01785	-0.10866	0.10834
120	8.03E+09	-0.95758	-0.75862	-0.12099	1.56499	0.4622	0.24428	2.28637	-0.18532	0.57071	0.44172	1.22761	0.41448	0.19865	1.18338	1.43568	0.70372	0.93153	-0.17307	-1.00449	-0.77454	-0.48346	-0.61968	0.58145	0.3304
121	8.03E+09	0.69735	0.16832	-0.74617	1.46982	-0.46385	0.09455	0.55931	-0.51834	-0.33974	0.28735	0.26246	-0.49087	-0.7089	-0.19242	0.21739	-1.53255	0.35403	-0.88551	0.01396	0.11567	0.37098	0.17665	-0.65634	-0.31597
122	8.03E+09	6.148	4.75666	-1.34226	-0.90947	-0.70378	3.3515	0.52028	-1.38847	-0.27651	-1.93549	0.03617	0.16757	-0.40639	-0.39879	-0.10188	-0.58834	-3.92621	-1.3736	-1.20452	-0.55426	3.52869	2.96382	1.31266	2.02959
123	8.03E+09	-0.72984	-1.40748	2.78681	-0.8143	1.48086	0.07038	1.14475	1.92555	2.164	1.27529	1.31271	-0.87887	1.13645	0.54707	0.78873	1.34975	-0.98213	-0.90661	-0.64514	-1.22475	-0.63206	0.08817	0.81437	-0.36409
124	8.03E+09	-0.57801	-1.48472	2.97582	-0.57637	1.544	0.10132	1.18378	1.87183	1.40529	0.53434	1.56802	-0.96118	0.90956	0.40949	0.48626	0.75341	-0.72169	-1.19848	-0.48349	-1.1522	-0.78066	-0.08879	0.77555	-0.39479
125	8.03E+09	-0.48691	-1.08305	1.97263	0.37535	1.21988	-0.36814	2.17903	1.3938	1.68348	1.46052	2.87164	0.1323	1.01544	1.30376	1.68774	0.87765	-1.41242	-0.85457	-0.77296	-1.17671	-0.26057	-0.70816	1.12943	-0.10034
126	8.03E+09	-0.56283	-1.0985	1.78362	0.04225	1.19883	0.74687	1.64238	1.1145	1.73406	0.87394	2.86197	-0.19692	0.54654	0.92542	1.04079	0.33101	-0.50654	-1.06626	-0.6498	-1.02761	-0.00052	0.4421	0.048	-0.50065
127	8.03E+09	-0.8513	-1.56196	2.78681	-1.05222	1.58188	0.14805	1.05694	2.0652	1.11445	0.84307	1.33979	-0.60845	0.84906	-0.02904	-0.16069	1.25036	0.19551	-0.86723	-0.28099	-1.06552	-0.55776	-0.35424	0.44957	-0.44941
128	8.03E+09	-0.89685	-1.16029	2.96128	-1.24257	1.20725	0.43287	1.33014	1.7107	1.02593	0.31823	2.62214	-1.067	1.49947	0.61586	0.86434	-0.26533	-0.50654	-0.88129	-0.08017	-1.10159	-0.66921	-0.88512	0.66891	-0.43372
129	8.03E+09	-1.07905	-0.40329	0.5478	0.13742	0.69371	0.10711	1.64238	0.39476	0.49484	-0.29923	1.23921	-0.86712	0.57679	-1.0437	-0.82445	-0.58834	0.70506	-0.78354	-0.06077	-0.50704	0.40813	-0.17727	-1.24779	-0.92243
130	8.03E+09	-0.9424	-0.52688	1.74	-1.62325	0.34434	0.57096	1.91559	1.80738	0.35574	1.12092	2.11925	-1.16106	-0.43664	-1.07809	-0.92527	-0.78712	1.18064	-0.35241	1.05869	-0.49266	-1.37505	-0.84088	-0.77665	-0.80751
131	8.03E+09	-1.00313	-0.63503	1.58007	-0.52878	0.45378	0.59278	1.73995	1.80738	1.79729	0.0095	1.67633	-0.85536	0.51629	-0.18382	0.20059	0.87765	0.42197	-0.71039	0.05179	-0.83067	-0.52061	-0.26575	0.83332	-0.16636
132	8.03E+09	-0.65393	-0.54233	1.66731	-1.09981	0.60532	0.4161	1.97413	1.6355	1.05122	0.28735	1.74016	-0.93766	0.44066	-1.0093	-0.65641	-0.63804	0.52389	-0.83136	0.57095	-0.68336	-1.30075	-1.50449	0.45514	-0.31472
133	8.03E+09	-0.03143	-0.17156	0.15525	-0.00534	0.79053	-0.73205	-0.29934	0.74389	-0.4409	0.37997	-0.09342	-0.69075	0.39528	-0.63955	-0.37915	-0.11624	0.33139	-0.35523	0.11544	-0.39958	-0.37201	-0.88512	-0.09524	-0.23105
134	8.03E+09	1.50204	1.48148	0.21341	-0.8143	-0.03871	0.7707	-0.89454	0.94262	0.17871	-0.11399	-0.6582	-0.74954	-0.55765	-0.69115	-0.53878	-0.26533	-1.70683	-0.38758	-0.07481	-0.42159	0.33383	-0.61968	-0.45536	-0.48717
135	8.03E+09	2.53448	2.73284	-0.19368	-1.00464	-0.34599	0.18422	-0.54327	0.79223	-0.59264	-1.07105	-0.71042	-0.52614	-0.5879	-0.51057	-0.39595	-0.5635	-1.3558	0.70535	0.50463	0.76753	-0.11197	-0.70816	-1.17433	-0.81232
136	8.03E+09	1.30467	1.1725	-0.41177	-0.52878	-0.68694	0.25983	-0.85551	0.13695	-0.8329	-0.57708	-0.46865	-1.12579	-0.82991	-1.07809	-0.95048	-0.46411	-0.64243	0.17858	0.12467	0.23268	0.29668	0.57482	-1.23446	-0.82049
137	8.03E+09	-0.38063	0.12197	-0.33907	-0.24327	-0.42176	0.16093	-0.89454	0.13695	-0.3018	-0.02137	-0.44737	-0.71427	-0.63328	-0.85452	-0.56399	-0.58834	0.9655	-0.61193	-0.05185	-0.19185	0.29668	-1.10633	-0.30481	-0.21804
138	8.03E+09	0.36333	0.4155	-1.0951	1.27947	-0.60697	-0.70299	-0.05541	-1.2327	-0.68116	-1.0093	-0.21914	0.17933	-0.52739	-0.3386	-0.74883	0.4304	0.9202	-0.2441	-0.63677	-0.03251	0.44527	1.50388	0.18018	0.55757
139	8.03E+09	-0.13771	0.01383	-0.35361	-0.90947	0.01601	-0.41954	-0.76769	-0.14773	-0.32709	-1.62676	-0.79745	-0.99645	-0.45177	-0.3386	-0.41275	-0.11624	-0.28008	-0.39461	-0.07106	-0.3588	0.55672	0.17665	-0.82068	-0.68095
140	8.03E+09	-1.18533	-0.9749	-0.54262	1.94567	-0.17341	-0.71819	-0.2408	-0.94803	-0.56735	-0.39185	-0.22301	1.31983	-0.43664	-0.08923	-0.00946	0.28131	1.52035	-0.03171	-0.79917	-0.61244	-0.48346	-0.7524	1.6603	1.2544
141	8.03E+09	-0.66911	-0.66593	1.17298	0.80362	1.88074	-1.39508	-0.65061	0.60424	0.96271	0.41085	3.41707	0.08526	1.80198	2.35281	2.09943	1.99579	-1.3558	-0.90028	-1.265	-1.15399	0.33383	-0.44272	-0.6232	-0.69328
142	8.03E+09	0.09004	-0.17156	0.24249	0.04225	0.95048	0.11625	-0.64085	0.45922	0.03962	-0.63883	0.03423	0.5203	0.65242	0.11714	-0.02626	0.05769	-1.49168	-0.42204	-0.6595	-0.69896	-0.29772	0.53058	-0.16061	-0.33832
143	8.03E+09	-1.01831	-0.68137	-0.09191	-0.38603	-0.34599	1.40372	2.63763	0.19603	0.89948	2.54107	-0.76457	-1.11403	-1.1173	0.10854	0.40224	-0.73743	1.06741	-1.19989	-0.52355	-0.57386	-1.96945	-1.37177	-1.76303	-1.18437

Appendix B: Statistical Description of Census Variables

	N	Minimum	Maximum	Mean	Std. Deviation
Age 65 and Older, % of pop	143	.5	51.7	11.207	6.5864
Median Age (years)	143	17.6	65.7	34.910	6.4729
Average Household Size	143	1.4	4.4	2.393	.6878
Renter occupied housing units, %Total Occupied HU	142	.9	96.0	48.112	21.0147
Hispanic, % pop	143	1.7	85.6	28.920	23.7568
Female, % pop	143	35.1	63.3	50.021	3.9492
African American, % pop	143	0.0	46.8	9.168	10.2487
Family Households, % households	143	9.3	89.6	51.150	18.6179
Female headed households, no husband present, families, % HH	143	0.0	55.4	11.387	7.9082
Under 5 years old, % population	143	0.0	18.6	6.669	3.2391
Speaks English less than Very Well, % pop	143	0.0	2238.0	471.301	517.0210
Households with no vehicles, % HH	143	0.0	41.7	10.775	8.5050
Less than 12 years education, % over 25 yo	143	0.0	27.5	7.387	6.6112
% below poverty level; Population for whom poverty status is determined	143	1.8	86.5	17.438	11.6296
% below poverty level; Families	143	0.0	81.1	13.113	11.9020
% Civilian labor force - Unemployment Rate	143	.5	34.4	6.668	4.0246
Mobile Home Occupied Units, %HU	143	0.0	8.9	.350	1.0417
% Population 16 years and over - In labor force	143	35.7	85.7	70.373	8.8313
Ambulatory Difficulty	143	0.0	15.1	5.301	2.6918
Visual Difficulty	143	0.0	5.3	2.094	1.2258
Independent Living Difficulty	143	.4	11.2	4.501	2.2604
PopulationDensity	143	29.1	25660.0	7636.189	4314.7726
Housing Density	143	14.9	18595.0	3787.557	3185.4047

Appendix C: Results of Factor Analysis

Variable	Component				
	1	2	3	4	5
Zscore: Age 65 and Older, % of pop	-0.26	-0.295	0.058	0.847	0.089
Zscore: Median Age (years)	-0.452	-0.452	0.052	0.68	-0.038
Zscore: Average Household Size	0.823	-0.069	0.444	-0.155	0.119
Zscore: Renter occupied housing units, %Total Occupied HU	-0.003	0.665	-0.469	-0.158	-0.06
Zscore: Hispanic, % pop	0.904	0.205	0.186	-0.048	-0.194
Zscore: Female, % pop	-0.052	-0.338	0.29	0.243	0.552
Zscore: African American, % pop	0.16	0.258	0.02	-0.059	0.822
Zscore: Family Households, % households	0.607	-0.243	0.68	-0.035	0.145
Zscore: Female headed households, no husband present, families, % HH	0.661	0.362	0.402	0.017	0.358
Zscore: Under 5 years old, % population	0.433	0.123	0.601	-0.224	0.259
Zscore: Speaks English less than Very Well, % pop	0.842	0.092	0.088	-0.102	0.036
Zscore: Households with no vehicles, % HH	-0.014	0.793	-0.38	0.153	-0.102
Zscore: Less than 12 years education, % over 25 yo	0.801	0.401	0.222	0.063	-0.144
Zscore: % below poverty level; Population for whom poverty status is determined	0.429	0.848	0.04	-0.01	0.044
Zscore: % below poverty level; Families	0.514	0.754	0.136	0.014	0.117
Zscore: % Civilian labor force - Unemployment Rate	0.23	0.75	0.203	0.078	0.192
Zscore: % Population 16 years and over - In labor force	-0.36	-0.236	-0.447	-0.54	0.024
Zscore: Median Home Value	-0.778	-0.216	0.267	-0.122	-0.188
Zscore: Median Household Income	-0.557	-0.577	0.401	-0.196	-0.089
Zscore: Per capita income	-0.809	-0.318	0.077	-0.036	-0.207
Zscore: Ambulatory Difficulty	0.168	0.437	-0.084	0.743	-0.085
Zscore: Independent Living Difficulty	0.13	0.486	0.009	0.659	0.133
Zscore: Housing Density	-0.178	0.078	-0.887	-0.041	-0.064
Zscore: PopulationDensity	0.133	0.051	-0.827	-0.139	0.007

Appendix D: Factor Loading Groups and Scores

Factor	Positive or Negative	Variable	Corresponding Data	Load
1	-	Age	Median Age (years)	-0.452
		Families	Family Households, % households	0.607
		HH Size	Average Household Size	0.823
		Race	Hispanic, % pop	0.914
		Language	Speaks English less than Very Well, % pop	0.842
		Education	Less than 12 years education, % over 25 yo	0.81
		Home Value	Median Home Value	-0.778
		Income	Median Household Income	-0.557
			Per capita income	-0.809
2	-	Age	Median Age (years)	-0.452
		Housing Tenure (Renters)	Renter occupied housing units, %Total Occupied HU	0.665
		Vehicle Access	Households with no vehicles, % HH	0.793
		Poverty	% below poverty level; Population for whom poverty status is determined	0.848
			% below poverty level; Families	0.754
		Unemployment	Zscore: % Civilian labor force - Unemployment Rate	0.75
3	+	Housing Tenure (Renters)	Renter occupied housing units, %Total Occupied HU	-0.469
		Families	Family Households, % households	0.68
		Children	Under 5 years old, % population	0.601
		Low Density	Housing Density	-0.887
			PopulationDensity	-0.827
4	-	Age	Age 65 and Older, % of pop	0.847
			Median Age (years)	0.68
		Unemployment	% Population 16 years and over - In labor force	-0.54
		Disability	Ambulatory Difficulty	0.743
			Independent Living Difficulty	0.659
5	-	Female	Female, % pop	0.552
		Race	African American, % pop	0.822

Appendix E: Dam Characteristics

	Intrinsic Characteristics					External Time Variant		Design Characterstics	
Dam ID	Name	Height	Dam Type	ındation T	rage Capa	Age	Seismicity	Spillway Adequacy	Mass Movement Factor
1	Bear Creek	179	Earth	Concrete	2000	30 - 59	V or lower	Spillway capacity is greater than required (Suspected)	Factor of safety against mass movement is greater than required
2	Beers Sisters	21	Earth	Concrete	41	30 - 59	V or lower	Spillway capacity is greater than required	Factor of safety against mass movement is greater than required
3	Cherry Creek	140	Earth	Concrete	13226	30 - 59	V or lower	Spillway capacity is greater than required	Factor of safety against mass movement is greater than required
4	Englewood	55	Earth	Concrete	1850	30 - 59	V or lower	Spillway capacity is greater than required	Factor of safety against mass movement is greater than required
5	Harriman	20	Earth	Concrete	762	30 - 59	V or lower	Spillway capacity is greater than required	Factor of safety against mass movement is greater than required
6	Holly	40	Earth	Concrete	0	30 - 59	V or lower	Spillway capacity is greater than required	Factor of safety against mass movement is greater than required
7	Kelly Road	32	Earth	Concrete	360	30 - 59	V or lower	Spillway capacity is greater than required	Factor of safety against mass movement is greater than required
8	Main	45	Earth	Concrete	583	30 - 59	V or lower	Spillway capacity is greater than required	Factor of safety against mass movement is greater than required
9	Marston Lake- South	33	Earth	Concrete	19795	30 - 59	V or lower	Spillway capacity is greater than required	Factor of safety against mass movement is greater than required
10	Marston Lake- East	17	Earth	Concrete	19795	30 - 59	V or lower	Spillway capacity is greater than required	Factor of safety against mass movement is greater than required
11	Marston Lake- NorthWest	15	Earth	Concrete	19795	30 - 59	V or lower	Spillway capacity is greater than required	Factor of safety against mass movement is greater than required
12	Marston Lake- North	30	Earth	Concrete	19795	30 - 59	V or lower	Spillway capacity is greater than required	Factor of safety against mass movement is greater than required
13	Skeel	35	Earth	Concrete	205	30 - 59	V or lower	Spillway capacity is greater than required	Factor of safety against mass movement is greater than required
14	Smith	28	Earth	Concrete	638	30 - 59	V or lower	Spillway capacity is greater than required	Factor of safety against mass movement is greater than required
15	South Platte	64	Rock	Concrete	6480	30 - 59	V or lower	Spillway capacity is greater than required	Factor of safety against mass movement is greater than required
16	Ward #5	10	Earth	Concrete	69	30 - 59	V or lower	Spillway capacity is greater than required	Factor of safety against mass movement is greater than required
17	Westerly Creek	45	Earth	Concrete	4150	30 - 59	V or lower	Spillway capacity is greater than required	Factor of safety against mass movement is greater than required
18	Windsor	20	Earth	Concrete	600	30 - 59	V or lower	Spillway capacity is greater than required	Factor of safety against mass movement is greater than required

Appendix F: Scores for Dam Index Calculation

SCORES													
		I1	I2	I3	I4	E1	E2	D1	D2				
Dam ID	Name	Height	Dam Type	Foundation Type	Storage Capacity	Age	Seismicity	Spillway Adequacy	Mass Movement Factor	Average "I" Score	Average "E" Score	Average "D" Score	Total Risk Score (I1+I2+I3+I4)/4 * (E1+E2)/2 * (D1+D2)/2
1	Bear Creek	10	10	3	6	5	1	2	1	7.3	3	1.5	32.6
2	Beers Sisters	3	10	3	1	5	1	2	1	4.3	3	1.5	19.1
3	Cherry Creek	10	10	3	6	5	1	2	1	7.3	3	1.5	32.6
4	Englewood	6	10	3	6	5	1	2	1	6.3	3	1.5	28.1
5	Harriman	3	10	3	3	5	1	2	1	4.8	3	1.5	21.4
6	Holly	3	10	3	0	5	1	2	1	4.0	3	1.5	18.0
7	Kelly Road	3	10	3	3	5	1	2	1	4.8	3	1.5	21.4
8	Main	6	10	3	3	5	1	2	1	5.5	3	1.5	24.8
9	Marston Lake- South	3	10	3	6	5	1	2	1	5.5	3	1.5	24.8
10	Marston Lake- East	3	10	3	6	5	1	2	1	5.5	3	1.5	24.8
11	Marston Lake- NorthWest	3	10	3	6	5	1	2	1	5.5	3	1.5	24.8
12	Marston Lake- North	3	10	3	6	5	1	2	1	5.5	3	1.5	24.8
13	Skeel	3	10	3	3	5	1	2	1	4.8	3	1.5	21.4
14	Smith	3	10	3	3	5	1	2	1	4.8	3	1.5	21.4
15	South Platte	6	10	3	6	5	1	2	1	6.3	3	1.5	28.1
16	Ward #5	3	10	3	3	5	1	2	1	4.8	3	1.5	21.4
17	Westerly Creek	6	10	3	6	5	1	2	1	6.3	3	1.5	28.1
18	Windsor	3	10	3	3	5	1	2	1	4.8	3	1.5	21.4

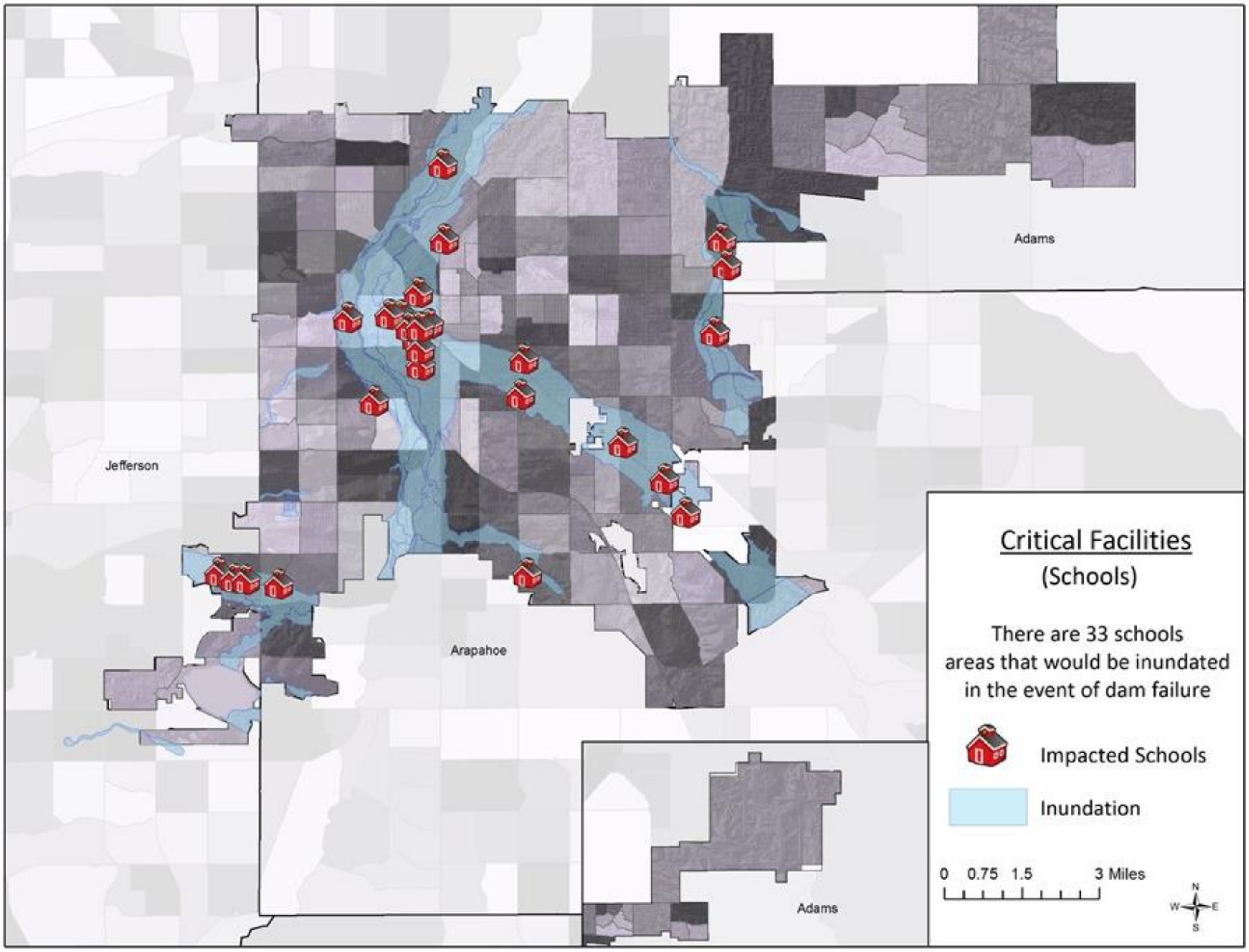
Appendix G: Census Tract Cumulative Social Vulnerability Scores

GEOID	VULNERABILITY SCORE	GEOID	VULNERABILITY SCORE	GEOID	VULNERABILITY SCORE
8031000102	-2.22	8031003001	-2.78	8031004601	0.37
8031000201	-0.26	8031003002	-1.24	8031004602	0.49
8031000202	0.49	8031003003	-1.86	8031004603	0.67
8031000301	-0.06	8031003004	-1.23	8031004700	-0.45
8031000302	-1.8	8031003101	0.51	8031004801	-0.49
8031000303	-2.69	8031003102	3.26	8031005001	0.77
8031000401	0.38	8031003201	0.54	8031005002	3.31
8031000402	0.09	8031003202	2.51	8031005102	-1.03
8031000501	-3.35	8031003203	-5.73	8031005104	2.2
8031000502	2	8031003300	-3.78	8031005200	-0.28
8031000600	-1.31	8031003401	-0.93	8031005300	4.2
8031000701	2.69	8031003402	-5.6	8031005502	-1.04
8031000702	2.71	8031003500	-0.05	8031005503	0.74
8031000800	4.2	8031003601	1.89	8031006701	-1.16
8031000902	0.27	8031003602	2.39	8031006804	-2.04
8031000903	1.31	8031003603	1.33	8031006809	-0.54
8031000904	2.17	8031003701	-0.97	8031006810	0.59
8031000905	0.19	8031003702	0.94	8031006811	-0.25
8031001000	0.53	8031003703	-0.87	8031006812	0.77
8031001101	0.68	8031003800	-1.82	8031006813	3.19
8031001102	-2.08	8031003901	-4.82	8031006814	1.58
8031001301	-0.09	8031003902	-3.37	8031006901	1.15
8031001302	-1.26	8031004002	-2.66	8031007006	
8031001401	0.73	8031004003	-1.2	8031007013	0.56
8031001402	1.13	8031004004	-1.67	8031007037	2.39
8031001403	-0.99	8031004005	0.13	8031007088	0.85
8031001500	0.32	8031004006	-4.15	8031007089	9.42
8031001600	-1.9	8031004101	3.04	8031008304	1.54
8031001701	-1.64	8031004102	3.27	8031008305	1.47
8031001702	-0.83	8031004103	0.25	8031008306	2.65
8031001800	1.23	8031004104	1.46	8031008312	2.56
8031001901	3.23	8031004106	-5.46	8031008386	0.65
8031001902	-3.25	8031004107	-2.94	8031008387	0.97
8031002000	-2.66	8031004201	-2.43	8031008388	0.34
8031002100	-0.27	8031004202	-2.59	8031008389	-0.84
8031002300	2.14	8031004301	0.16	8031008390	1.73
8031002402	1.79	8031004302	-1.77	8031008391	0.47
8031002403	1.58	8031004303	-6.36	8031011902	-1.2
8031002601	1.02	8031004304	-1.78	8031011903	0.07
8031002602	0.21	8031004306	-2.7	8031012001	-1.2
8031002701	2.9	8031004403	1.11	8031012010	-0.91
8031002702	1.02	8031004404	4.65	8031012014	-0.98
8031002703	2.66	8031004405	-1.12	8031015300	1.44
8031002801	-1.98	8031004503	-0.51	8031015400	-0.84
8031002802	0.14	8031004504	0.54	8031015500	0.7
8031002803	2.08	8031004505	1.14	8031015600	0.3
8031002901	-2.06	8031004506	2.12	8031015700	0.35

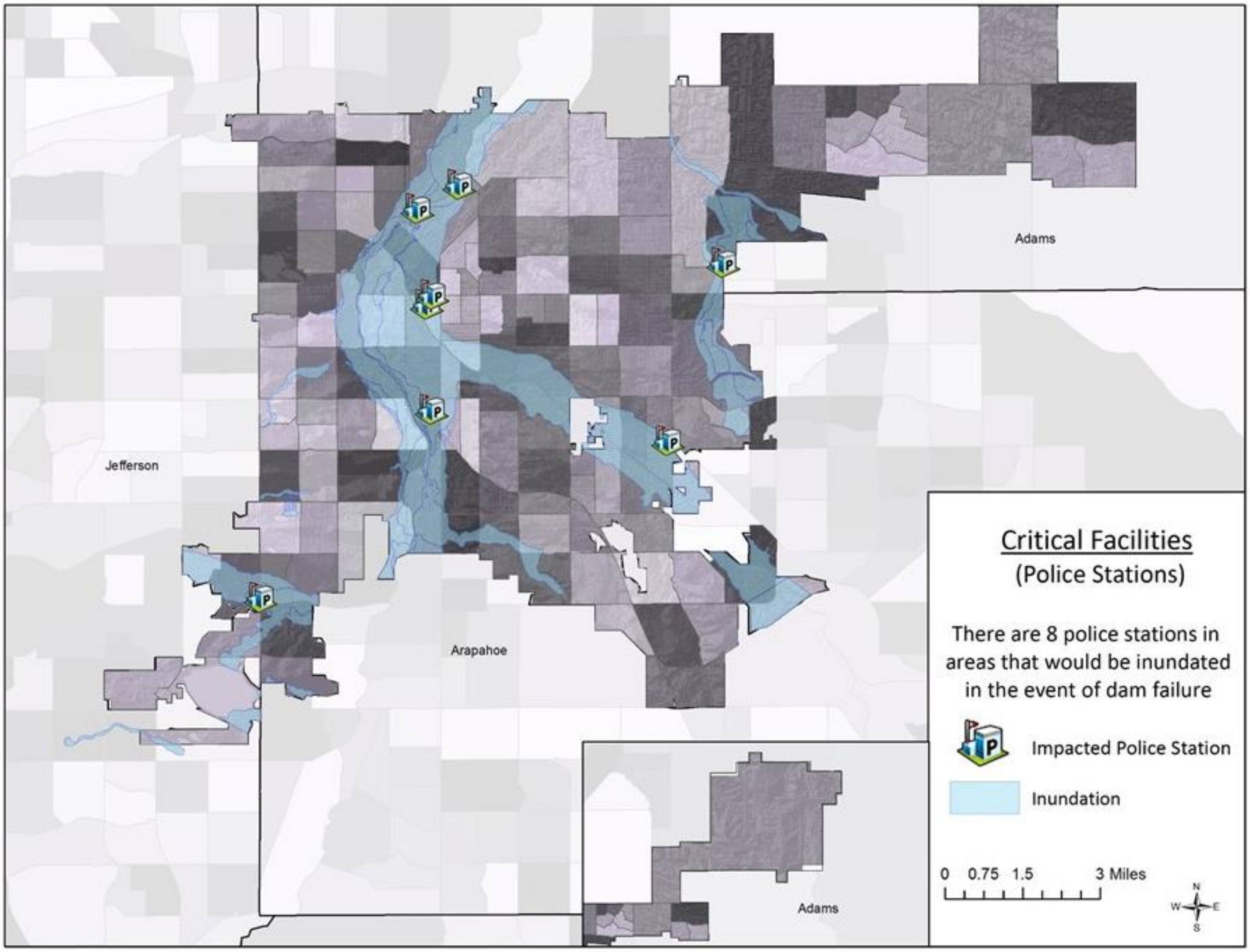
Appendix H: Dam Inundation Impacts

		People Impacted			Critical Facilities					Transportation	
		# People	# Households	# HU	# Schools	# Police Stations	# Fire Stations	# Hospitals	Total Critical Facilities	Highway (miles)	Arterial Streets (miles)
Total	Denver County	600,158	285,797	263,107	202	23	34	28	287	421	75
	Cumulative Social Vulnerability	120,604	54,013	58,918	37	5	5	10	57	52	8
	Factor 1	150,711	45,503	48,581	54	4	6	-	64	43	5
	Factor 2	114,573	50,419	56,430	50	9	7	11	77	81	18
	Factor 3	107,992	40,574	43,418	35	9	10	1	55	125	27
	Factor 4	103,533	49,718	54,029	35	6	5	6	52	75	8
	Factor 5	128,360	49,113	52,887	46	4	11	3	64	80	7
Inside Inundation Area	Denver County	176,496	84,048	77,375	33	8	4	2	47	94	16
	Cumulative Social Vulnerability	19,922	8,922	9,733	-	-	-	1	1	9	2
	Factor 1	19,581	5,912	6,312	-	-	-	-	-	5	1
	Factor 2	41,735	18,366	20,555	-	-	-	2	2	35	11
	Factor 3	12,874	4,837	5,176	-	-	-	1	1	25	7
	Factor 4	27,650	13,278	14,429	-	-	-	1	1	18	2
	Factor 5	6,454	2,469	2,659	-	-	-	-	-	9	0

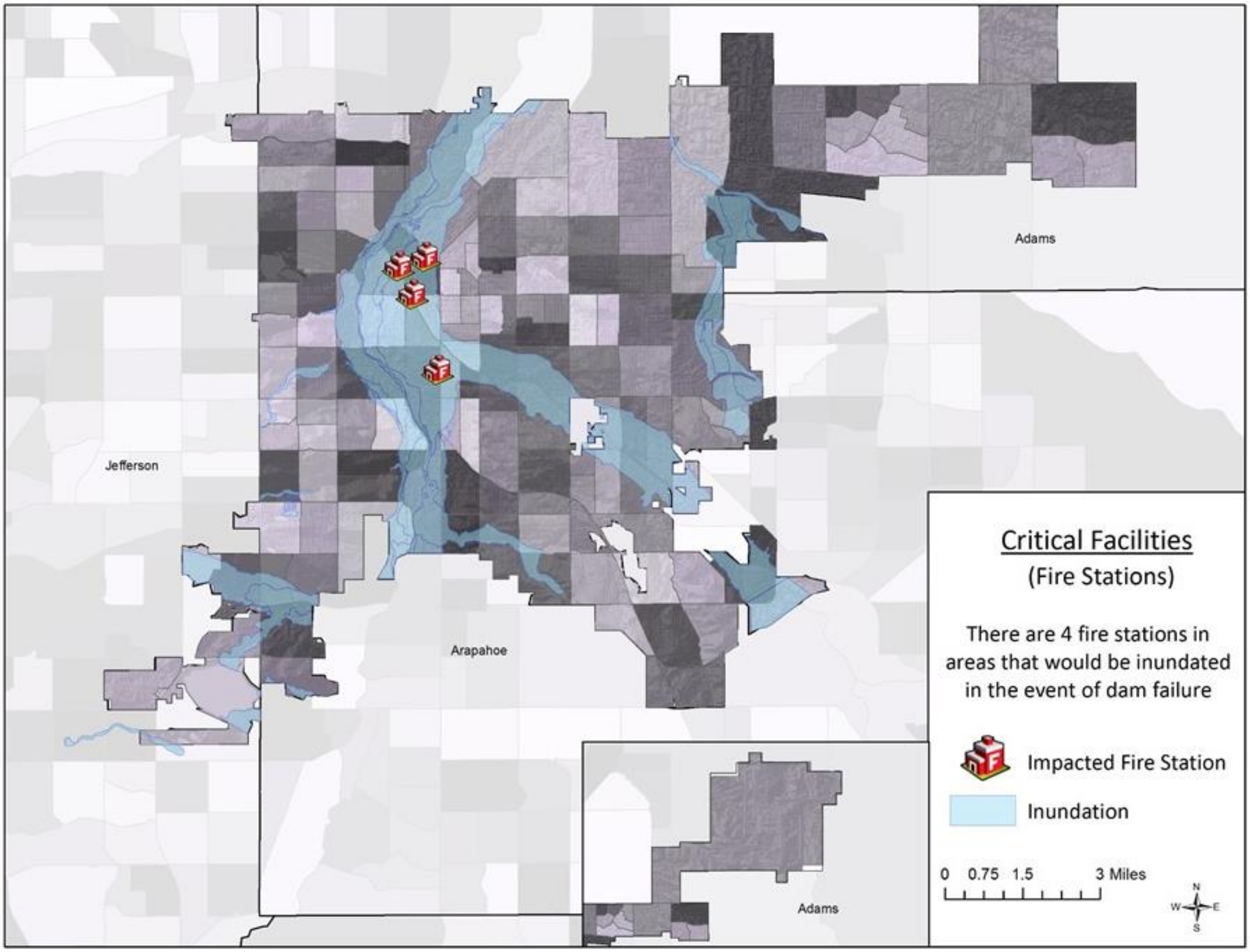
Appendix I: Inundated Schools



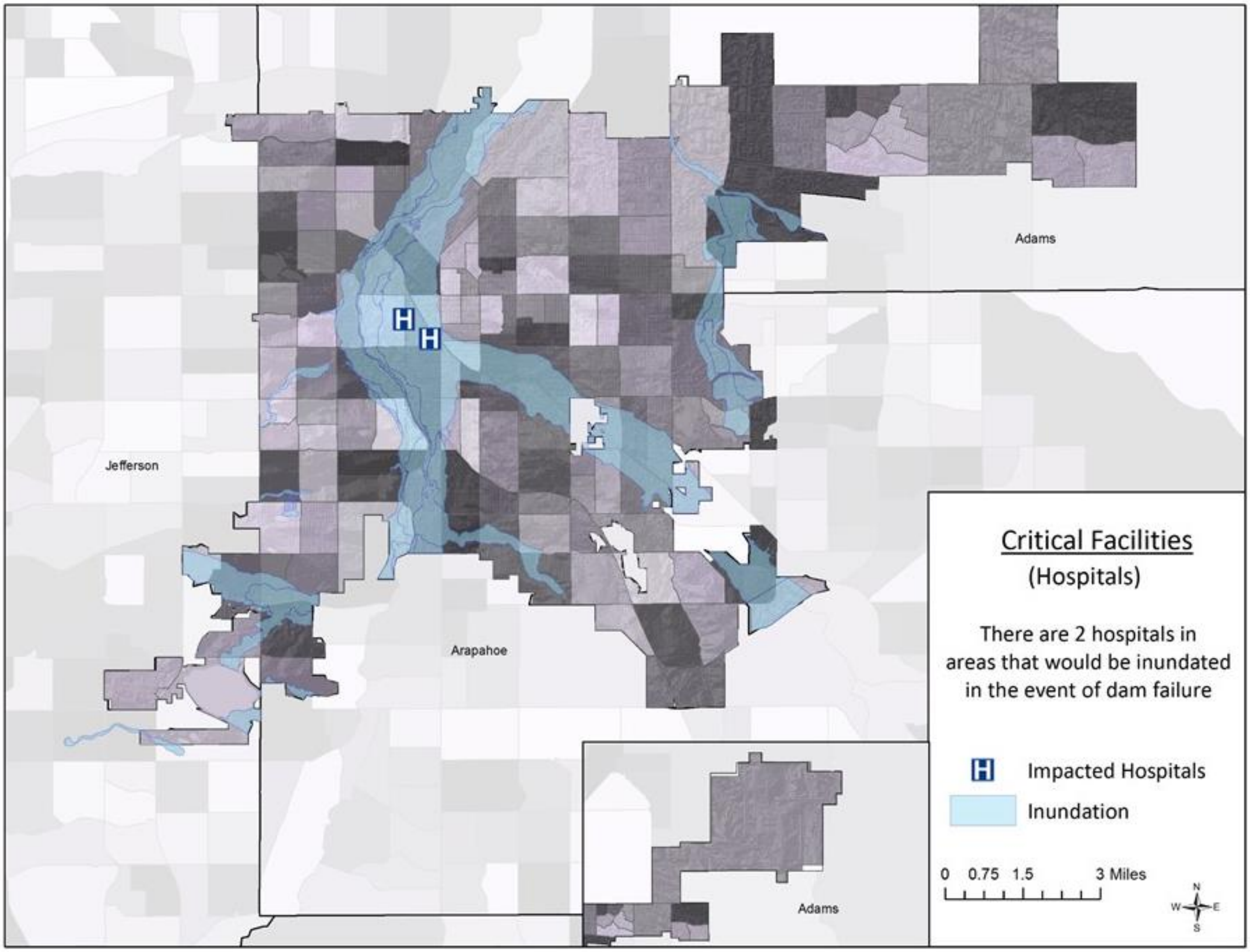
Appendix J: Inundated Police Stations



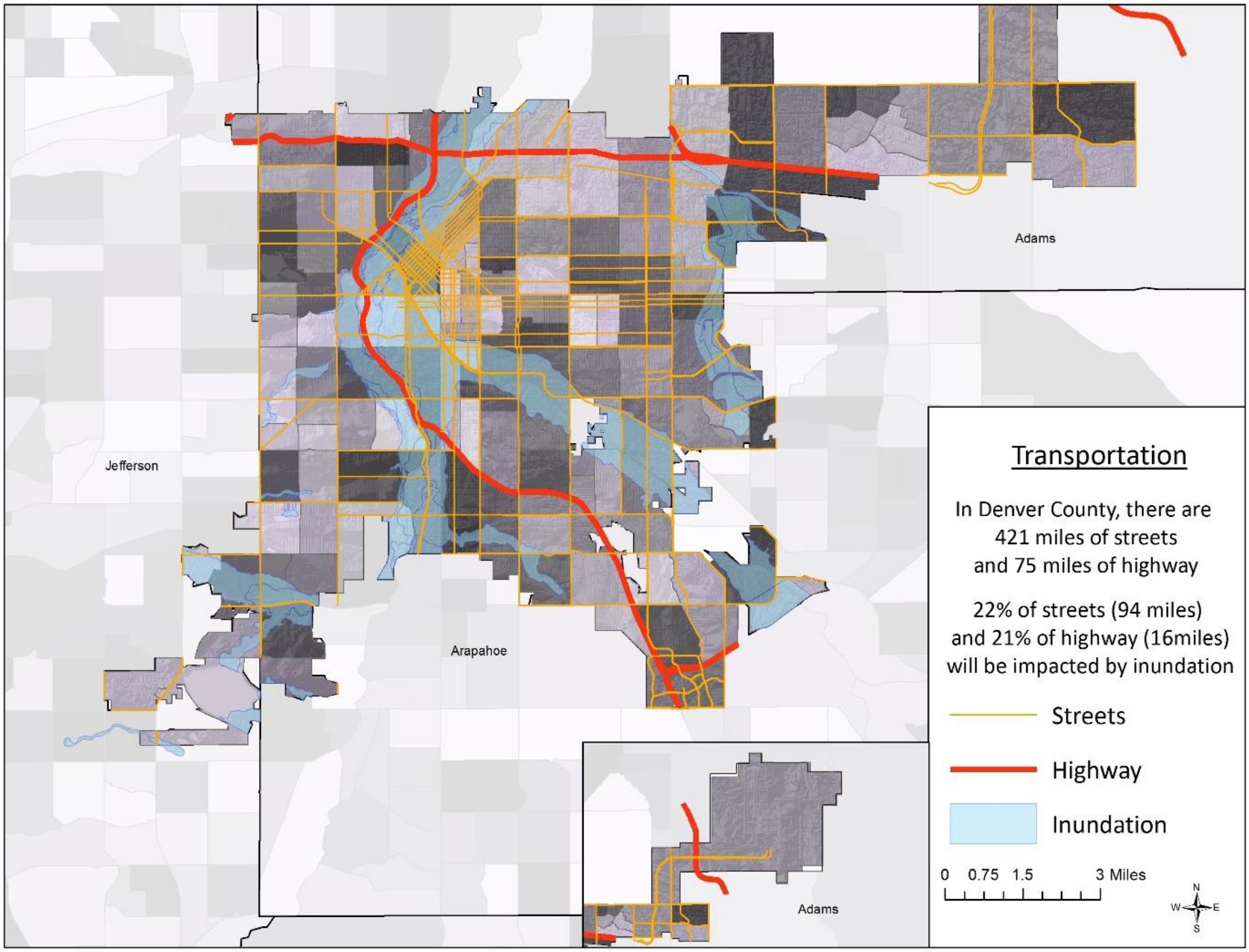
Appendix K: Inundated Fire Stations



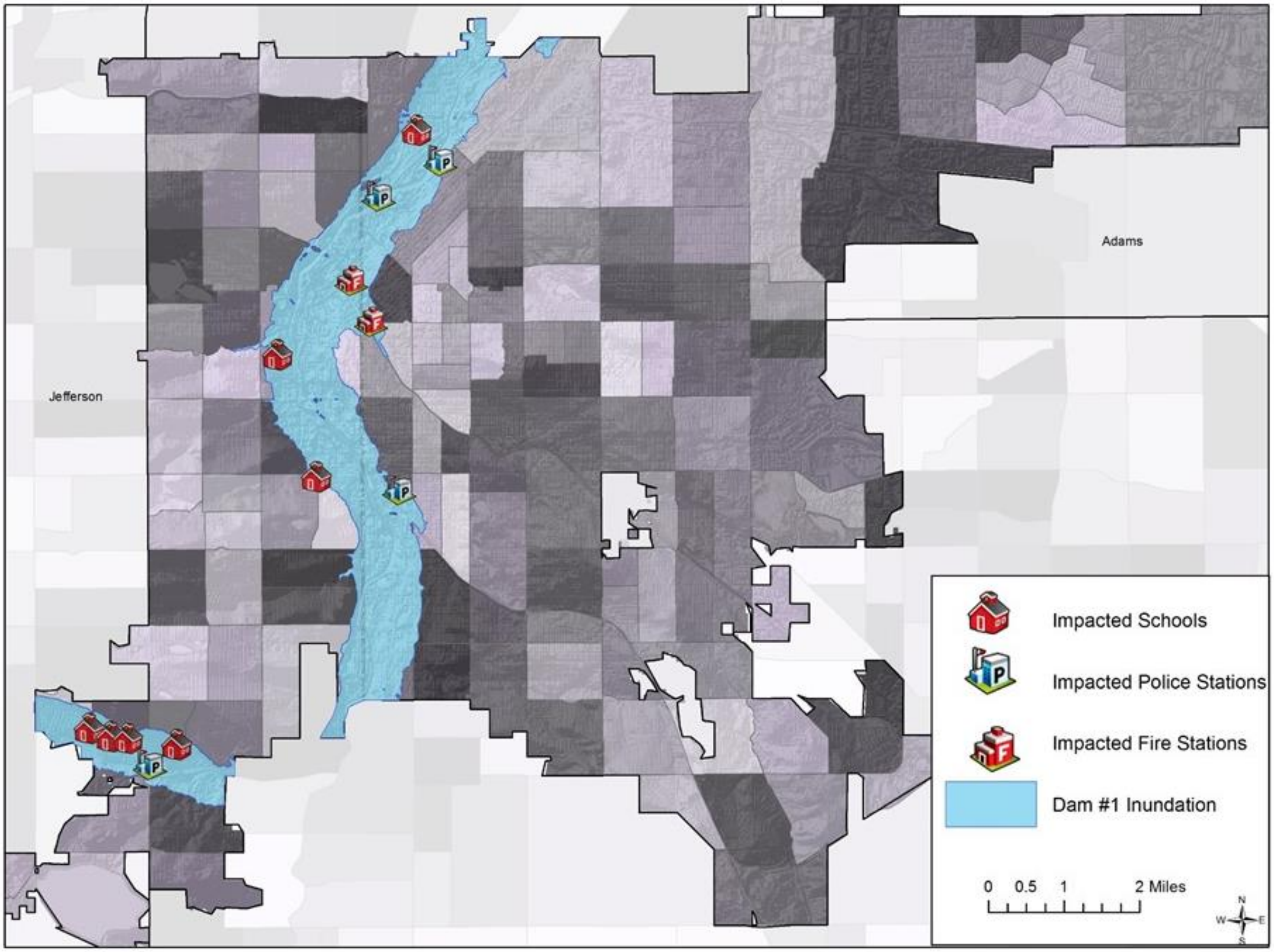
Appendix L: Inundation Hospitals



Appendix M: Inundated Transit

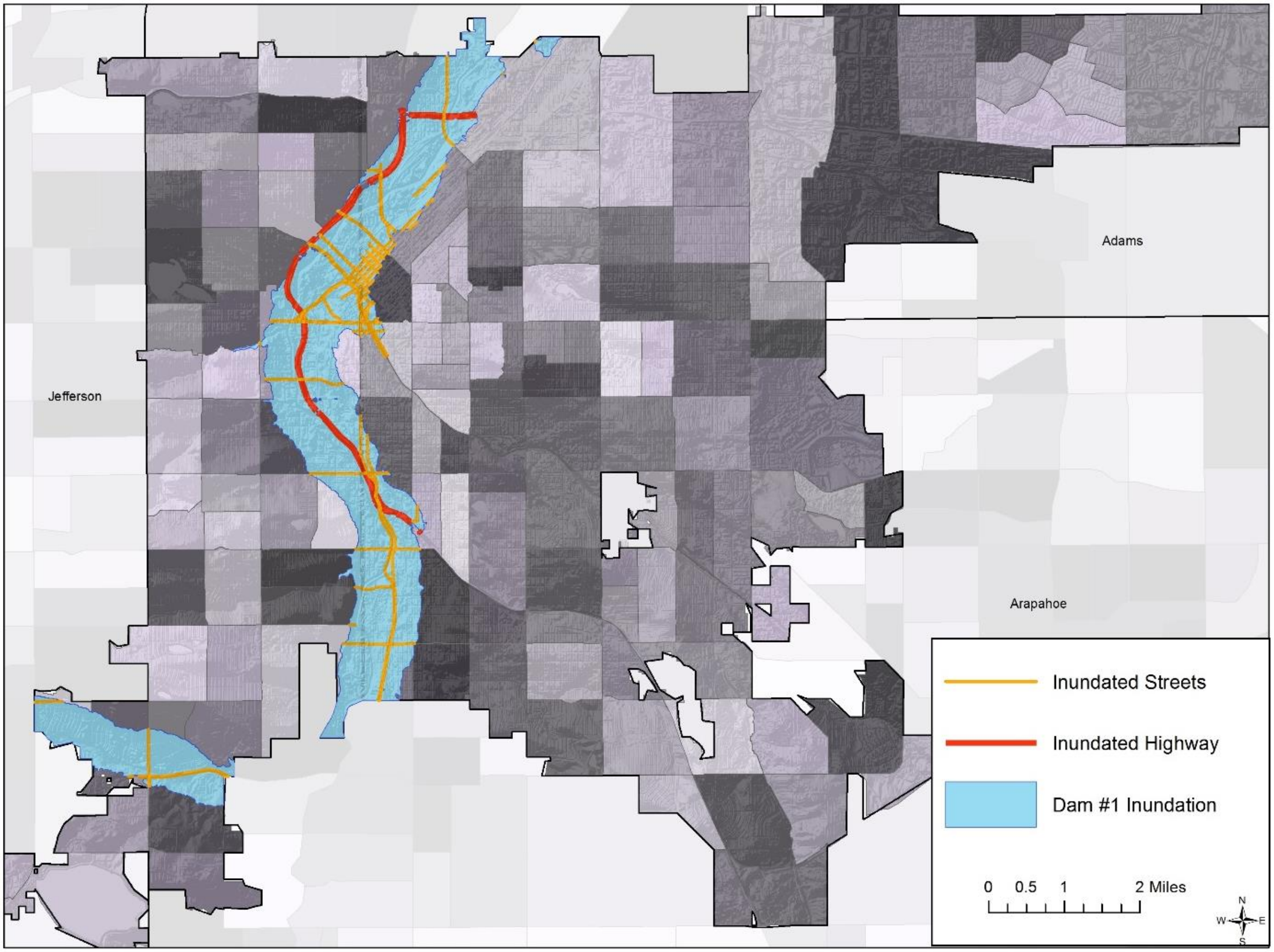


Appendix N: Dam 1 Critical Facilities



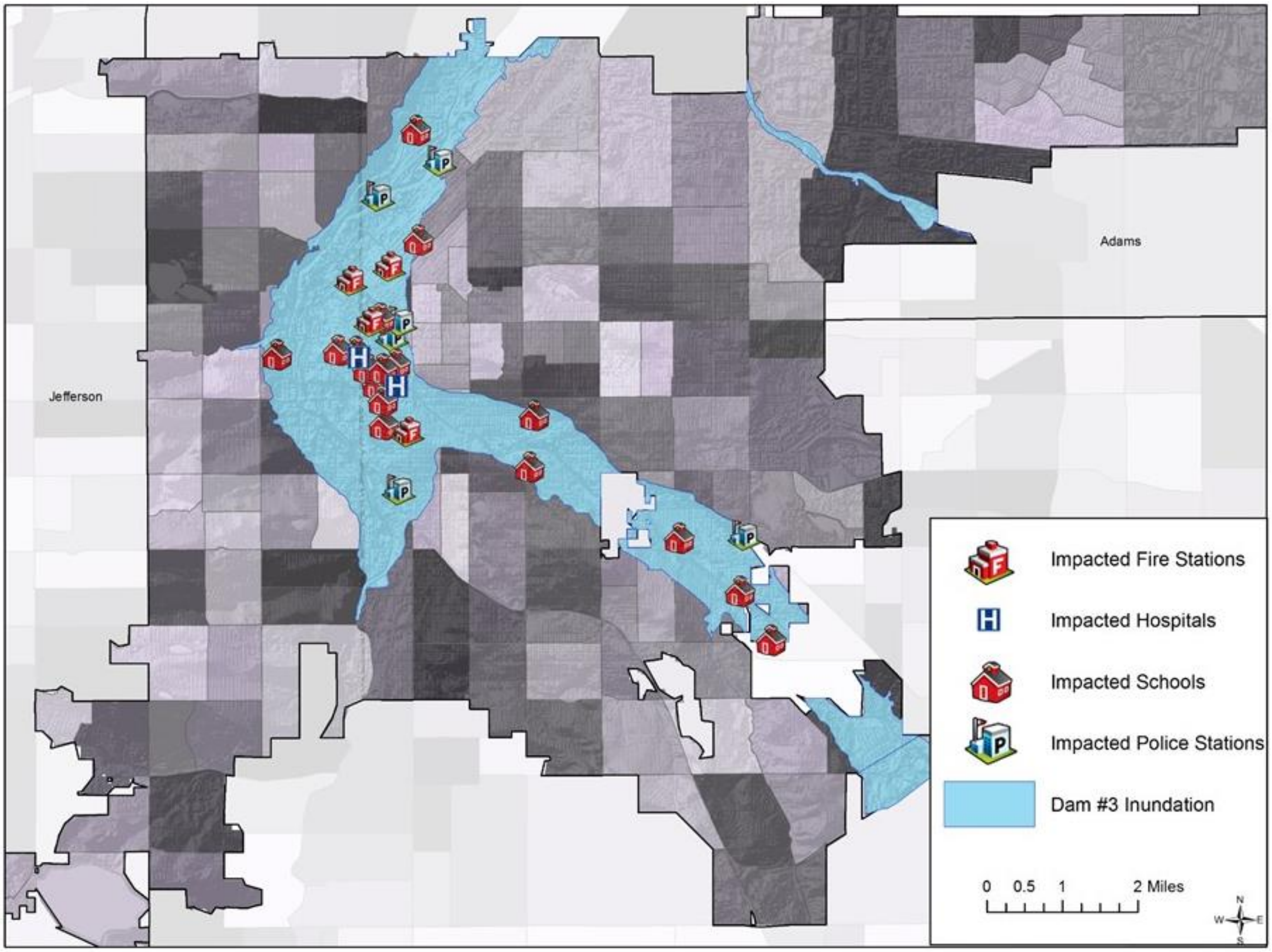
Schools	Police Stations	Fire Stations	Hospitals
7	4	2	0

Appendix O: Dam #1 Transit



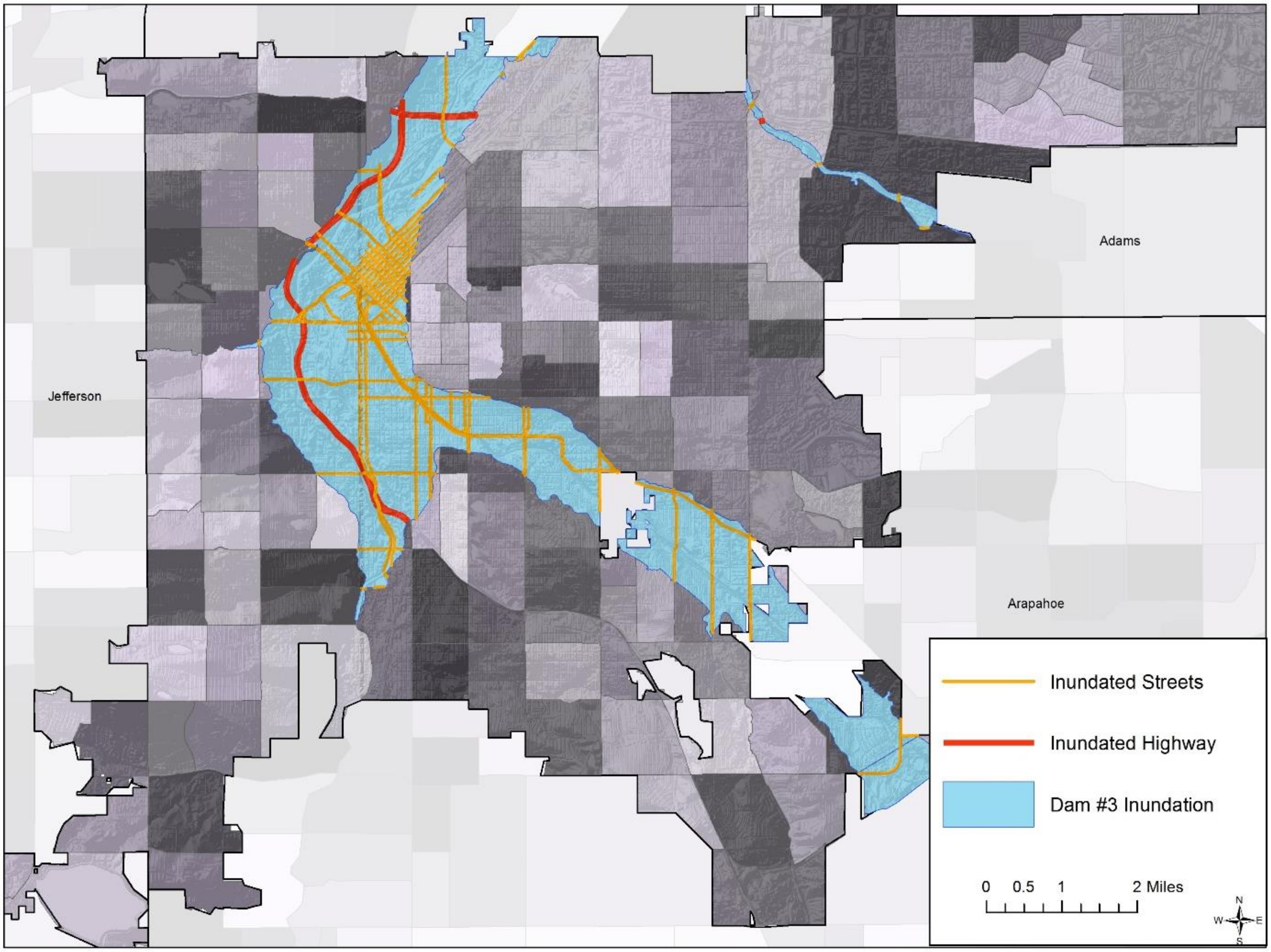
Total Highway Inundation	I-25 (miles)	I-70 (miles)	Streets Inundation (miles)
14.1	12.1	2	37.7

Appendix P: Dam #3 Critical Facilities



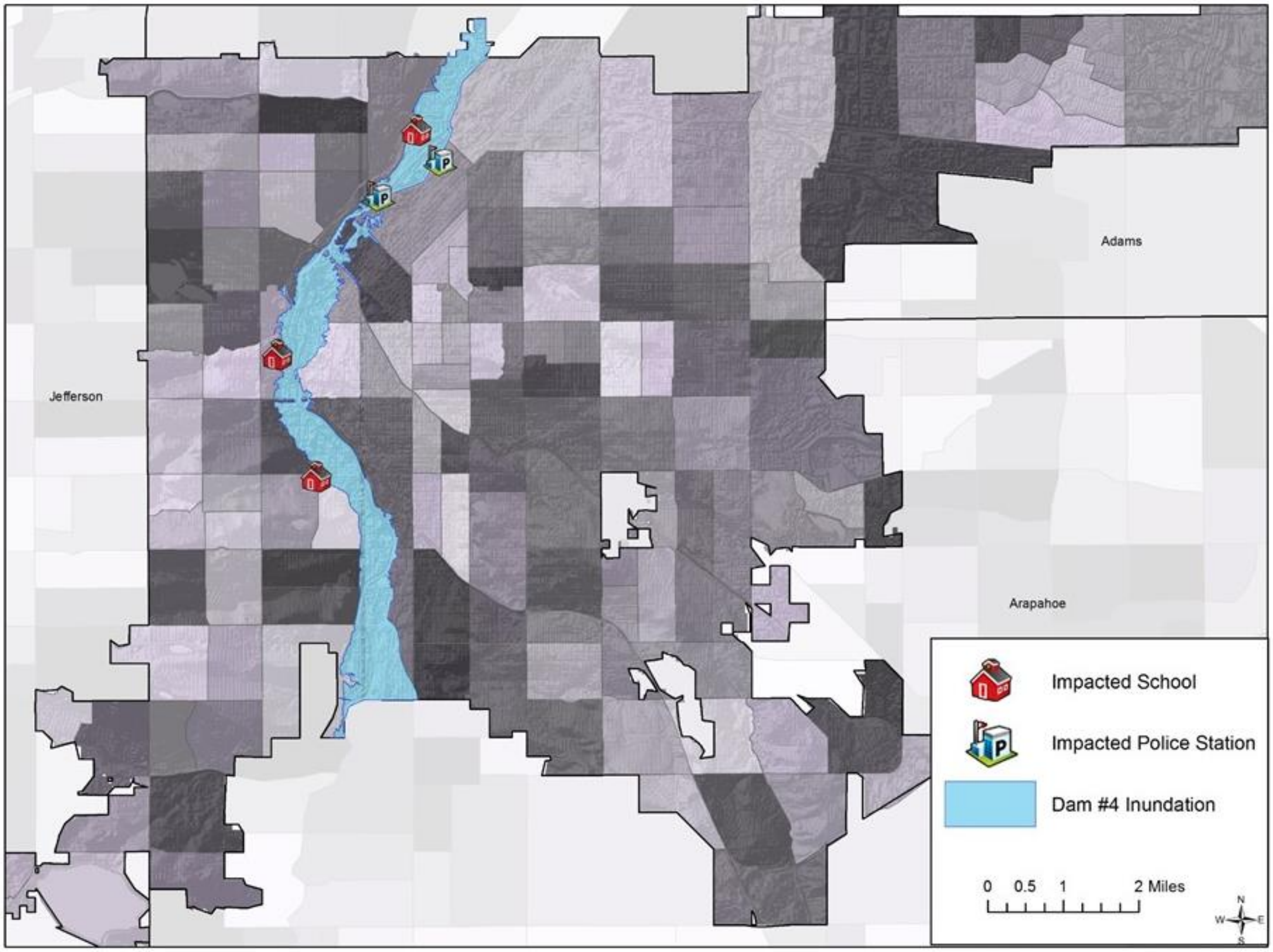
Schools	Police Stations	Fire Stations	Hospitals
24	6	4	2

Appendix Q: Dam #3 Transit



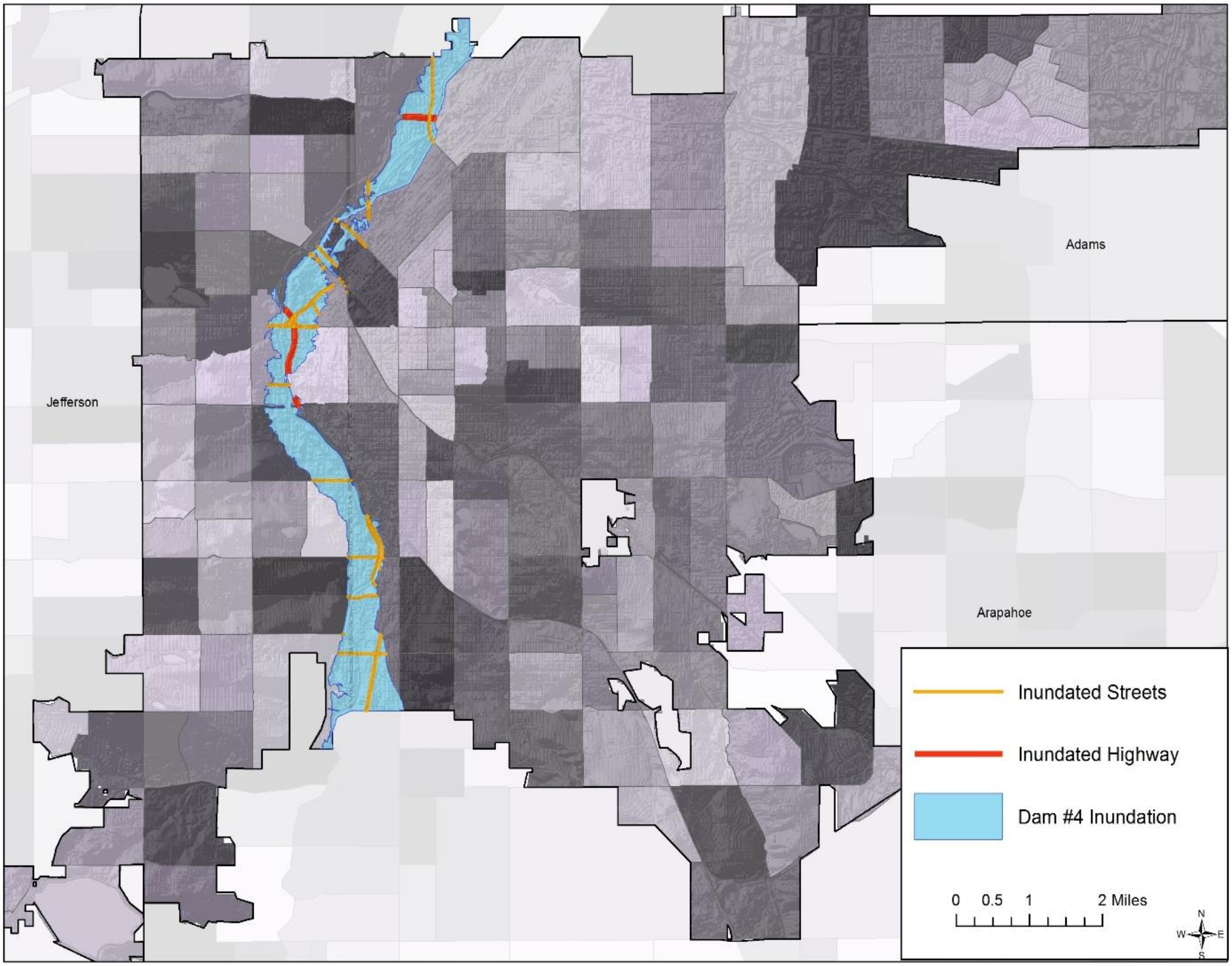
Total Highway Inundation	I-25 (miles)	I-70 (miles)	Streets Inundation (miles)
15.6	13.2	2.4	74.4

Appendix R: Dam #4 Critical Facilities



Schools	Police Stations	Fire Stations	Hospitals
3	2	0	0

Appendix S: Dam #4 Transit



Total Highway Inundation	I-25 (miles)	I-70 (miles)	Streets Inundation (miles)
3	2.1	0.9	13

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