THE PHYSICAL AND ECONOMIC IMPACTS OF URBAN FLOODING ON CRITICAL INFRASTRUCTURE & SURROUNDING COMMUNITIES

A DECISION-SUPPORT FRAMEWORK

By

Gloria Neal

Dr. Ignatius W. Fomunung
Associate Professor
(Chair)

Dr. Mbakisya A. Onyango
Assistant Professor
(Committee Member)

Dr. Joseph O. Owino
Department Head and UC Foundation
Associate Professor
(Committee Member)

Dr. Benjamin Byard
Adjunct Professor
(Committee Member)

THE PHYSICAL AND ECONOMIC IMPACTS OF URBAN FLOODING ON CRITICAL INFRASTRUCTURE & SURROUNDING COMMUNITIES

A DECISION-SUPPORT FRAMEWORK

By

Gloria Neal

A Thesis Submitted to the Faculty of the University of
Tennessee at Chattanooga in Partial Fulfillment
of the Requirements of the Degree of
Master of Science

The University of Tennessee at Chattanooga
Chattanooga, Tennessee

May 2014

ABSTRACT

In recent years there has been a rise in the frequency and severity of natural disasters. The economic costs associated with these extreme events exceeded $110 billion in the year 2012 alone. While the causes for these events are many and the subject of current controversy there is little doubt that man's role in rapid urbanization is amplifying the impacts of such occurrences and adds a layer of complexity to efforts aimed at mitigation. While there are systems in place there is a need for a national overhaul of the methods currently active for the mitigation and protection of vulnerable critical infrastructure and the communities devastated by natural disasters. This thesis presents a framework and research approach to provide a means to reducing physical and economic damages associated with natural disasters. A case study is presented illustrating the devastation that would be caused by 100, 500 and 1000-year flood events in the Hamilton County, TN area. It was found that the damages resulting from each storm would cause federal declarations of disaster. Mitigation, recovery and resilience efforts are discussed in the aftermath.

DEDICATION & ACKNOWLEDGEMENTS

I dedicate this thesis to my family. Without all of your love and support throughout the years I would have never been able to realize my dream of becoming an engineer. I wish to acknowledge my advisor, Dr. Fomunung, and all of the members of my committee who took the time to share their expertise and feedback to help me make this thesis what it is today.

"It always seems impossible until it's done"

- Nelson Mandela

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASCE, American Society of Civil Engineers

BFE, Base Flood Elevation

CIKR, Critical Infrastructure & Key Resources

CIPDSS, Critical Infrastructure Protection Decision Support System

DEM, Digital Elevation Model

DHS, Department of Homeland Security

DSS, Decision Support System

EM-DAT, Emergency Database

FEMA, Federal Emergency Management Agency

FIRM, Flood Insurance Rate Map

FTA, Fault Tree Analysis

GAO, Government Accountability Office

GCC, Government Coordinating Councils

GDP, Gross Domestic Product

GIS, Geographic Information Systems

HAZUS-MH, Hazards United States Multi Hazard

NFIP, National Flood Insurance Program

NIPP, National Infrastructure Protection Plan

NWS, National Weather Service

PDA, Preliminary Damage Assessment

SCC, Sector Coordinating Councils

SFHA, Special Flood Hazard Area

TVA, Tennessee Valley Authority

USGS, United States Geological Survey

LIST OF EQUATIONS

CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Infrastructure systems play a vital role in a nation's economic well being and national security posture. These systems are elaborate and dynamic in nature and the importance of each system is emphasized by the need to sustain continuity in services. While in service a certain level of performance is expected by the user in order to maintain a standard of quality, reliability, and comfort. The level of service is constantly challenged by the aging process, limited resources and disasters. The concept of infrastructure resilience has been used to determine how to combat the impact of these challenges. By incorporating mathematical concepts such as reliability, risk and recursion, and the business model of change management this work sets out to establish a comprehensive framework on how to improve resilience of critical infrastructure systems and increase public understanding of the importance of awareness of infrastructure to public safety and socioeconomic welfare.

1.2 Research Objectives

Experts within the public and private sector have begun to pay more attention to the growing need to protect the nation's critical infrastructure. September 11, 2001 was an awakening in terms of noticing a need to protect national safety and security. Many citizens were faced with the realization that they may have to live without one of the basic necessities that we all have come to depend on. The Department of Homeland Security has since established such policies that have made an effort to organize various organizations with the intent to secure our country's most valuable assets. With this background the objectives of this research are to:

1. Establish a decision support framework by incorporating principles from other areas of interest to tie together all areas of critical infrastructure and emergency management in relation to natural disasters.
2. Use the said framework with a case study to test its validity.

1.3 Research Approach

Quantitative and qualitative research approaches work well when the subject matter is clearly defined and a simple decisive conclusion is necessary to answer a question. However, in the case of developing a framework from various sources using one method over the other tends to limit how the information will be interpreted. Qualitative approaches tend to be broad and focus on the stages of developing research plans where quantitative analysis occurs in the process of conducting research. The approach used in this thesis will be pragmatic so that it transcends the distinction between knowledge that is context and knowledge-based that is universal. This method will allow the use of both quantitative and qualitative concepts and techniques depending on what is necessary to the subject matter. The pragmatic research process model used will have six steps: (1) determination of the question, (2) data collection, (3) data analysis, (4) data interpretation, (5) legitimize or data validation and (6) conclusions.

1.4 Thesis Outline

This thesis documents the process summarized above. The thesis is organized as follows:

- Chapter 1 is the introduction to the thesis detailing problem statement, research objectives, research approach and thesis outline.
- Chapter 2 is the literature review covering topics such as the definition of critical infrastructure, the interdependencies of infrastructure, the current policies protecting infrastructure, the importance of infrastructure and decision support systems.
- Chapter 3 details the risks associated with natural disasters impacts to infrastructure resilience and the physical, social and economic damages related to natural disasters.
- Chapter 4 features the framework for the critical infrastructure protection plan as well as an overview of the program used for analysis HAZUS-MH (Hazards United States – Multi Hazard)
- Chapter 5 discusses the framework plan in detail as well as mitigation strategies to combat the effects of natural disasters.
- Chapter 6 describes urban flooding, climate change and their ever-growing impacts on the world. Fault tree analysis is introduced and utilized as a means of determining the root issue of urban flooding.
- Chapter 7 outlines the economic impacts related to a flood event.
- Chapter 8 is an overview of the case study performed for this thesis. It gives a detailed description of all analysis as well as the results of the study.
- Chapter 9 discusses the findings of the analysis.
- Chapter 10 is the conclusion and recommendations for future study.

- Appendix A gives a step by step tutorial related to an evacuation method described in Chapter 5

CHAPTER 2

LITERATURE REVIEW

2.1 Critical Infrastructure Definition

Infrastructure refers to systems that physically tie together metropolitan areas, communities, and neighborhoods, and facilitate the growth of local, regional, and national economies. These interdependent systems work together to provide the essential services of a modern society. Over the years infrastructure has evolved in both the public's view and how the government addresses it. Many years ago infrastructure was defined primarily in debates about the adequacy of the nation's public works, which were viewed as deteriorating, obsolete, and of insufficient capacity. The growing threat of international terrorism in the 1990's renewed federal interest in infrastructure issues. Unlike the previous period, which was focused on infrastructure adequacy, federal agencies in the 1990's were increasingly concerned about infrastructure protection. This concern led, in turn, policy makers to reconsider the definition of "infrastructure" in a security context. The word critical refers to infrastructure that provides an essential support for economic and social well-being, for public safety and for the functioning of key government responsibilities. Thus critical infrastructure refers to systems which, if disabled or destroyed, would result in catastrophic and far-reaching damage. Formally, "critical infrastructure" are those assets the loss of which would result in great harm to the nation's security, economy, health and safety, and morale. They include assets necessary to generate and distribute such basic goods and services such as electricity, drinking water, telecommunications, banking and finance, etc. These systems are built to provide services to several generations for several decades. They have become so integrated into modern life that they are taken for granted. Today, in U.S. businesses and industries, it is expected and relied on that the required infrastructure is available to transport raw materials, to manufacture products, to deliver food and durable goods to markets and ports, and to enable the sharing of ideas and the conduct of transactions electronically. By 2030, an additional 60 million Americans and unknown number of businesses will have similar demands and expectations for the services provided by these systems.

2.2 Interdependency of infrastructure

Our nation's social and economic welfare is dependent upon the interdependencies of our critical infrastructure system. These systems cover a large number of sectors including the natural gas system, electric power grid, public water services and transportation networks. In order to enhance critical infrastructure protection plans, it is imperative to understand how they connect and interact. Each of these systems are complex individually but understanding their interaction is crucial especially if any of these systems are under duress. For example, after Hurricane Katrina, the supply of crude oil and refined petroleum products was interrupted because of loss of electric power at the pumping stations for three major transmission pipelines: the Colonial, Plantation and Capline pipelines. [1] Because of the loss of power, about 1.4 million barrels of crude oil were lost per day and due to interruption, those pipelines were not restored to full capacity for another 17 days after the hurricane made landfall. This is an example of how the failure to understand the dynamics of these relationships especially in chaotic environments can lead to misuse of resources, personnel, limited supplies and relief efforts. Interdependency is a bidirectional relationship where the state of one system is directly influenced by the state of the other. For example, system *i* is dependent upon the performance of system *j* to execute its function and vice versa as illustrated in Figure 1. These complex relationships are characterized by multiple connections among infrastructures, feedback and feed-forward paths, and intricate branching topologies [2].

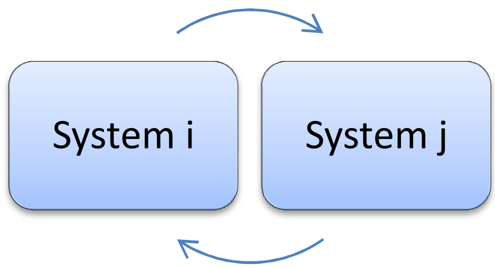


Figure 1 - Example of Interconnected, Dependent System

Interdependencies between infrastructure systems are categorized by type according to Rinaldi, Peerenboom and Kelly [2] as:

- Physical – two infrastructures are physically dependent if the state of each is dependent on the material output(s) of the other.
- Cyber – an infrastructure has a cyber-interdependency if its state depends on information transmitted through the information infrastructure.
- Geographic – infrastructures are geographically interdependent if a local environmental event can create state changes in all of them.
- Logical – two infrastructures are logically interdependent if the state of each depends on the state of the other via a mechanism that is not a physical, cyber or geographic connection.

Categorizing and understanding how infrastructure is connected is essential to providing a means to protecting it. Advancements in technology have increased the interconnectedness of each system. Understanding the relationships will help us move forward in the preservation and protection of these critical systems.

2.3 Current Recovery Policies for Critical Infrastructure

In order to improve resilience of critical infrastructure against future disasters, it is important to understand existing policies and seek breaches in the current procedures. According to the Federal Emergency Management Agency (FEMA) there is certain protocol to be followed before, during and after an event has taken place [3]. FEMA's multi-hazard mitigation planning is to identify policies and actions that can be implemented over the long term to reduce risk and future losses. According to FEMA, the planning process is just as important as the plan itself because it provides a framework for risk-based decision plan making to reduce damages to lives, property, and the economy from future disasters [4]. Mitigation is defined as the act of lessoning the force of something unpleasant and in the context of infrastructure, it is the effort to reduce loss of life and property by decreasing the impact of disasters. The National Disaster Recovery Framework provides recovery support functions that are led by coordinating agencies at the national level whose expertise are relevant to the functional area of assistance [5]. When disaster strikes, these organizations are expected to help local communities recover.

The Homeland Security Presidential Directive 7 has laid out a document titled the National Infrastructure Protection Plan (NIPP) in accordance with the Department of Homeland Security (DHS) [6]. This plan is structured to create partnerships between Sector Coordinating Councils (SCC) from the private sector and Government Coordinating Councils (GCC) from the public sector with the goal of protecting critical infrastructure and key resources (CIKR) and ensuring resiliency. These affiliations form a structure through which representative groups from all levels of government and the private sector can work together or share different approaches to CIKR protection. The concept of the NIPP provides a basic risk management framework that includes the following steps:

- Set Goals & Objectives: Define specific outcomes, conditions, end points, or performance targets that collectively constitute an effective risk management posture [7]
- Identify assets, systems, and networks: Develop an inventory of the assets, systems, and networks, including those located outside the United States, that make up the Nation's CIKR or contribute to the critical functionality therein, and collect information pertinent to risk management that takes into account the fundamental characteristics of each sector [7]
- Assess Risks: Evaluate the risk, taking into consideration the potential direct and indirect consequences of a terrorist attack or other hazards (including, as capabilities mature, seasonal changes in the consequences and dependencies and interdependencies associated with each identified asset, system, or network), known vulnerabilities to various potential attack methods or other significant hazards, and general or specific threat information [7]
- Prioritize: Aggregate and compare risk assessment results to: develop an appropriate view of asset, system, and/or network risks and associated mission continuity, where applicable; establish priorities based on risk; and determine protection, resilience, or business continuity initiatives that provide the greatest return on investment for the mitigation of risk [7]
- Implement protective programs and resiliency strategies: Select appropriate actions or programs to reduce or manage the risk identified; identify and provide the resources needed to address priorities [7]
- Measure effectiveness: Use metrics and other evaluation procedures at the appropriate national, State, local, regional, and sector levels to measure progress and assess the effectiveness of the CIKR protection programs [7]

This framework is on a continuous loop that allows the Federal Government and its' partners through this program to advance the progression over time in order to improve the protection of CIKR.

2.4 Why Is Infrastructure Important

Infrastructure has an immediate impact on our personal and economic health and the current infrastructure crisis is having a direct effect on our future prosperity. For many years the infrastructure of this nation has been deteriorating and the impacts are often overlooked because they cannot be readily defined or quantified. The importance of infrastructure is directly proportional to the service that it provides and each component has an immediate effect on the quality of life in its servicing community. If the population of a community grows and there is no improvement made to infrastructure the effects will be evident. Leisure and personal time lost due to traffic congestion, water quality issues arising from inadequate treatment facilities, and accidents and fatalities due to weakened bridges are all problems to be anticipated unless more consideration is given to infrastructure systems. Every day we face deficient systems that can no longer afford to be ignored for the safety and security of our families and loved ones.

2.5 Decision Support Systems

Infrastructure projects are complex in nature. There are several different variables at any given point during the decision making process. Human judgment can differ when working with a group of people based on various approaches to the same problem. If catastrophic circumstances are added into the equation the complexities of the decision making process only get more convoluted. Because of this, Decision Support Systems (DSS) are integrated to help the decision making process. The objective of the decision support system is to reduce the vulnerability of places and infrastructure systems through the use of mitigation strategies that increase system resilience and resistance to the stresses imposed by disasters [8]. A decision support system is a computer application that gathers and presents data from a wide variety of sources and presents such information with the purpose of making decisions easier. For example, the program used in this thesis simulates flood events and compiles data associated with damages. This aids decision makers in determining future mitigation plans. A successful DSS compiles raw data, personal knowledge and relevant documents into a system to organize information and solve problems. It is important to note that DSS do not make decisions. It is merely a tool to present information efficiently to help in the decision making process. There are typically four different components or subsystems that form a DSS. They are categorized by the following: data management subsystem, model management subsystem, knowledge management subsystem, and user interface subsystem.

2.5.1 Data Management Subsystem

The foundation to any DSS is the data. The data management subsystem executes the task of accumulating and retaining the information that the client wants the DSS to use. Quality data are useful, legitimate and dependable. The data stored are relevant to the topic for which the DSS has been devised. The information that is used in data management component comes from one of the following sources: external information, personal information and organizational information. This component of the system should allow the user to be aware of the data available throughout the system and let them know how to gain access to it.

2.5.2 Model Management Subsystem

The model management subsystem is a mirror of the data management system. This system stores the models for the entire DSS. It allows the users to create models easily and quickly and to manipulate such models to perform experiments and sensitivity "what if" analysis. This system uses multiple models to support problem solving and accrues, retrieves, and manages a wide variety of models in a logical manner. It transforms the data from the data management subsystem into useful information to aid in the decision making process.

2.5.3 Knowledge Management Subsystem

Once the data had been acquired and the model interface has been created, the knowledge management subsystem can be utilized. This subsystem provides the proficiency in solving unstructured and semi-structured problems. Unstructured problems occur when the decision making process is not straightforward and the use of unstructured, unorthodox procedures are necessary to make a decision. These problems involve such subjects as economic, human issues and technical problems that are multifaceted in nature. A semi-structured problem occurs when there is data and structured evidence to support decision making available but there is still a need for human judgment. The knowledge management subsystem clarifies what models to use, how to use them, and how to interpret the results. It consists of rules that can bind a possible result and methods for evaluating them. This leads to intelligent DSS.

2.5.4 User Interface Subsystem

The final and most important component in the DSS interface is the user subsystem. This component allows the user to input data into the database and the model which then presents said data in a variety of formats and output devices. If a DSS has a poorly made user interface, no matter how sophisticated it may be, it will not be properly utilized. The output data on a properly made user interface subsystem will provide graphics, plots and other media that will aid in the decision making process.

Understanding the relationships between infrastructure systems and their interactions during disaster events is essential to help minimize the damage sustained in their aftermath. There are committees formed at a national level that discuss and plan future policy regarding how to deal with these issues. However, there is a need for formation of state and local commissions to deal with these problems because they are reliant on the conditions of each area. Risk management is a process employed by persons in charge of decision making. The next chapter discusses risk in terms of natural disasters and how to improve resiliency of infrastructure.

CHAPTER 3

RISK

3.1 Risk Management

Risk carries several different meanings depending on the context in which it is used. In terms of assessing risk it is defined as the probability of an accident occurring times the expected loss in case of the accident. Risk management identifies, assesses, and prioritizes risks and organizes economical applications of the available resources in order to monitor, minimize and control the impacts of unfortunate events. The first step in risk management is to assess the risk. Risk assessment is the qualitative or quantitative application used to determine the level of risk associated with a specific hazard. This process defines the probability and severity of an undesirable event that may possibly result from a hazard. As the assessment is conducted it is essential to look for vulnerabilities that would make an asset more susceptible to damage from a hazard. Qualitative risk assessment does not try to assign concrete mathematical values to assets. It focuses on relative values from things such as surveys, questionnaires and workshops and has a faster turnover rate than quantitative approaches because it does not rely on data. Data collection and analysis is a process that requires time and effort that a person or business or agency may not have. Qualitative approaches aid in saving both and because of this they provide faster results. Quantitative analysis is used when a numeric value is necessary to assess a specific risk. Each component in a system is assigned a value and a cost benefit analysis is performed. Quantitative does not necessarily mean accurate as it is difficult to exactly assign numbers to intangible items affected in a disaster such as the social impacts affecting a community in the aftermath.

After the risk has been properly assessed the next step in risk management is risk analysis. Risk analysis involves identifying the most probable threat and analyzing the related vulnerability to the threat. Although the exact nature of potential disasters is difficult to determine, it is still beneficial to examine possible scenarios in order to evaluate potential damage. The first step is to identify possible risks. These risks can come from a number of sources. In terms of infrastructure damage the probable risks associated can occur naturally from weather and disasters or structurally from impacts or deterioration. Once the risk has been identified, the next step is to estimate the risk. An accepted way of estimating risk is to determine the probability of an event occurring and multiply that value with the associated cost if that event occurs. This is one of the most important steps; that is why it's imperative for one to take their time during this step. If at all possible, past information and historical data can be used to help make an accurate hypothesis. Once risks have been estimated mitigation strategies are put forth to prevent future hazards. Risk mitigation or treatment is the process of selecting and executing procedures to modify risk. This step includes identifying options for mitigation, developing action plans, approving said plans and implementation of treatment. Identification of treatment options vary with the nature of risk associated. Decision makers have to take into account stakeholder interest and the end users. Development of treatment plans are crucial in order to illustrate how the selected plan will be implemented. These plans must be comprehensive and provide all the necessary information about resource requirements, performance measures, roles and responsibilities of decision makers, proposed actions and priorities. A good plan will allow immediate action with minimal project control in crisis situations. Once these plans have been developed approval is necessary for the implementation. Since factors may change during the development of plans it is necessary to have constant communication from all levels of its development. Execution of risk management plans should be carried out in such a way that it is embedded into an organization's process so that it becomes effective and efficient. The risk analysis process is a vital phase of business recovery planning. Infrastructure management is related to business recovery planning because one of the paramount procedures related to both is the need to anticipate and reduce the effects of potential risks. In unforeseen circumstances there is a need for continuity of services. The probability of a disaster occurring is extremely uncertain. Infrastructure and business management have different processes within their lifecycles but risk management is always included. Development of comprehensive risk and recovery plans that address all critical operations and functions is imperative in times of disaster.

Risk impacts associated with natural disasters are usually classified under three categories; economic, social and environmental impacts. Many of the values related to these impacts are not quantifiable therefore they are identified by monetary and non-monetary terms. Table 1 illustrates the quantifiable impacts of disasters.

Table 1 Summary of Quantifiable Disaster Impacts

	Monetary		Non-Monetary	
Social				
Household			Number of Casualties Number of Injured Number affected	Increase of diseases Stress Symptom
Economic				
Private Sector Household	House damaged or destroyed	Loss of wages, reduced purchasing power		
Public Sector Education Health Water & Sewage Electricity Transport Emergency Spending	Assets destroyed or damaged: buildings, bridges, machinery, etc.	Loss of infrastructure services		
Economic Sector Agriculture Industry Commerce Services	Assets destroyed or damaged: crops, machinery, etc.	Losses due to reduced production		
Environmental			Loss of natural habitats	Effects on biodiversity

Social impacts are those that affect individuals directly as a result of a disaster. This can encompass loss of life, injuries sustained, illnesses incurred or loss of personal items with sentimental value. Indirect social costs can include disruption to living environments in the event of an evacuation, mental anxiety and stress. Economic losses from disasters have increased because exposure to people and assets has increased over time. The losses associated with this sector are grouped into three categories; direct, indirect and secondary losses. Direct losses are immediate damages as a result of an event. Indirect losses are a consequence of the physical destruction caused. Secondary losses involves estimating the aggregate impacts on the economic variables like gross domestic product (GDP), consumption and inflation due to the effects of disasters, as well as, due to the reallocation of government resources to relief and reconstruction efforts [9]. Finally environmental impacts are those that effect biodiversity, nature and other systems that cannot be quantified tangibly, but are important to the environment and surrounding community.

3.2 Resiliency

The services provided by critical infrastructure are crucial for safety, security, and incident management and for the continuity of government operations before, during and after an event followed by a quick recovery to normal system operations or a reduced probability of system failure, and reduced time to system restoration. For these reasons it is imperative for infrastructure systems to be resilient. Resiliency can be defined in a number of ways depending on the context of the issue. In terms of infrastructure management resiliency is the ability of a system to withstand shock and return to form after something devastating has occurred. Resilience can be illustrated in a number of ways including the following:

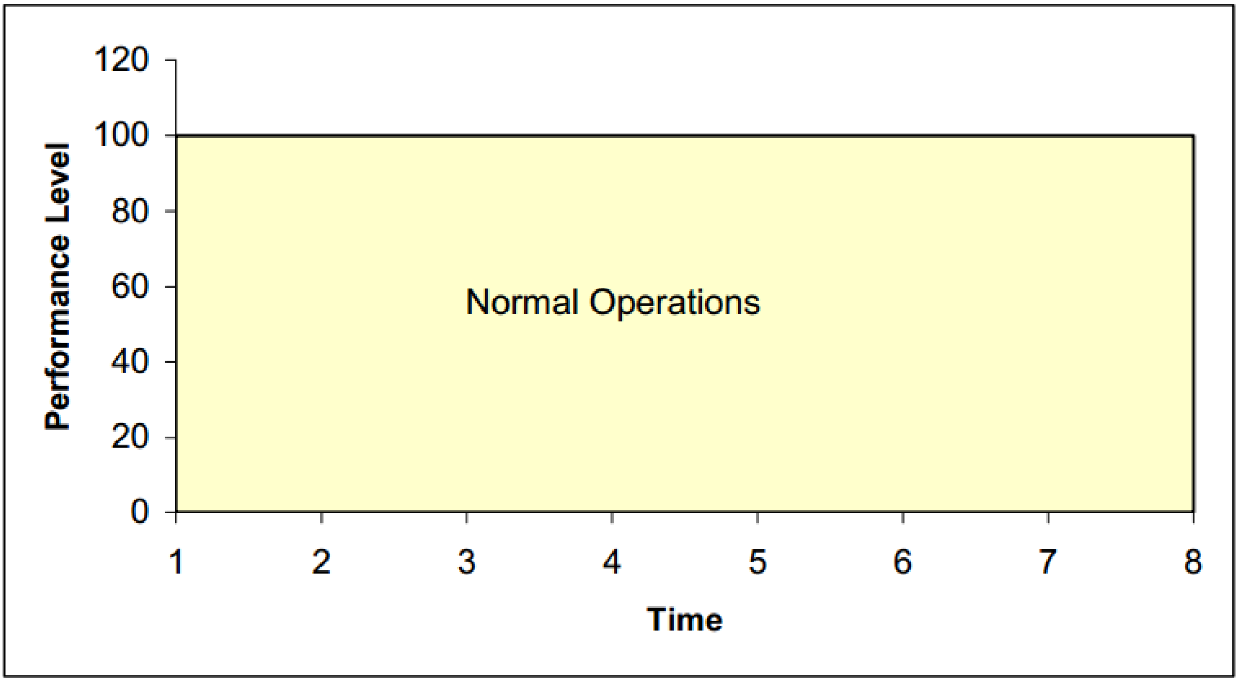


Figure 2 - Infrastructure System under Normal Operations [10]

Figure 2 shows a system operating under normal conditions. This could be an interrelated system of infrastructure such as an electric power grid, public water system, and an interstate highway system. The performance can be measured in a number of ways. For example, the level of service of the interstate or the public water system meets all demands for water consumption. For illustrative purposes the performance of the system in Figure 2 is measured in dimensionless units over some dimensionless time period. In this case, this system performs at a constant 100 units over the entire time under normal operating conditions.

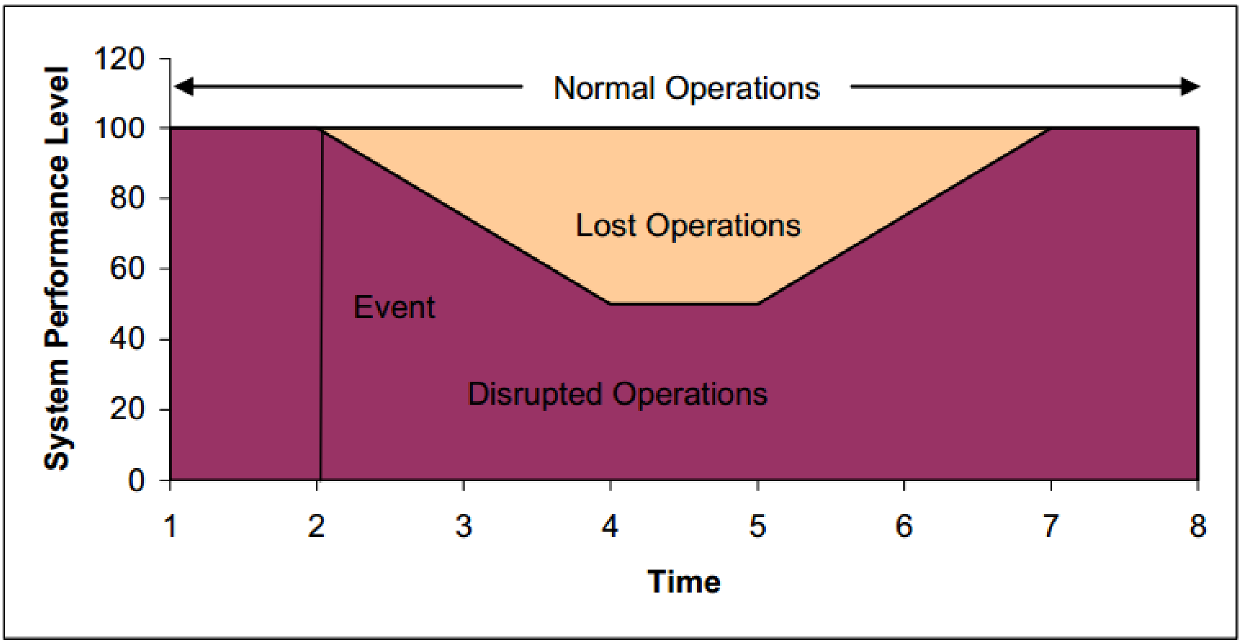


Figure 3 - Infrastructure System under Disruption of Service [11]

Figure 3 depicts the performance of a system that has reduced over time due to a disruption. The event occurs when time = 2 which leads to a performance drop. At time = 4 recovery efforts begin and stop the decline in performance. Performance is brought back to normal operations at time = 7 but the lighter portion of the graph represents lost operations during the time of the event. Reduction of the total loss of performance increases resilience. Policymakers consider what is most important during decision making for critical infrastructure resilience. If it is monetary losses during disruption of service, measuring the total amount of lost revenue will be critical in determining allocation of resources. When critical infrastructure systems are robust and resilient, as opposed to deteriorating, it can mitigate the effects of a disaster by limiting deaths and injuries, property losses, impacts on ecosystems and the time it takes for a community to recover [12].

The illustrations above show how important creating a resilient infrastructure system is to their performance during and after a natural disaster. It also shows that resilience is a function of time and preparedness. Infrastructure systems that have been updated to withstand certain hazards beforehand sustain a desired level of service during and after a disaster situation and reduce the damage and disruption of service. A framework for critical infrastructure protection must be created to support decision making. The following chapter discusses a framework on how to approach infrastructure protection and emergency planning.

CHAPTER 4

FRAMEWORK FOR CRITICAL INFRASTRUCTURE PROTECTION DECISION SUPPORT SYSTEM

Any successful system needs a framework to refer back to from time to time in order to support decisions being made. A critical infrastructure protection decision support system (CIPDSS) provides information for the protection of critical infrastructure based on an assessment of risks, the likelihood of those risks occurring and the associated consequences. As previously stated decision support systems do not make the decision, they rather support the decision making process. Due to the interdependences and complicated nature of critical infrastructure systems there is not a "one size fits all approach" to a protection plan. The framework presented in this thesis is an overall qualitative approach with quantitative information within the system to support the theory. The five part framework is as follows:

- Understanding the problem
- Problem Analysis
- Choose an appropriate turnaround strategy
- Implementation of change process
- Monitoring of change process

4.1 Understanding the problem

Having identified a need or a problem, the first phase of any investigation is to understand it in the context in which it occurs. The difficulty in risk management for disasters is that they are unpredictable by nature and many are so unimaginable that they are disregarded due to their rare occurrence. A good first step is to specify the objectives of the project. As simple as this step sounds it may be difficult because individuals approach situations differently. The entire process can go wrong because those in charge may assume everyone involved sees the situation and its resolution the same way. Knowledge of the fundamentals is very important. Knowing the mechanisms of a system, its functions, and the probability of its failure modes will help. Fault tree analysis is an exceptional technique that can be utilized in this process.

Fault tree analysis (FTA) is an approach of quantitative and qualitative risk analysis used for evaluating the likelihood, consequences, and risk of unfavorable events. This concept is based on two assumptions. The first being the likelihood of the input events and the latter is the assumption regarding the interdependence among the events. FTA develops a logical relationship among the events leading to an accident and estimate the risk associated with the accident [13]. FTA describes the consequences of an event and the likelihood of possible outcomes. An event corresponds to any of the possible states a physical system can assume, or any of the possible predictions of a model describing the system. By providing a detailed analysis of outcomes it helps reduce the probability of occurrence and reduces the effects of all associated consequences. The FTA represents the dichotomous conditions (e.g., success/failure, true/false, or yes/no) of the initiating event until the subsequent events lead to the final outcome events [13]. Uncertainties arise during this process and can be controlled by appropriate data collection and expert judgment. Usually, uncertainties in the real world include two parts:

stochastic uncertainty and epistemic uncertainty. Stochastic uncertainty arises from the variance of the event itself and epistemic uncertainty arises from ignorance about the subject matter [14]. Reducing stochastic uncertainty can be accomplished by performing a quantitative assessment of variance by using classic theories of precise probabilities. Expanding knowledge and information on the subject matter helps reduce epistemic uncertainty.

Probabilistic approaches enable variation and uncertainty to be quantified in risk assessment. In order to get a dependable analysis it is imperative to accurately illustrate and represent uncertainty. Imprecise probability is applicable when information is scarce or when it is not practical or feasible to collect information. Therefore available information is used to carry out the proposed analysis. The information is used to generate upper and lower previsions, which are then used to construct a set of probability measures. Existing probability distributions will be considered for the analysis thus, making the upper and lower previsions capture the available information without losing or distorting any available piece of information [14].

4.2 Problem Analysis

Once the crisis has been properly identified and all probable outcomes have been determined, the next step is to establish how to solve the problem. This step is the process responsible for controlling the lifecycle of all problems. After the FTA has taken place the subsequent step is to prioritize the severity of the events in order to trace the problem. In terms of critical infrastructure we can ask questions such as:

- How much will it cost to fix the problem?
- How long will it take to fix the problem?

- How many people will be affected during the recovery time?

The costs associated with infrastructure repair are taken into account during the planning phase of design. Yearly maintenance, replacement and rehabilitation costs are accounted for in the life cycle cost analysis. In the event of a disaster infrastructure is considered a public facility under Sec. 102 Definitions (42 U.S.C. 5122) of the Robert T. Stafford disaster relief and emergency assistance act [15], and is therefore eligible for emergency federal assistance. The amount of federal aid provided by the government is directly proportional to the degree of damage caused by the disaster.

The timetable associated with disaster relief is impossible to determine and is again directly proportional to the amount of damage. This can however be tied into the time that it takes to receive federal aid and mobilization efforts of volunteer organizations and communities. A community's preparedness system is the ability to identify hazards and develop communication plans in the event of an emergency. A more organized and aware community will be able to withstand and react appropriately before, during and after a disaster.

4.3 HAZUS MH Overview

What would happen if a 500-year flood hit a community? How can the costs of a levee or other flood protection measures be justified? These are all questions that must be answered in the mitigation process for disaster planning. HAZUS MH (Hazards United States- Multi Hazard) is a program that combines science, mathematics and engineering with a GIS based interface to determine the social, economic and physical impacts of a natural disaster. The three natural hazards allowed to be explored using this program include earthquakes, hurricane winds and floods. For the purpose of this study the flood module was utilized. HAZUS-MH is not an engineering tool; rather it is used as an aid in the hazard analysis and mitigation process. It uses a state of the art geographic information system (GIS) in the form of ESRI's ArcGIS platform to map hazards as well as estimate damage and economic loss associated with said hazards. The estimates determined in HAZUS are used for decision making in emergency preparedness and recovery planning as well as developing mitigation plans. HAZUS-MH utilizes a five step approach to enable the user to "Know Your Risk". Once the risks are understood, informed decisions can be made to protect the community and improve resiliency. Figure 4 shows a graphic of the five step approach utilized in the program.

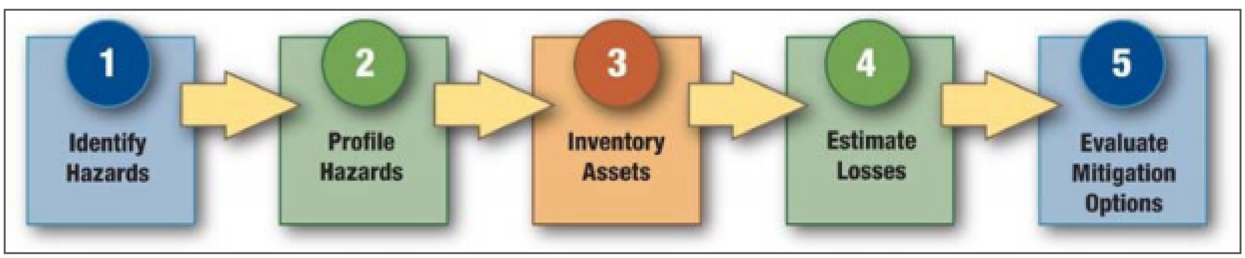


Figure 4 - HAZUS-MH 5 Step Approach [16]

4.4 Model Inputs

The analysis conducted in HAZUS-MH is used to generate maps and estimate exposure to hazards. Existing data within the program was used in aid of a level 1 analysis. This entails default national data stored within the program to perform a loss estimate. User supplied data was added when necessary. The first thing that needs to be defined in HAZUS-MH is the study region and type of hazard to be studied. The specific study region used for this paper will be described in detail in the case study section. HAZUS-MH allows the user to define the study region based on various geographic levels including: state, county, census tract, census block, and watershed boundaries. Once the appropriate study region is selected, a map displaying the region is generated within the program. Careful examination is necessary to determine that the appropriate region has been chosen for analysis. The base map of the study region is used to break the information in later analysis into applicable terms. In order to perform any hydrologic or hydraulic analysis a digital elevation model (DEM) must be imported. A DEM is a 3D model representation of the terrain or topography data. Usually formed from either raster (a grid of squares) or TIN (triangular irregular network) data, the closer together the grids points, the more precise the information will be in the file. The DEMs used in HAZUS-MH are produced from the U.S. Geological Survey 30-m resolution. An example of a 30-m DEM is shown in Figure 5.

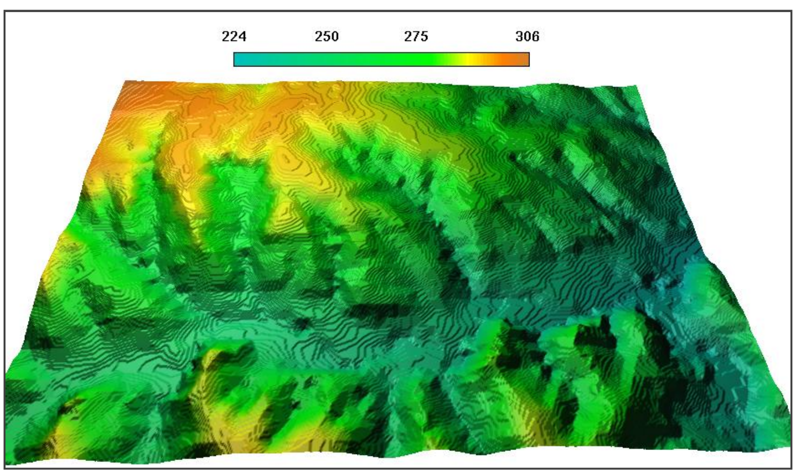


Figure 5 - Sample DEM USGS [17]

For improved estimates of damage, additional model input data for HAZUS-MH can be broken into two categories: aggregate data and site-specific data. Aggregate data includes general building stock (building distribution in a community based on usage and construction materials), demographic data (age, income, sex, household, etc.), agricultural data (statistics associated with crop valuation and production) and vehicle data (valuations and counts of vehicles). Site-specific data includes essential facilities (police stations, fire stations, emergency operations centers, schools, and medical facilities), lifelines (utilities and transportation) and high potential loss facilities [18]. Parcel tax data can also be added to the model to get a detailed community assessment. For larger study areas such as regions, national data is used but for a smaller community evaluation it is best to add local data.

4.5 Choose an appropriate turnaround strategy

A turnaround strategy is part of a business principle entitled turnaround management. This process involves an introspective glance into a company that acknowledges its problems and considers a different strategy in the way the business is ran. The problems facing the organization can be financial, management style, operational, etc. Outside consultants are brought into the company to perform a comprehensive review to determine the issues. The company is then given a plan that involves suggested methods of improvement as well as forecasts for future projections. Basically a turnaround strategy is a well thought out plan for improvements for future successes. Choosing a turnaround strategy for the improvement of infrastructure and emergency planning is a step forward in terms of improving the current state in addition to learning from the past to ensure a prepared future.

Developing a framework to analyze a problem is a good start to establish the source of an issue. In order to fully understand something, an in depth analysis is necessary. Chapter 5 discusses mitigation strategies to combat the effects of flooding on infrastructure and surrounding communities.

CHAPTER 5

MITIGATION STRATEGIES

5.1 Response

As soon as there is an imminent threat to a region it is up to emergency officials to act accordingly. Conducting a risk assessment is the first step to identify potential emergency scenarios. An understanding of what can happen will help determine how to allocate resources and develop a plan. The first priority in emergency response is safety and the second is stabilization of the incident. This phase is the implementation of the disaster plan. It focuses primarily on providing aid, minimizing the damage to essential facilities, meeting the basic requirements of the impacted population, and providing spiritual and mental health care to those in need. Individuals who have prior experience with floods and proper warning time are more likely to respond effectively in the presence of imminent danger. The following sections describe how warning time, transportation exposure and shelter requirements help in the response to a natural disaster.

5.2 Warning Time

An effective warning system can play a large part in the protection from exposure to natural hazards. In fact one of the most effective measures for disaster preparedness is a well-functioning early warning system. Although many hazards seem to appear randomly without much warning most disasters have long gestation periods during which warnings accumulate. It is often a decision left up to the officials on whether the signals are legitimate concerns or false warnings. According to several sources, there are four key elements to an effective early warning system: risk knowledge, monitoring and warning service, dissemination and communication and response capability.

Assessing the risks and vulnerability before disaster strikes is an effective way to warn citizens in harm's way. This evaluation is usually based on historical data and field observations. The simulations performed for the case study include flood mapping and the estimated damages associated with the return period. Mapping gives an approximate location of where the damage will occur according to depth of water. The associated map of thematic depth shows the depth of water at each location. As noted before, the depth of water helps determine the damage as it relates to the structure and its contents. Figure 6 shows an example of the thematic map depicting the depth of water after the flood event.

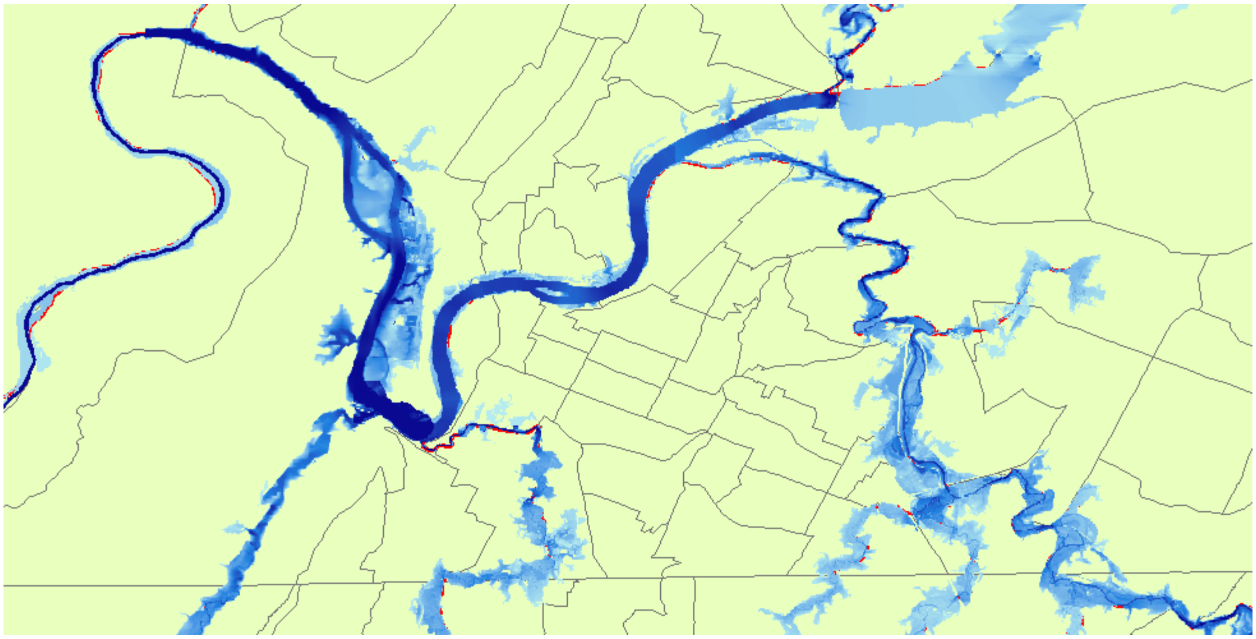


Figure 6 - Thematic Map of 500 Year Flood

Once the risk assessment has taken place the next step in early warning systems is monitoring the hazard. Scientific data that is risk based is necessary to evaluate risks and their probability of occurrence. GIS technology such as the program used in this study is essential to determining the exact location of damage along with figuring out the scope of the disaster.

5.3 Transportation Exposure

Mobility is a very important aspect of disaster response. Transportation is used by the population for evacuation purposes and by emergency responders to rescue immobilized individuals. If roads and bridges are inundated alternative routes must be designated for proper evacuation. Evacuation is the urgent and rapid movement of people away from the threat or actual occurrence of a hazard. Before evacuation takes place there is a period called "Pre Movement Time" where certain planning methods take place. The detection phase is first and immediately following is the decision phase. Emergency planners evaluate the hazard and make the decision on whether to evacuate or not. Once the decision is made the next step is alarm. This is the step in the process when the information is given to the general public usually in emergency broadcast form or by actual alarms and sirens. The next step in the process is the reaction by the populace. Rarely is evacuation absolutely mandatory and there are usually citizens that refuse to leave their property. This decision is also based on one's perception of danger or complete denial of the situation. The reaction time to a hazard varies depending on the scale of the disaster. Evacuees need time to warn loved ones, develop personal evacuation plans and protect their personal valuables and home. Once those decisions have been made the next step involves movement to an area of refuge. Depending on the area, movement can be an especially difficult phase of evacuation. Certain individuals of the population are immobilized due to lack of personal transportation and being handicapped. Demand increases on transportation infrastructure systems that may be inundated or out of use due to damage from the storm. Alternative routes must be designated for efficient and safe evacuation.

Linear programming is a specific method of mathematical optimization that allows the user to come up with the best possible outcome in a given mathematical model. A good representation of this method is the optimization of routes on a transportation network. In the time of crisis finding the shortest path to an emergency center or shelter or delivering supplies to these places is often a matter of life or death. This method is often used by GPS systems and maps to give the user the shortest path from a single source to a destination. This concept was created by Edsger W. Dijkstra [19] and it is called the weighted digraph. This method only works when all weights within the problem are positive. The basic steps in solving this type of problem are:

1. Identify the variables
2. Define the constraints
3. Define the objective function

Consider the following example.

There has been a request for evacuation from an area due to the effects of inundation and rising flood waters. There is an emergency evacuation center about 20 miles from the starting location and the emergency planners want to tell the evacuees the best route for relocation. The diagram of the road network is shown below. A similar example was presented by Brandon Foltz on his educational website [20].

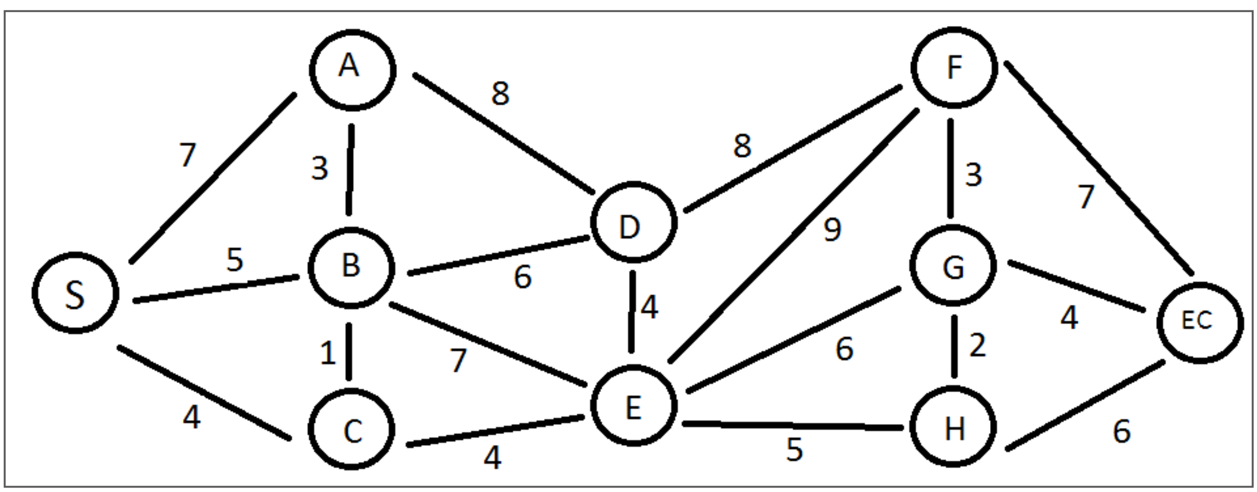


Figure 7- Diagram of Road Network for Evacuation Example

As you can see in Figure 7, this is a complicated network that begins at the source destination and ends at the emergency center. The best method of solving this problem is using the Dijkstra method of linear programming. First the variables need to be identified. The variables are the distances from the starting point to the emergency center. These variables will be alternated within the algorithm to find the shortest or minimized route to the destination. Next the constraints need to be determined. There is a net flow within the network that gives the information about the shortest route. The source node is the supply node. This node starts the algorithm therefore it gives the network the object. Therefore the source node value is one. All of the connector nodes are used to feed net flow within the program. The value at each of these nodes is zero because the information does not stop at these nodes it only passes through to get to its destination. Finally the emergency center is the destination or demand node so the information is going into this node and nothing is outgoing therefore its value is negative one. The constraints for this system are so that the net flow of the system is equal to the supply and demand of the system. The objective function is to find the shortest or cheapest path to the destination. Microsoft Excel was utilized to solve this problem. First the nodes were put into Excel showing their origin and their destination nodes along with the distances associated with each move. Next the supply and demand is set up so that it is equal to the net flow of the system. Figure 8 shows a diagram of the layout for this problem.

Begin	Destination	On Route	Distance
Source	A	0	7
Source	B	0	5
Source	C	1	4
A	B	0	3
A	D	0	8
B	A	0	3
B	C	0	1
B	D	0	6
B	E	0	7
C	B	0	1
C	E	1	4
D	E	0	4
D	F	0	8
E	D	0	4
E	F	0	9
E	G	1	6
E	H	0	5
F	G	0	3
F	Emergency Center	0	7
G	F	0	3
G	H	0	2
G	Emergency Center	1	4
H	G	0	2
H	Emergency Center	0	6
	Total Distance	18	

Nodes	Net Flow		Supply/Demand
Source	1	=	1
A	0	=	0
B	0	=	0
C	0	=	0
D	0	=	0
E	0	=	0
F	0	=	0
G	0	=	0
H	0	=	0
Emergency Center	-1	=	-1

Figure 8 - Excel Setup for Evacuation Route Problem

Appendix A has the step by step instructions on how to solve this problem in Excel. As shown above, the shortest route from the source destination to the emergency center is C-E-G with a total distance of 18 miles. This sort of problem can also be used to distribute the goods among emergency centers and the optimal route to get them there. Once evacuees have arrived at the evacuation shelters it is up to the trained professionals there to have adequate space reserved and proper care for the injured.

5.4 Recovery

Recovery efforts rely heavily on the scale of the disaster and the immediate assessment of damages incurred. Another consideration to take in the recovery process is what standard are you recovering to? Are the efforts made going back to status quo before disaster struck or are measures taken to improve future resilience to disasters? Businesses and communities that remain the same over time set themselves up to be vulnerable to the impacts of disasters. In a constantly changing world, society must also change in response in order to preserve an advantage. When the focus is placed on resilience over recovery, communities stand a better chance of reducing future damages caused by storms. In literature there are two primary kinds of resilience: engineering and ecological. Engineering resilience refers to the speed of return to a steady state after a system perturbation; and ecological resilience is defined as the magnitude of disturbance that can be absorbed before the system restructures, which implies a focus on maintaining existence of function [21]. Looking at the definitions for both engineering and ecological resilience it is interesting to think about which type infrastructure systems should aim for. Engineering resilience refers to the return to the pre-disturbed state of a system but ecological illustrates a system that absorbs and responds naturally to perturbation and ultimately adjusts to its changing environment. So if a system were to increase its ecological resilience it would increase the amount of damage a system could sustain before it experiences a complete shutdown. Mitigation starts at the local level, however, monetary assistance usually comes from the federal government as well as the state level. There has to be a new way of funding recovery efforts that focuses on pre event planning more than the post event reconstruction.

5.5 Federal and State Assistance

The Robert T. Stafford Disaster Relief and Emergency Assistance Act [15] was introduced in 1988 as an amended version of the Disaster Relief act of 1974. The Department of Homeland Security (DHS) watches for potential disasters and emergency situations. They work in accordance with local state emergency operations centers to determine the level of threat after advanced warning systems have shown imminent disaster. The DHS will dispatch emergency field personnel to the affected area to verify the damage incurred. The Governor of the affected state must work in accordance with FEMA under the direct execution of the State's emergency plan. They must provide an estimate of the damage in the form of a preliminary damage assessment (PDA) conducted by State and Federal officials. Once this is completed the Governor must write to the President giving the estimate of damage and the amount of assistance needed. If the request is warranted the President gives an official declaration of disaster therefore activating any Federal programs that are designed to provide emergency aid. The Stafford Act gives FEMA the responsibility to carry out the associated relief efforts. These funds are only provided in addition to local relief efforts that have been overwhelmed by the demand. This program is not without its criticisms. For instance, the Stafford Act states that if destroyed buildings are to be repaired with Federal funds it must be built exactly the same as before. For example, if a 100 year old building is destroyed it must be replaced by a building exactly the same with no upgrades. What is to become of this building if another disaster is to destroy it again? Although there are amendments within the Stafford Act that provides funds for pre-disaster mitigation there needs to be a more effective financing option for disaster mitigation and relief. A thirty year average (1982-2011) conducted by the National Weather Service shows that flood damages in the United States costs $8.20 billion per year [22]. This average only accounts for direct losses associated with flood damages. Business related losses and regional losses are indirect losses related to the lack of mobility due to the infrastructure damage incurred. Various industries use transportation infrastructure to deliver their goods and people use them to get to work. The longer infrastructure is out of service or functioning at a lower capacity the economy suffers severe losses. Mitigation costs are also considered indirect flood-related costs. Funding for both flood mitigation and infrastructure repair has to undergo drastic changes in order to keep individual communities safe from disaster and increase regional economic vitality.

5.6 Mitigation & Preparation

No matter what type of flooding occurs there are loads that cause damages related to various structures. These loads are generally broken into three categories: impact loads, hydrodynamic loads and hydrostatic loads.

Impact loads are those resulting from floating debris or any floatable object or mass carried by flood waters that strike against buildings or structures. These loads are especially destructive because the forces associated may be an order of magnitude higher than those of hydrodynamic and hydrostatic loads. Impact loads are broken into three categories: normal impact loads, which result from isolated impact from normally encountered objects, special impact loads, which result from large objects and extreme impact loads, which result from very large objects floating in floodwaters. It is customary to account for normal and special impact loads in flood impacted areas. It is not justifiable to always account for extreme impact loads unless there is a high probability that structures in that area will be exposed to extreme impact loads during the design flood. There have been several studies conducted for the purpose of modeling impact forces associated with flood waters. One of the most commonly used equations is as shown in Equation 1 [23]:

Equation 1 - Impact Force

$$F_i = \frac{wV}{gT} \quad (1)$$

Where : F_i = impact force in lb acting at the Stillwater level

w = weight of the object in lb

V = velocity of water in ft/sec or approximated by $^1/_2\,(gd_s)^{1/2}$

g = gravitational constant (32.2 ft/sec^2)

d_s = design stillwater flood depth in feet

T = duration of impact in seconds

This is just an equation of approximation that contains several uncertainties that must be quantified before the impact of debris loading on the building can be determined. The design stillwater depth is the vertical distance between the eroded ground elevation and the stillwater elevation associated with the design flood. The items to be quantified are as follows:

- Size, shape and weight (w) of the waterborne object
- Flood velocity (V)
- Velocity of the object compared to the flood velocity
- Portion of the building that will be struck and the most vulnerable portion of the building where failure could mean collapse
- Duration of the impact (T)

Hydrostatic loads are those caused by water either above or below the ground surface, free or confined, which is either stagnant or moves at very low velocities, or up to five feet per second. Hydrostatic loads are both lateral (pressures) and vertical (buoyant) in nature. The lateral pressures result from differences in interior and exterior water surface elevations. These pressures are usually not great enough to cause permanent deflections unless there is a substantial elevation difference between the inside and outside water elevations. The vertical loads are those acting downward on horizontal or inclined surfaces of structures. When the buoyant forces of the flood waters exceed those of the building and its contents the structure will float away from its foundation. Although these types of forces are highly improbable the buoyant forces can cause a problem with saturated soils beneath the foundation which can lead to cracking and other foundation related problems.

Hydrodynamic loads are those that act on buildings or structures by the flow of flood water moving at moderate or high velocity around buildings or structures above ground level. These loads are carried from upstream flow and drag on the sides of the structure and create a negative suction pressure at the rear of the structure. The magnitude of the forces created on each side of the structure is directly related to the velocity of the flood waters and the shape of the structure. Just like hydrostatic loads the lateral loads on the building may be capable of causing walls to collapse but only in extreme cases.

Mitigation is necessary to reduce the damages that are associated with these flood loads. Engineers are brought in after the flood event has taken place to determine the extent of damage caused and determine the correct method of repair. Once the damages have been totaled the reconstruction phase can begin. This phase can also be thought of as the pre-disaster event for the next major storm that may hit the area. It is very important to use this opportunity to learn from past mistakes, correct them and put the community in a better position for future hazards. There are various methods used in the mitigation process. The following sections discuss methods associated with various soft and hard engineering practices.

5.7 Soft Engineering

Soft engineering is the practice of using ecological principles to reduce erosion and achieve stabilization of shorelines. This method works with the natural processes of the environment to reduce the effects of flooding while improving the habitat and saving money. Compared to hard engineering this method is a lot cheaper to implement and maintain over the long run and it tends to be more aesthetically pleasing. In addition to the lower economic costs soft engineering practices are better for the environment because they work with natural structures that mature over time to reduce the effects of flooding. River edges and shorelines are improved by using vegetation and other materials to soften the land-water interface. By doing so the ecological attributes of each are improved without compromising the engineered integrity. Afforestation is one of the most popular methods of soft engineering which entails creating a new forest where none has existed before. By planting trees in the upper region of the drainage basin they can catch and store the additional water from flooding which helps reduce the risk of the river becoming overwhelmed. Afforestation is not a guaranteed method to prevent flooding and it also takes a lot of time to see its benefits and large amounts of open land. The costs associated with this method include purchase of land in the flood basin.

5.8 Hard Engineering

Although soft engineering has many environmental and economic advantages local governments tend to favor hard engineering practices due to their often instant flood control and job creating potential. It often takes years for the effects of soft engineering practices to become effective within a community and there is never a solid guarantee that they will effectively reduce flooding. Hard engineering practices tend to alter the natural landscape in a controlled disruption manner by using man-made structures. Other practices of hard engineering change the landscape of rivers to make them suitable for flood control. The most commonly used hard engineering practices are dams and levees. With exception to the Great Wall of China, dams are the largest structures ever built around the world. They are used to generate power, prevent droughts and flooding just to name a few. The tremendous costs of constructing dams are hardly justifiable unless there is a major flooding problem within an area and a market to harvest hydropower. Depending on the type of dam, costs associated with new construction can exceed one billion dollars and the average costs overrun of dams is 56%. Since the 1980's new construction of dams has slowed down due to the fact that most of the appropriate locations for these structures have already been developed. The current problem facing the United States is that by the year 2020 85% of the dams will be more than 50 years old and in serious need of repair. If the funding is not set in place and repair targets are not met, this poses a major flooding issue for much of the United States. If some of the dams are not economically viable for repair they will be demolished. Due to the nature that dams completely change an ecosystem and disrupt the natural flow of rivers demolishing a structure this large will likely cause adverse effects to the surrounding region.

For the purposes of flood control there are more economically viable options in hard engineering tactics in the form of levees. A levee is a natural or artificial flood barrier used to protect communities from unwanted water. Also known as a dike or storm barrier, a levee can be found along lakes, rivers or by the sea. Natural levees are created when a river floods over the bank and deposits sediments, silts and other materials along the bank which causes it to be slightly elevated from the river bed and the floodplain. The banks form levees made of sediment, silt, and other materials pushed aside by flowing water. Levees are usually parallel to the way the river flows, so they can help divert the flow of the river. The main function of a levee is to control floodwaters. They can also be used to contain water flow, increase water speed and divert water from riverbeds for agricultural purposes and increase habitable land. Levees are generally made of earthen materials such as clay with some man-made levees being reinforced by rocks or concrete to prevent erosion. In many places where the flow of the river is strong, levees may also be made of blocks of wood, plastic or metal. Where the area beside a river or body of water is in particular danger, levees may even be reinforced by concrete. Levees can be permanent structures to protect inundation areas or emergency constructions built for a flood emergency. In emergency situations, levees can be made of sandbags. Levees can also be artificially created or reinforced. Artificial levees are usually built of piling soil, sand or rocks on a cleared level surface. Artificial levees need to be protected as they have to stand up to factors such as erosion.

There is no set height for levee systems as they are designed and modified for the area where it is constructed and the desired level of flood control. For this reason the price range varies depending on the materials used, the location and the purchase of private land. Typical earthen levee costs can range roughly $4,000 - $8,000 per linear foot. For coastal areas that require many miles of levee systems and reinforcement by stronger materials the projects are difficult to get funded. Although no one can argue about the benefits of flood control, it is often a hard task in convincing taxpayers and legislators to increase funding. But if a levee breaks, the consequences can be devastating.

A levee failure occurs when a break, also known as a breach occurs. Levees are generally added onto every couple of decades and are not given the same engineering precision as other hydraulic structures which leave much to be desired during emergency flood situations. This lack of care leads to failures within a levee system. It only takes one break to flood an entire area. There are many ways a levee can fail but most failures are attributed to one of the following as described in Table 2.

Table 2 Levee Failure Mechanisms [24]

Levee Failure Mechanisms	
Failure Mechanism	Description
Overtopping	Caused when the floodwaters exceed the lowest crest of the levee system and go over to the land side of the levee which cause flooding damages. This failure mechanism can lead to landside erosion or a complete breakdown of the system.
Seepage	Seepage occurs when water makes its way through the permeable soils used for the levee which leads to erosion from the inside out. This failure can be combated by allowing proper drainage within the system.
Erosion	During periods of high water, the waves generated by the wind will cause surface erosion of the water side of the levee.
Shear Failure (Slope Instability)	Occurs when large slabs of the levee slide during or immediately after periods of high water. If the level of water stays high for many days the surface of the levee will become saturated leading to a loss of surface cohesion and the surface layer sliding down the levee.
Piping and Under-Seepage	During a flood the water column exerts a weight upon the levee sides and adjacent floodplain that pushes water into any holes or cracks in the levee structure. If the water reaches the landside of the levee it will flow from the levee and carry levee material with it, resulting in the levee eroding from the inside out. Flood water flows through permeable soil material that underlies the levee. The water arises to the surface near the landside base of the levee in what is termed a ”boil”. Again, the water is flowing, so it is carrying levee foundation material out from under the levee.
Hydrostatic Pressure	Sideways hydrostatic pressure, which essentially “pushes over” the levee from the high water side. This usually means that the levee is not massive enough.

Source: Information Adapted from RiverPartners.org

Other failure mechanisms of levee systems can be attributed to things such as poor maintenance and lack of funding. Due to their fundamental purpose levees are systems that are rarely used because of the rarity of flooding in certain areas but they must be ready to protect in emergency situations. For this reason local governments may not feel the urgency to fund maintenance and repair projects until it is absolutely necessary. That is why it is important to incorporate the natural aspects of soft engineering into hard engineering practices to make them more sustainable.

The aftermath of major storm surges have civil engineers from the United States looking to the Dutch to improve current conditions. The Netherlands are surrounded by water on three sides with more than half of the country below sea level. A storm in 1953 that broke 500 levees and killed 2,000 people was the wake-up call the Netherlands needed. Since then they have installed a network of dams, canal pumps, levees, and storm surge barriers to keep the water of the North Sea out. It is arguably the best protected low-land area in the world using 10,000 year design flood elevations. The levees were replaced with storm barriers. As the waters rise during a storm event, computers close the walls and fill the tanks along the barrier causing the walls to sink to the bottom keeping the water away from the land. They have incorporated engineering practices that include absorbing water into marsh plains, fiber optics and electronic sensors in their monitoring systems and projections 200 years into the future based on current climate control patterns. Perhaps their most ambitious project was the construction of the Oosterschelde barrier. This barrier has several layers which include a beam under which water flows when the gates are open, a steel gate that is lowered when the sea level reaches danger height, a 5-million ton stone block beam steadies giant piers which have holes that fill with sand and a synthetic mattress filled with sand and gravel to strengthen the nearby sea floor [25]. The system built by the Dutch is a marvel of hydraulic engineering and a testament of the determination to keep their constituents safe. A key factor to point out is their government and citizens are willing to pay to keep their country safe. They are more than happy to pay the taxes to keep their system up to date because they look at it as their survival method.

There is no one method to solve the issues surrounding emergency preparedness. Natural disasters are only increasingly in magnitude and frequency and until the nation as a whole makes a decision to increase protection there will always be vulnerable populations and infrastructure systems. As history tells us the economic vitality of the nation is dependent upon the continuity of services provided by infrastructure, a vibrant workforce and regional economies; all of which are threatened by the impacts of natural disasters. There will almost certainly never come a time when disasters can be completely coped with but employing a continuous cycle of mitigation, learning from past mistakes and designing more sustainable protection will lead to a prepared future. Chapter 6 provides background on urban floods, discusses fault tree analysis, urbanization and climate change and the role they both play in the increase in urban flooding. A fault tree analysis is performed to determine the root causes of urban flooding.

CHAPTER 6

FAULT TREE, URBANIZATION & URBAN FLOODS

6.1 Flooding & Urban Floods

Water is the elixir of life. Since the beginning of mankind humans have found it to be desirable to live close to bodies of water. Water provides a means to tend to agriculture, waterways for transportation, energy sources, consumption, recreation activities amongst its many other uses. The disadvantage of living close to water is that the levels often change and high amounts of water flowing often leads to flooding. Flooding is a natural phenomenon that occurs when the quantity of water in a stream, river or lake exceeds the capacity and overflows to the adjacent land. It is one of the most common and costly types of natural disasters. The following sections will explain the hydrology of flooding as well as the frequency of certain types of floods.

Over the last several decades the United States as well as other countries around the world has become increasingly more urbanized. For the first time in history over half of the world's population lives in cities and towns. Urbanization brings forth economic growth, city expansion and higher population density rates in once rural areas. This can lead to a number of positive effects improving job markets, education, transportation as well as many other social and economic programs. Of all of the positive effects of urban expansion it can also have negative effects on the environment. Because of the effects of urbanization new development gives rise to the concrete world of buildings, roads, and infrastructure all made of impermeable materials. This disrupts the natural drainage area in a floodplain which leads to a specific type of flooding called urban flooding. Although several factors attribute to urban flooding such as snowmelt, river, coastal, and flash floods this type is specific due to a lack of drainage in an urban area. Human factors are the basis of urban flooding. As urbanization grows the natural landscape of a floodplain is replaced by new development. During rainfall water is absorbed into the soil as groundwater and is slowly discharged into streams over time. In natural situations the water is absorbed through vegetation, grasslands and depressions in the ground. Impermeable surfaces reduce the amount of surface area for infiltration of the surface water to groundwater to occur. This causes large volumes of overland flow water to move quickly into a stream or river. In an urban environment water infrastructure such as storm sewers and drainage systems must carry this water to its proper destination. When the surface water does not have a way to the soil the storm systems become overwhelmed and increase the runoff to nearby streams. Once water enters a drainage network, it flows faster than it would under normal circumstances leading to flooding conditions that are occurring more frequently and severely in nature.

Because urban areas have higher populations and economic activity the amount of damage caused by floods can be very severe. Roads become inundated with water and people cannot travel to work and other destinations, business interruptions occur, damage to buildings and residential areas all add up to large economic losses. Many of these new developments are built in areas of the floodplain prone to extensive flooding. There are laws and regulations to prevent such development but they are often overlooked for monetary or political reasons leading to an increased risk for the inhabitants. According to FEMA, 20-25% of economic damage caused by flooding occurs in areas not designated as being in a floodplain. A sound understanding of the probability of occurrence is an essential step in dealing with flood risk.

When engineers are designing structures they are concerned with floods in terms of their probability of exceedance. The probability of exceedance describes the likelihood of a specified flow rate (or volume of water with specified duration) being exceeded in a given year. [26] Scientists and engineers use statistical probability to put a context to floods and their occurrence. If the probability of a particular flood magnitude being equaled or exceeded is known, then risk can be assessed [27]. It is important to note that the return period varies by catchment area, width of the floodplain, climate of the region and other factors. The return period is explained as the annual exceedance probability later in the section. The most common design flood is the 100 year flood also known as the base flood. It is used as the basis for the National Flood Insurance Program (NFIP) for delineation of Special Flood Hazard Areas on Digitized Flood Insurance Rate Maps as described in the next section. This is a flood event that has a 1% probability of occurring in a given year meaning it has a return rate of 100 years. Figure 9 shows an illustration of a typical 100 year floodplain.

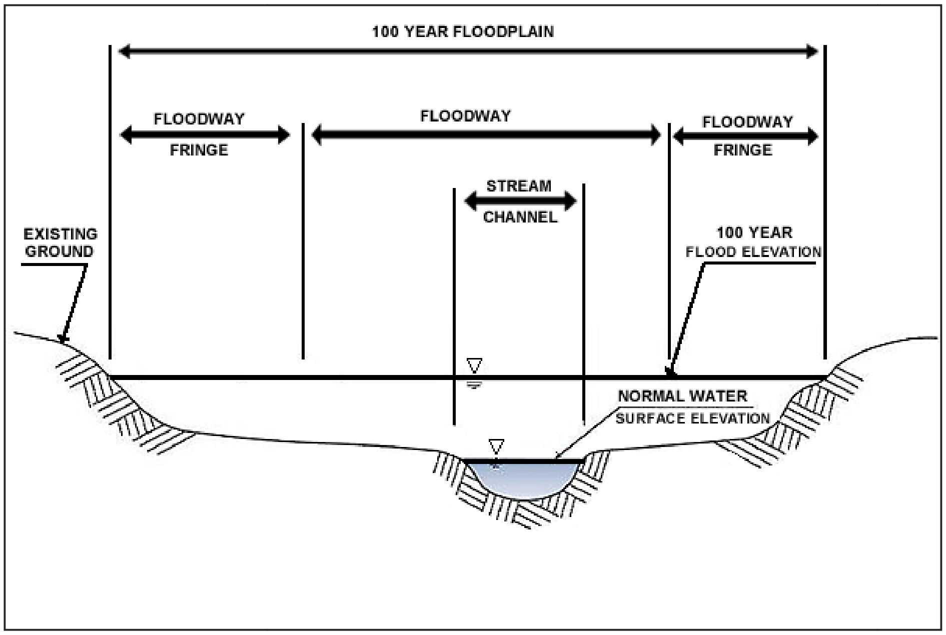


Figure 9 - 100 Year Floodplain [28]

`It is understood that this does not mean that this event will occur every 100 years rather it has the probability of occurrence depending on the available data. This term is used to simplify the definition of the flood. For example, when constructing a home in a 100 year flood plain the developers want to know the probability of a 100 year flood event occurring over a period of 30 years. This is known as the design risk or exceedance probability, P_e, which can be calculated using Equation 2.

Equation 2 - Exceedance Probability

– (2)

Where P_e is the probability of exceedance, R is the design risk, n is the number of years and T is the return period. So by this method the probability of a 100 year event occurring in a 30 year period is 26%.

There are three different ways to describe the annual exceedance probability as shown in Table 3.

Table 3 Annual Exceedance Probability

AEP (as percent)	AEP (as probability)	Annual Recurrence Interval (ARI)
50%	0.50	2-year
20%	0.20	5-year
10%	0.10	10-year
4%	0.04	25-year
2%	0.02	50-year
1%	0.01	100-year
0.2%	0.002	500-year

6.2 FEMA Special Flood Hazard Area

A special flood hazard area (SFHA) is the land areas that are high risk for flooding and require mandatory purchase of flood insurance. The SFHA includes Zones A, AO, AH, A1-30, AE, A99, AR, AR/A1-30, AR/AE, AR/AO, AR/AH, AR/A, B, C, D, X, VO, V1-30, VE, and V and are described in Tables 4 through 7.

Table 4 FEMA Moderate to Low Risk Areas [29]

ZONE	DESCRIPTION
B and X (shaded)	Area of moderate flood hazard, usually the area between the limits of the 100-year and 500-year floods. Are also used to designate base floodplains of lesser hazards, such as areas protected by levees from 100-year flood, or shallow flooding areas with average depths of less than one foot or drainage areas less than 1 square mile.
C and X (unshaded)	Area of minimal flood hazard, usually depicted on Flood insurance rate maps (FIRMs) as above the 500-year flood level.

Table 5 FEMA High Risk Areas [29]

ZONE	DESCRIPTION
A	Areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage. Because detailed analyses are not performed for such areas; no depths or base flood elevations are shown within these zones.
AE	The base floodplain where base flood elevations are provided. AE Zones are now used on new format FIRMs instead of A1-A30 Zones.
A1-30	These are known as numbered A Zones (e.g., A7 or A14). This is the base floodplain where the FIRM shows a Base flood elevation (BFE) (old format).
AH	Areas with a 1% annual chance of shallow flooding, usually in the form of a pond, with an average depth ranging from 1 to 3 feet. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Base flood elevations derived from detailed analyses are shown at selected intervals within these zones.
AO	River or stream flood hazard areas, and areas with a 1% or greater chance of shallow flooding each year, usually in the form of sheet flow, with an average depth ranging from 1 to 3 feet. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Average flood depths derived from detailed analyses are shown within these zones.
AR	Areas with a temporarily increased flood risk due to the building or restoration of a flood control system (such as a levee or a dam). Mandatory flood insurance purchase requirements will apply, but rates will not exceed the rates for unnumbered A zones if the structure is built or restored in compliance with Zone AR floodplain management regulations.
A99	Areas with a 1% annual chance of flooding that will be protected by a Federal flood control system where construction has reached specified legal requirements. No depths or base flood elevations are shown within these zones.

Table 6 FEMA High Risk Coastal Areas [29]

ZONE	DESCRIPTION
V	Coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm waves. These areas have a 26% chance of flooding over the life of a 30-year mortgage. No base flood elevations are shown within these zones.
VE, V1 - 30	Coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm waves. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Base flood elevations derived from detailed analyses are shown at selected intervals within these zones.

Table 7 FEMA Undetermined Risk Areas [29]

ZONE	DESCRIPTION
D	Areas with possible but undetermined flood hazards. No flood hazard analysis has been conducted. Flood insurance rates are commensurate with the uncertainty of the flood risk.

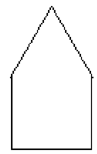
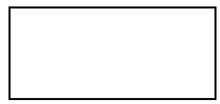
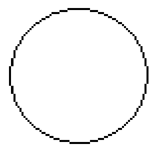
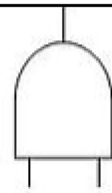
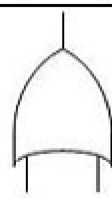
Once the probability of exceedance is determined it allows decision makers to interpolate and extrapolate historical events from that particular region to determine the effects of future hazards. To establish this, an assumption has to be made regarding the distribution of flood frequency. It is well known that flood frequency is probability based because 100 year floods do not occur just once in a hundred years. Sometimes these events happen rarely and other times they can occur multiple years in a row. The effects of climate change are becoming increasingly prevalent and these super storms and hazardous events are happening more and more frequently.

There is a direct correlation between the effects of urbanization and climate change. As cities become industrialized they output the majority of anthropogenic carbon dioxide emissions into the atmosphere. Along with emissions, urban areas create urban heat islands through the use of heat storing structures and impermeable surfaces that retain heat. Rapid population growth in these areas place a strain on its limited resources and already crumbling public infrastructure making them least equipped to deal with climate change and other economic and social struggles. Cities are driving climate change and are the most vulnerable to its effects. Metropolitan areas are susceptible to the rising sea level, extreme unpredictable weather conditions and rising temperatures. Climate change not only affect coastal cities but inland communities are faced with unstable hillsides and limited resources. Another troubling fact with urbanization is that over the course of the 21st century the rate of industrialization is higher in less developed nations. This means that when these more frequent and destructive storms take place these countries will have a lower capacity to deal with its effects and it will be up to more developed nations to provide aid. Social and economic vitality is dependent upon the investment in climate proof and resistant infrastructure investment. With more at stake in urban areas there is also a greater chance of innovative ideas to come out of these areas to combat the changes that are taking place. Although it is important for local officials to come up with mitigation techniques, there should be a call to higher offices for legislative measures. Vulnerable communities are only as vulnerable as they are prepared.

Urban flooding is a dangerous hazard that is increasingly causing more severe damage to metropolitan areas around the world. It is very difficult to determine all of the sources of urban flooding but it is important to try to find the root of the issue. Fault tree analysis (FTA) is a deductive analysis method that resolves an undesired event into its causes. This system is used a lot in many fields but more specifically in reliability engineering to identify the best ways to reduce risk or to determine event rates of a safety accident or a particular system level failure. It helps analyze a problem and stimulates critical thinking to break down all of the components of failure within a system and improves the overall understanding of the system. They are best utilized when an undesired event leads to a large perceived threat of loss. The undesired event must be already identified in order to begin the process. The analysis starts with a general conclusion in the form of an undesired top event. From there it is necessary to try and understand a system and use technical information to determine possible causes for the undesired event. For each fault it is necessary to list all of the possible causes leading to the top event. The objective is to work toward a root cause for the top event. Once there is a firm understanding of the system the next step is to construct the tree. Putting the information into a logical format on each level helps the user see if they really grasp the understanding of the system. After the tree is constructed in a desirable manner the next step is validation and evaluation. This can be done either quantitatively or qualitatively. This is where all possible hazards that affect the main event directly or indirectly are listed. The final step in FTA is to interpret the results. What is the root cause that leads up to the main event and how can this be prevented in the future? If there is no single incident that leads to the main event a better understanding of the system will help risk managers determine proper means of mitigation.

FTA depicts the events that lead up to an undesired event of hazard. There are symbols used to depict the relationship between each level. These symbols are broken into two categories; event symbols and gate symbols. Event symbols are used for the initiating events and the intermediate events that follow and ultimately the basic or primary events. The initiating and basic events are known as the cause events and the intermediate are known as the fault events. The gate symbols in FTA are the logic symbols that interconnect the events. The two most commonly used gate symbols in a classical FTA are AND and OR gates. AND gates are used when all components must fail in order for the system to fail. OR gates are used if any of the events fail independently. Table 8 shows the diagram for each event and gate symbols along with their descriptions.

Table 8 FTA Symbols

Symbol Type	Symbol	Description
Initiating Event		The event being studied in the FTA.
Intermediate Event		Used between initiating and basic events. Need further elaboration.
Basic Event		Error or failure to a system component. Primary cause with no further investigation.
AND Gate		Output event occurs only if all input events occur.
OR Gate		The output event occurs if at least one input event occurs.

The FTA conducted for this study will be centered on urban flooding so the initiating event for the fault tree is an urban flood. As discussed previously the main causes of urban flooding relate to a lack of drainage within the system. There are five intermediate events below the initiating event that will be analyzed. These events include inflow route interruption, combined sewer overflow, separate sewer overflow, levee failure and sewer flooding. Each of these events have several intermediate and basic events or causes that lead to their failure. The full diagram of the FTA is shown in Figures 10 & 11.

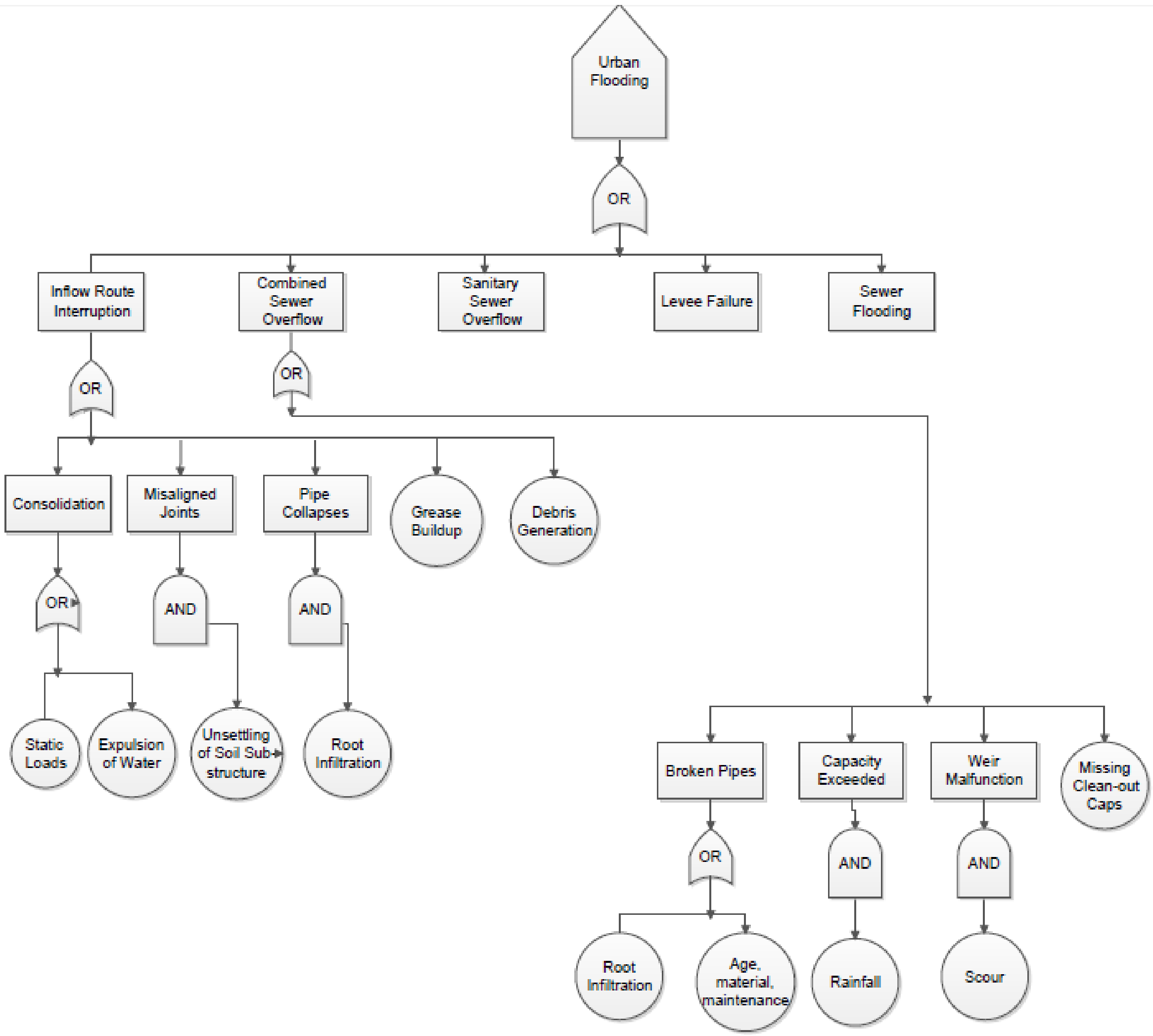


Figure 10 - FTA for Urban Flooding

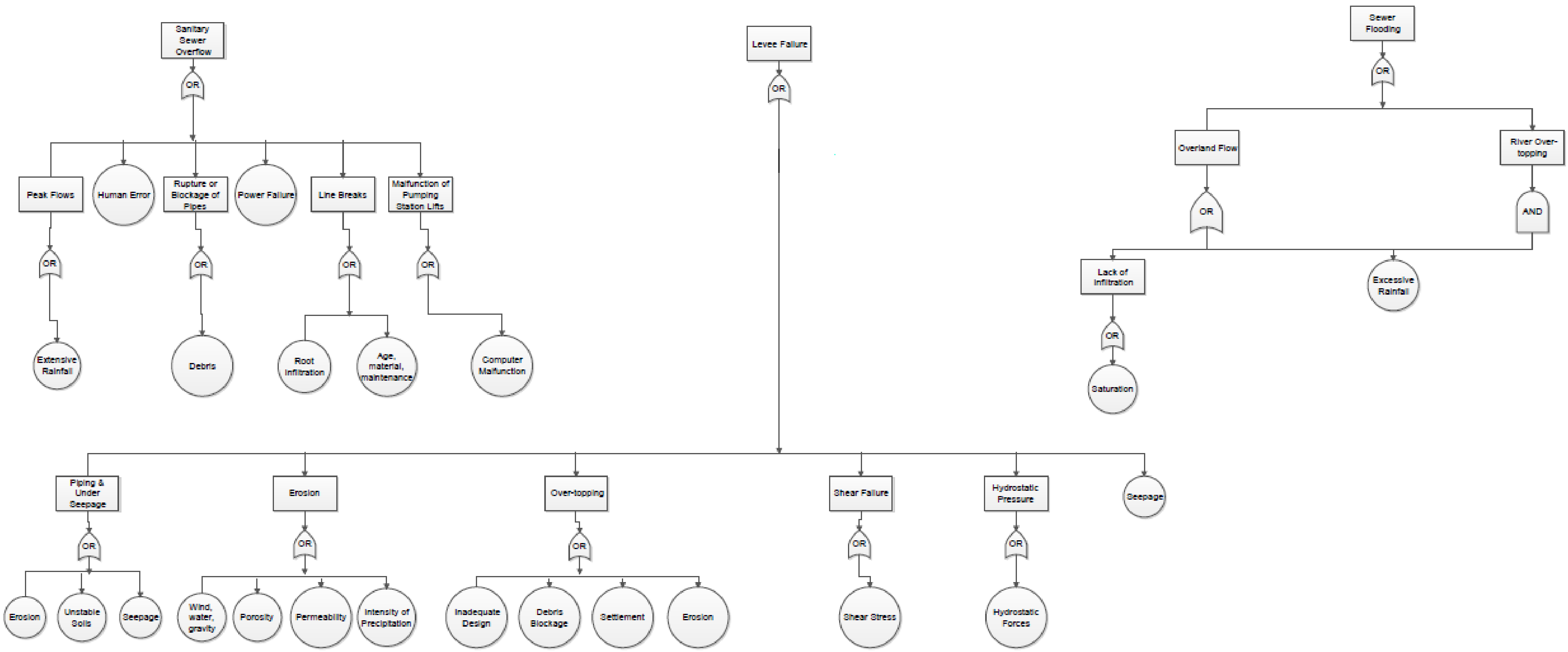


Figure 11 - FTA for Urban Flooding (Continued)

Although each of the events within the FTA are different the basic events that lead to the failure of the urban flood system are similar in nature. Environmental factors such as seepage, erosion, extensive rainfall, settlement and scour play a role in almost every event that leads to failure. When the landscape changes from permeable soils to impermeable water has to find a new route to the river system and it often flows faster through man-made reservoir systems and the underground pipe network. Extensive rainfall during a disaster event overwhelms these systems and leads to failure. It can be stated that human error is the main source of system failure in urban flood protection. Inadequate design and failure to maintain and improve the system leads to flooding crises. Water infrastructure networks in the United States were built shortly after WWII and the cost of not replacing these systems is showing. There are an approximate 240,000 water main breaks every year along with 75,000 sanitary sewer overflows. Tree roots are infiltrating the systems causing line breaks and out of date materials are deteriorating causing pipes to rupture. The ASCE 2013 infrastructure report estimates that a total investment of $298 billion over the next twenty years is necessary to improve current conditions with pipe networks needing the largest capital investment. The National Committee on Levee Safety estimates that approximately $100 million is needed for investment as well as the establishment of a national safety standard for construction. There is currently no precedence set for safety on a national level as far as levee construction is concerned. Due to the number of individuals and critical infrastructure that levees protect there is a need for legislation to control design and construction. The National Levee Safety Act of 2007 developed recommendations for plans regarding a national program but there has not been much progress made toward implementing a system. Determining the root causes related to urban floods is the first step in understanding how to alleviate damages and reduce risk. The key issue relating to disaster mitigation and reduction is the lack of funding given to the programs implemented to reduce damages. It is important to realize the economic impacts of such disasters to open the minds of those in charge as well as vulnerable populations to get a conversation started regarding mitigation. Chapter 7 discusses the economic impacts of disasters.

CHAPTER 7

ECONOMIC IMPACTS

7.1 Introduction

The case study presented in this thesis will be based on a flood event and how this event can affect the surrounding region. A lot of times when a public project is presented to a committee for approval it has to be justified economically using a benefit cost analysis. This process is used for a number of reasons because public projects are intended to be nonprofit and there is no standard used as a measure of financial effectiveness and the monetary impact of many benefits of public sector projects is difficult to quantify. As the name implies, the benefit cost ratio involves the calculation of a ratio of benefits to costs. All of the benefits and costs associated with a project are quantified and used in the conventional or modified equations shown in Equation 3:

Conventional B-C ratio with PW:

Equation 3 - Conventional Benefit Cost Ratio

$$B - C = \frac{PW(benefits\ of\ the\ proposed\ project)}{PW(total\ costs\ of\ the\ proposed\ project)} = \frac{PW(B)}{I + PW(O\&M)} \tag{3}$$

Where:

- PW(*) = present worth of (*)
- B = benefits of the proposed project

- I = initial investment in the proposed project
- O&M = operating and maintenance costs of the proposed project

Modified B-C ration with PW:

Equation 4 - Modified Benefit Cost Ratio

$$B - C = \frac{PW(B) - PW(O\&M)}{I} \tag{4}$$

These methods are used as a way to make certain that the allocation of public funding is being used effectively. With that being said, projects associated with the prevention of unforeseen events are even more difficult to justify because these are situations that may or may not occur. For example, the basis of a 100 year flood event, or base flood, is that its occurrence only has a 1% chance per year to transpire. If the costs of a project to replace the rip-rap on the bank of a flood prone river exceeds historical flood insurance data for that area the project will not be accepted. Many public leaders use the "wait and see" approach to disaster prevention and as seen with recent storms such as hurricane Katrina and Sandy this approach leaves communities devastated and surrounding regions are left feeling the effect as well. The saved dollars associated with disasters must be applied to the benefit of the project for validation. As is the case with many public projects costs associated are both direct and indirect. It is no longer feasible to look at the direct costs and dismiss the validity of a project because many times the consequence of not acting on foreseen events outweighs the price.

As presented in chapter 3 quantifiable costs for disasters are broken into economic, social and environmental pacts. Many times the focus of disaster prevention is focused on one particular area but it is important to look at how the aftermath affects the surrounding areas and economies as well. Many projects are overseen by economists that use historical data as well as established rates to take all factors into account and answer certain questions. If a flood hits an area and washes out a railway, what costs are associated with repairing the rail as well as lost business during repair? If the interstate has to be shut down, how does it affect commercial as well as personal travel? What is the lost revenue from potential airport flooding? Answering all of these questions and more help put public projects into perspective and validate funding.

The damages that are incurred during and following a natural disaster have a significant effect on the regional economy. In some cases, depending on the geographical location of the disaster area and the severity of the event, the economic effects can be felt throughout the nation and on a global scale. When Hurricane Katrina hit the Gulf Coast in 2005, the price of oil rose because of the damages incurred by the storm and the Department of Energy was forced to tap into emergency oil reserves. Determining the economic impacts from natural disasters is a fairly imprecise science because of the complex interdependencies of all of the sectors affected, the magnitude of the disaster and the differences in disaster type. In the case of a tornado, some areas can be incalculably devastated while others in the proximity are left completely unscathed. Another important factor that plays into the severity of the disaster is the population of the area where the event takes place. Obviously a more densely populated area will cause greater destruction and loss of life than a rural area. After the event has occurred insurance companies, the public and private sector and various relief organizations must come together and assess the damage to prepare for reconstruction and rehabilitation. An assortment of methodologies is used to evaluate damages but they are often inconsistent and the findings lack focus. Also different models use different assumptions which make it difficult to relate them to each other. A framework for the economic evaluation of natural disasters has to come from a multi-discipline effort to reduce damages and improve resilience. The first step in economic evaluation is to determine the kinds of losses and how to calculate each.

7.2 Losses

Losses are those economic values attached to items that are damaged during a natural disaster event. A disaster, from an economic perspective, can be defined as a natural event that causes a perturbation to the functioning of the economic system, with a significant negative impact on assets, production factors, output, employment or consumption [30]. Determining the losses associated with said disasters can become very tricky. Losses calculated abruptly thereafter tend to be an overestimation of the actual monetary values. This can be an effect of looking at a disaster area for the first time and being overwhelmed without actually evaluating the damages. Unfortunately, losses will never be estimated with full certainty but classifying them according to their impact on society and the economy is a good way to start the evaluation.

7.3 Direct Losses

Direct losses are those associated with the immediate outcome of a natural disaster. These losses are mostly related to the physical damage that occurs during and following an event and the loss of the asset value. Direct losses are broken up into two categories or types. Primary direct losses are those resulting from the immediate destruction of buildings, lifeline systems and infrastructure caused by an event such as wind damage from a hurricane. Secondary direct losses are those additional impacts resulting from follow-up physical destruction such as accompanying water damage to structures from a flood event. Direct market losses are those that are associated with damage to manufactured goods whose values can be easily determined.

Perhaps the most important direct loss from natural disasters occurs in the loss of lives. There is no way to place a value on a human life so this loss along with health and mental issues that arise from disasters are direct non-market losses.

7.4 Indirect Losses

Indirect losses are those associated with the residual effects of a disaster event. These losses can be related to decline in sales, wages, and profits of businesses, disrupted transportation networks and loss of local tax revenue. Business disruption is a major problem in the aftermath of a storm. When communications break down and disjointed transportation networks have yet to be repaired local businesses shut down causing a rise in unemployment and a loss in revenue. There are very few ways to determine the indirect losses associated with lost business.

7.5 Gains

Although it is difficult to imagine a positive arising from a natural disaster there can be such in economic terms. Gains are encountered in the recovery and reconstruction period after the disaster has taken place. It can be difficult for businesses that provide commodities and time related goods and services to recover losses from lost production but industries such as construction often see large gains post disaster.

7.6 Stages of Natural Disaster Management

Natural disaster management is a field of study that is being given a resurrection in recent years due to an increase in large scale natural disasters brought about by climate change. There are many different schools of thought in terms of dealing with the effects of natural disasters and until they are reviewed at all levels, global, national, regional, state and local, problems will continue to arise and communities will remain vulnerable. Although there can be no go-to plan for disaster management because no two disasters are alike a framework for creating disaster awareness and preparedness is needed.

7.7 Awareness

The major reason people are caught off guard or not prepared for the impacts of a natural disaster is their lack of awareness. Individuals are generally miss-informed or completely oblivious to the warnings presented to them. This underestimation of the oncoming event leads to un-preparedness and numbness within a region. Flow of emergency goods, communications and rescue becomes nearly impossible which leads to an increase in loss of life, public and private property damage as well as slow recovery action. Warnings must be given in a timely manner allowing people time to evacuate if necessary and they must be clear, concise, and simple so that they are easily and readily understood by the surrounding population. The early response warning system must be a top down warning process starting with the data collected by the National Weather Service (NWS) being updated and presented in real time to local news, radio, public servants and ultimately the exposed communities. Questions must be answered regarding early warning and response systems in order to improve the process. What is the hazard in question and how will this hazard be identified and evaluated? What are the current methods being implemented? How do you measure the amount of time necessary for the pertinent hazard type?

The economic vitality of regions experiencing frequent natural disasters is dependent on the efforts used to reduce the impacts of these events. The amount of money necessary for mitigation is completely contingent on the individual needs of the community being explored. Examination of needs can be determined by performing a case study. The next chapter presents the case developed in this thesis to establish mitigation efforts.

CHAPTER 8

CASE STUDY

8.1 Case Study Overview

To test the effectiveness of the framework presented in this thesis a theoretical storm surge is explored in the study region to determine both the damages caused and ways to mitigate the situation. Flood simulations based on the 100, 500, and 1000 year return periods are explored using HAZUS-MH and the riverine hazard scenario function. Based on the estimates established from the program a benefit cost analysis will be used to determine the validity of the mitigation measures. Public engineering projects must be economically justified in order to come to fruition and the first step is to determine the hazard.

8.2 General Description of the Region

The primary location for this study is Hamilton County, TN and the surrounding region. Hamilton County is located in Southeastern Tennessee and has a total area of 576 square miles. Of this total area 542 square miles is land and 33 square miles is made up of water. It is the fourth largest county in Tennessee and as of the 2000 Census, there were 307, 896 people, 124,444 households and 83,759 families residing in the county. The population density was 568 people per square mile. The data used for this analysis is based off of the 2000 Census to make it compatible with the HAZUS-MH format.

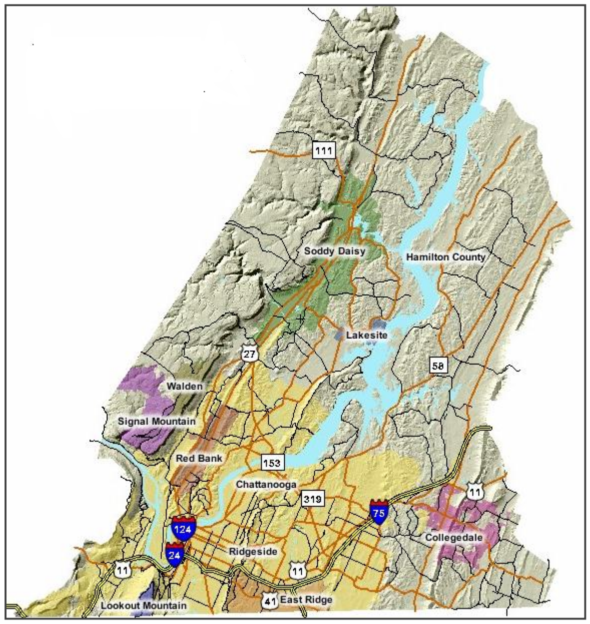


Figure 12 - Hamilton County Map [31]

Hamilton County includes two distinct geographic areas, the Cumberland Plateau and Mountains and the Southern Appalachian Ridges and Valleys [32]. Soils in both of these areas formed under forest vegetation and are dominantly light in color. The soils in the Cumberland Plateau and Mountains are moderately deep over sandstone and shale bedrock. The soils in Southern Appalachian Ridges and Valley are moderately deep or deep over limestone and shale bedrock [33]. Hamilton County is divided from north to south by the Tennessee River and the Chickamauga and Nickajack Reservoirs.

Hamilton County has a moderate climate with cool winters and hot summers. Abundant sunshine and mild temperatures and rainfall characterize the fall and spring seasons. The average temperature for January is 39.4°F, for July, 79.6°F and an annual average of 60.5°F. The average annual precipitation is 54.5 inches with March, July and December typically being the wettest months and September through November being the driest months. Figure 13 shows the average monthly precipitation.

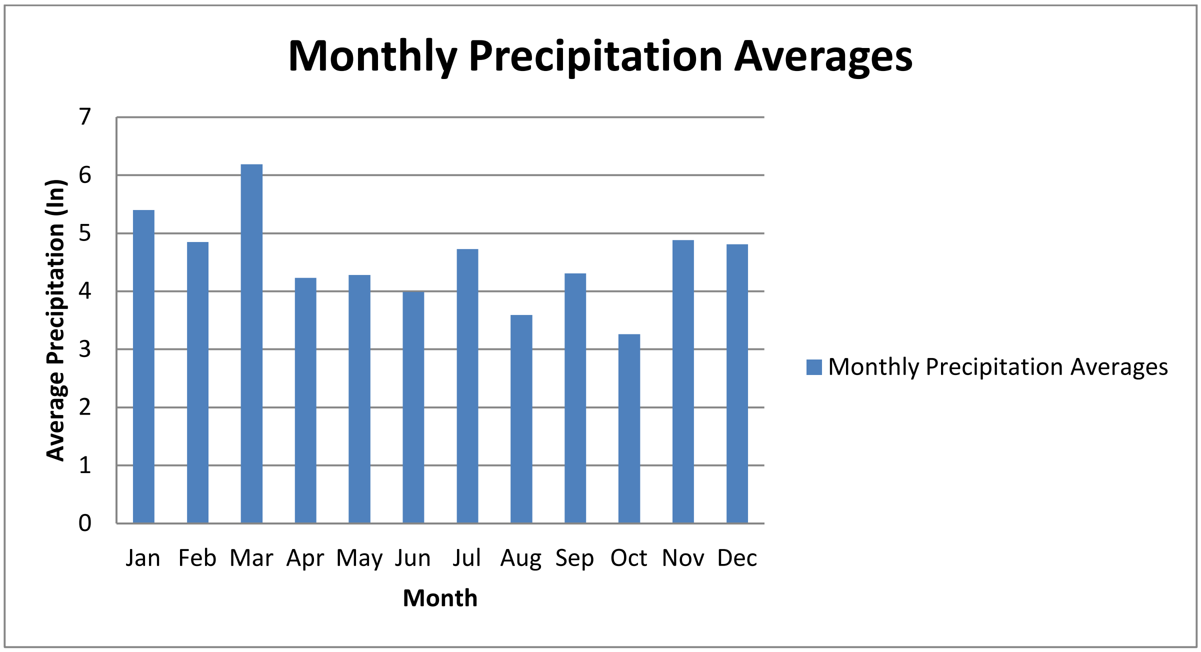


Figure 13 - Monthly Precipitation Averages [34]

The average annual runoff in the region is about 23 inches, or 44 percent of the average rainfall. The monthly average runoff varies from almost four inches in March to less than one inch in August, September and October.

Generally, runoff is heaviest in winter and early spring when vegetation is dormant and the ground is saturated. As a result, heavy storms moving across the Tennessee Valley region between December and early May become potential causes of major floods [35].

Hamilton County was chosen for this thesis because according to the Tennessee Valley Authority (TVA) the Chattanooga metropolitan area is the most flood prone area in the state of Tennessee because of its location. The city sits in a low plain just above where the Tennessee River passes through the Cumberland Mountains. The TVA flood control website explains the Hamilton County flood area as follows:

> Before TVA started flood control operations, major storms occurring in the 21,400 square mile drainage area above Chattanooga would cause the Tennessee River to rise rapidly. When it reached Chattanooga, the swollen river would attempt to carry more water through the narrow mountain gorge below the city that the river channel would allow. The excess water that could not flow immediately through the mountains would naturally back up into the city, flooding it on average at least once a year [36].

In order to capture the geographic influences of this area, surrounding counties were included in this study. The additional counties included were Marion and Bradley Counties in Tennessee and Walker, Dade, and Catoosa Counties in Northern Georgia. The geographical size of the study region is 2,152 square miles and contains 14,577 census blocks. Figure 10 below shows a view of the study region. The region contains over 219 thousand households and has a total population of 553,126 people. There are an estimated 243,876 buildings in the region with a total building replacement value (excluding contents) of 38,404 million dollars (2006 dollars). Approximately 91.74% of the buildings (and 70.45% of the building value) are associated with residential housing.

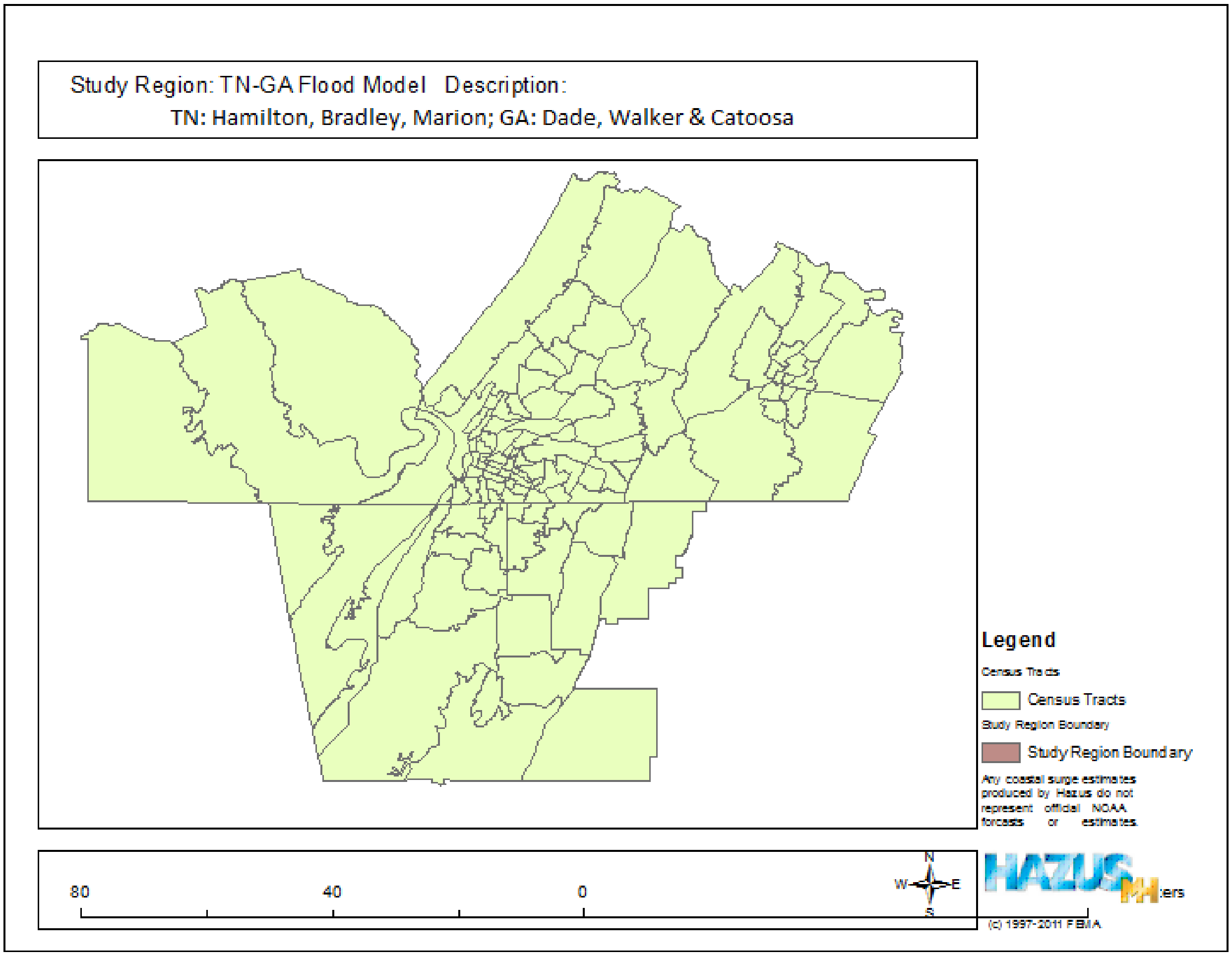


Figure 14 - Study Region for Flood Model

8.3 Region Data

Table 9 Regional Population and Building Value Data

Regional Population and Building Value Data				
		Building Value (thousands of dollars)		
	Population	Residential	Non-Residential	Total
Georgia				
Walker	61.053	2,415,850	793,796	3,209,646
Dade	15,154	580,225	282,167	862,392
Catoosa	53,282	2,249,795	688,974	2,938,769
Total	129,489	5,245,870	1,764,937	7,010,807
Tennessee				
Bradley	87,965	4,040,217	1,512,411	5,552,628
Hamilton	307,896	16,696,018	7,682,541	24,378,559
Marion	27,776	1,072,362	389,914	1,462,276
Total	423,637	21,808,597	9,584,866	31,393,463
Total Study Region	553,126	27,054,467	11,349,803	38,404,270

Table 10 presents the relative distribution of the value with respect to the general occupancies by study region.

Table 10 Building Exposure by Occupancy Type for the Study Region

Building Exposure by Occupancy Type for the Study Region		
Occupancy	Exposure ($1000)	Percent of Total
Residential	27,054,467	70.4%
Commercial	7,131,701	18.6%
Industrial	2.509,487	6.5%
Agricultural	90,175	0.2%
Religion	1,051,191	2.7%
Government	246,339	0.6%
Education	320,910	0.8%
Total	38,404,270	100.00%

A well protected transportation system in the event of a natural disaster will allow for proper evacuation and efficient emergency response. Table 11 shows the total transportation exposure for the study region. The three major types of transportation in this area are highway segments, highway bridges and railway segments. HAZUS-MH does not account for the damage to highway segments but there are other ways to find estimates relating to the damage.

Table 11 Transportation Exposure for the Study Region

Transportation Exposure for the Study Region		
Transportation Type	Exposure ($1000)	Percent of Total
Highway Tunnel	$12,864	0.14%
Highway Segment	$7,649,361	83.55%
Highway Bridge	$802,290	8.76%
Railway Segment	$541,034	5.91%
Railway Bridge	$3,424	0.04%
Railway Facility	$39,945	0.44%
Bus Facility	$5,755	0.06%
Port Facility	$57,913	0.63%
Airport Facility	$42,604	0.47%
Total	$9,155,190	100.00%

To capture the geographic nature of the region, a DEM was imported from the USGS into the program. This allows ArcMAP to represent the terrain surface of the region and calculate the depth of the river bed to perform hydrologic analysis. The DEM imported into the program is slightly larger than the study area to account for the geographic effect on the hydrology. Figure 15 shows a diagram of the imported DEM.

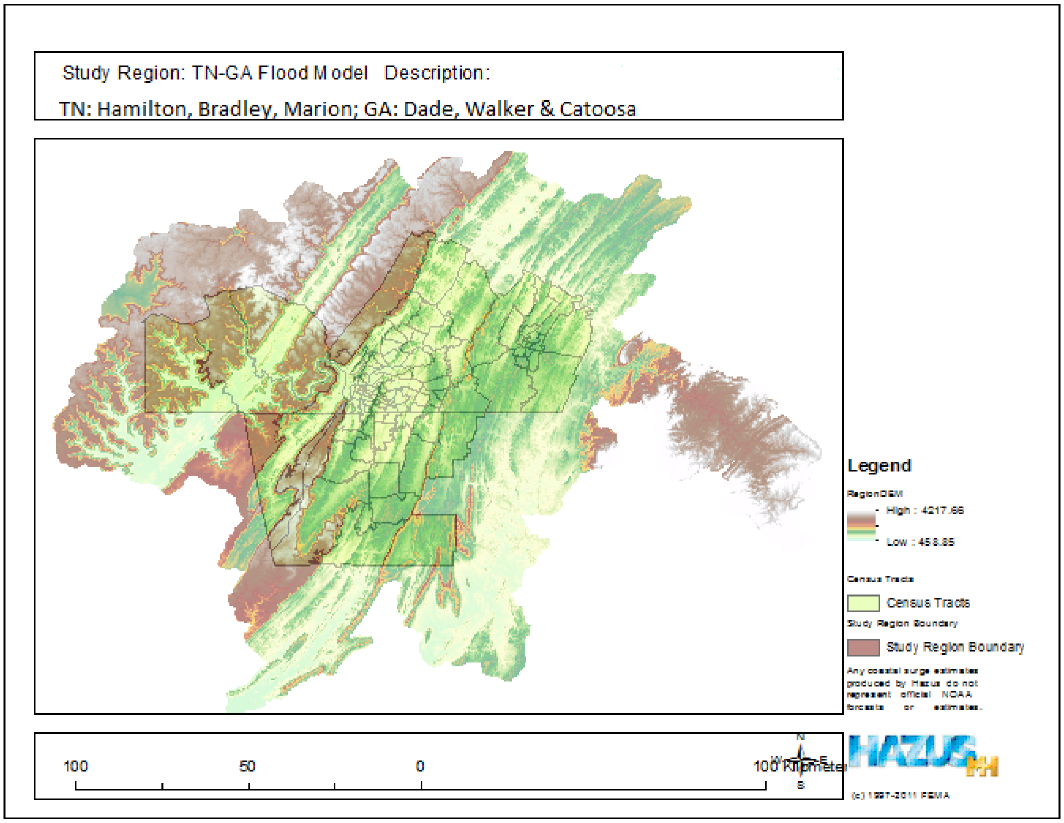


Figure 15 - Regional DEM for Study Area

Once the DEM is imported into the program the analysis can begin. The first thing that needs to be done is to determine the type of flood that will be analyzed. The options are coastal and riverine analysis. Since Tennessee is not a coastal area the obvious choice is a riverine analysis. The second step in the analysis is to develop the stream network of the study area. This is completed by selecting the minimum drainage area that each reach has within the floodplain. Obviously the smaller the drainage area, the larger the amount of reaches found within the program. The drainage area chosen for the analysis was 4.0 square miles. Smaller reaches would not contribute a great deal to a larger return year flood analysis. The next step is hydrologic and hydraulic analysis. This is used to determine the number of reaches and the depth of the reaches within the floodplain. The resulting map of the study region river reaches is shown in Figure 16.

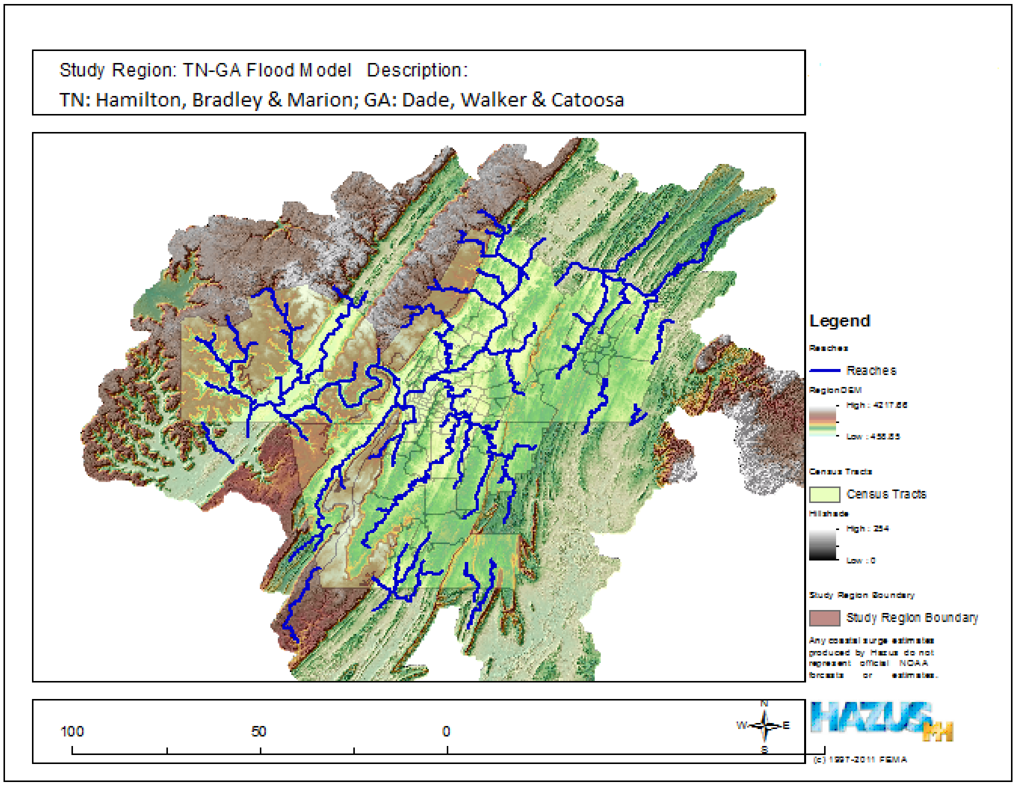


Figure 16 - Study Area Reaches

The next step in the analysis is to delineate the floodplain. This process determines the areas subject to floodwater inundation for expected recurrence intervals. It also determines the depth of water at each position within the floodplain. The importance of this step cannot be understated because the depth of water is used to determine the damages to properties and their contents. As previously stated, three recurrence levels are explored in this thesis, 100-year, 500-year and 1000-year. Each recurrence level is run separately to explore the results and come up with the appropriate mitigation strategies pertaining to the storm interval. The probability of occurrence is used in the benefit cost analysis to justify projects for floodplain improvement. According to the 100 year return period there is a certain amount of building exposure subject to flood damages. This is estimated by the depth of water determined from the delineated floodplain. Table 12 shows an estimate of the results of exposure based on the occupancy type of each structure.

8.4 100 Year Return Period

Table 12 Building Exposure by Occupancy Type for the Scenario (100 Year Return Period)

Building Exposure by Occupancy Type for the Scenario (100 Year Return Period)		
Occupancy	Exposure ($1000)	Percent of Total
Residential	$3,208,423	66.5%
Commercial	$968,840	20.1%
Industrial	$453,205	9.4%
Agricultural	$10,016	0.2%
Religion	$121,094	2.5%
Government	$43,072	0.9%
Education	$18,163	0.4%
Total	$4,822,813	100.0%

HAZUS estimates that about 1,330 buildings will be at least moderately damaged. This is over 70% of the total number of buildings in the scenario. There are an estimated 307 buildings that will be completely destroyed. The definition of the “damage states” is provided in Volume 1: Chapter 5.3 of the HAZUS Flood Technical Manual. Table 13 below summarizes the expected damage by general occupancy for the buildings in the region. Table 14 summarizes the expected damage by general building type.

Table 13 Expected Building Damage by Occupancy (100 Year Return Period)

Expected Building Damage by Occupancy (100 Year Return Period)												
	1 – 10		11-20		21-30		31-40		41-50		Substantially	
Occupancy	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
Commercial	0	0.00	8	42.11	7	36.84	2	10.53	1	5.26	1	5.26
Education	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Government	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Industrial	0	0.00	6	46.15	2	15.38	3	23.08	1	7.69	1	7.69
Religion	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Residential	0	0.00	28	2.16	321	24.73	155	11.94	489	37.67	305	23.50
Total	0		42		330		160		491		307	

Table 14 Expected Building Damage by Building Type (100 Year Return Period))

Expected Building Damage by Building Type (100 Year Return Period)												
Building Type	1-10		11-20		21-30		31-40		41-50		Substantially	
	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
Concrete	0	0.00	1	20.00	2	40.00	1	20.00	1	20.00	0	0.00
ManufHousing	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	86	100.00
Masonry	0	0.00	1	1.54	11	16.92	7	10.77	33	50.77	13	20.00
Steel	0	0.00	5	41.67	3	25.00	2	16.67	1	8.33	1	8.33
Wood	0	0.00	29	2.49	315	27.09	151	12.98	461	39.64	207	17.80

For essential facilities, there are 10 hospitals in the region with a total capacity of 2,006 beds. There are 208 schools, 42 fire stations, 37 police stations and 1 emergency operation center. Before the flood analyzed in this scenario, the region had 2,006 hospital beds available for use. On the day of the scenario flood event, the model estimates that 2,006 hospital beds are available in the region. Table 15 shows the expected damage to essential facilities in the region.

Table 15 Expected Damage to Essential Facilities (100 Year Return Period)

Expected Damage to Essential Facilities (100 Year Return Period)				
		# Facilities		
Classification	Total	At Least Moderate	At Least Substantial	Loss of Use
Fire Stations	42	1	0	1
Hospitals	10	0	0	0
Police Stations	37	1	0	1
Schools	208	3	0	3

8.5 Debris Generation

HAZUS estimates the amount of debris that will be generated by the flood. This model breaks debris into three general categories: 1) Finishes (dry wall, insulation, etc.), 2) Structural (wood, brick, etc.) and 3) Foundations (concrete slab, concrete block, rebar, etc.). This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 154,153 tons of debris will be generated for the 100 year return period. Of the total amount, Finishes comprises 24% of the total, Structures comprises 41% of the total. If the debris tonnage is converted into an estimated number of truckloads, it will require 6,166 truckloads (at 25 tons/truck) to remove the debris generated by the flood.

8.6 Shelter Requirements

HAZUS estimates the number of households that are expected to be displaced from their homes due to the flood and the associated potential evacuation. HAZUS also estimates those displaced people that will require accommodations in temporary public shelters. The model estimates 3,120 households will be displaced due to the 100 year flood. Displacement includes households evacuated from within or very near to the inundated area. Of these, 7,180 people (out of a total population of 553,126) will seek temporary shelter in public shelters.

8.7 Economic Loss

The total economic loss estimated for the flood is 611.77 million dollars for the 100 year return period, which represents 12.68% of the total value of the scenario buildings.

8.8 Building Related Losses

The building losses are broken into two categories: direct building losses and business interruption losses. The direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. The business interruption losses are the losses associated with inability to operate a business because of the damage sustained during the flood. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the flood.

The total building related losses were 608.60 million dollars. 1% of the estimated losses were related to the business interruption of the region. The residential occupancies made up 34.44% of the total loss.

Table 16 Building Related Economic Loss Estimates (100 Year Return Period)

Building Related Economic Loss Estimates (100 Year Return Period)						
(Millions of dollars)						
Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
	Building	130.99	66.11	34.33	6.82	238.26
	Content	79.39	154.02	81.64	28.33	343.38
	Inventory	0.00	6.72	19.92	0.32	26.96
	Subtotal	210.38	226.85	135.89	35.46	608.60
Business Interruption						
	Income	0.01	0.84	0.01	0.04	0.90
	Relocation	0.19	0.19	0.01	0.02	0.41
	Rental Income	0.05	0.13	0.00	0.00	0.19
	Wage	0.04	1.00	0.01	0.63	1.68
	Subtotal	0.30	2.16	0.03	0.69	3.18
ALL	Total	210.68	229.01	135.92	36.16	611.77

The analysis was run again for the same study region for a 500-year return period. The building exposure by occupancy type is shown in Table 17. Obviously, since the delineated floodplain is larger for a 500 year event, the building exposure dollar amount is higher than the 100 year scenario.

8.9 500 Year Return Period

Table 17 Building Exposure by Occupancy Type for the Scenario (500 Year Return Period)

Building Exposure by Occupancy Type for the Scenario (500 Year Return Period)		
Occupancy	Exposure ($1000)	Percent of Total
Residential	$4,157,789	64.4%
Commercial	$1,312,775	20.3%
Industrial	$714,979	11.1%
Agricultural	$14,820	0.2%
Religion	$159,679	2.5%
Government	$54,864	0.8%
Education	$41,865	0.6%
Total	$6,456,771	100.0%

HAZUS estimates that about 2,029 buildings will be at least moderately damaged. This is over 70% of the total number of buildings in the scenario. There are an estimated 564 buildings that will be completely destroyed. Table 18 summarizes the expected damage by general occupancy for the buildings in the region. Table 19 summarizes the expected damage by general building type.

Table 18 Expected Building Damage by Occupancy (500 Year Return Period)

Expected Building Damage by Occupancy (500 Year Return Period)												
	1 – 10		11-20		21-30		31-40		41-50		Substantially	
Occupancy	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
Commercial	3	9.38	11	34.3	7	21.88	5	15.63	2	6.25	4	12.50
Education	1	100.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Government	4	80.00	1	20.00	0	0.00	0	0.00	0	0.00	0	0.00
Industrial	0	0.00	11	55.00	3	15.00	3	15.00	2	10.00	1	5.00
Religion	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Residential	0	0.00	39	1.97	441	22.28	234	11.82	706	35.67	559	28.25
Total	8		62		451		242		710		564	

Table 19 Expected Building Damage by Building Type (500 Year Return Period)

Expected Building Damage by Building Type (500 Year Return Period)												
Building Type	1-10		11-20		21-30		31-40		41-50		Substantially	
	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
Concrete	1	11.11	3	33.33	2	22.22	1	11.11	1	11.11	1	11.11
ManufHousing	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	165	100.00
Masonry	1	0.96	2	1.92	17	16.35	9	8.65	49	47.12	26	25.00
Steel	1	5.26	9	47.37	2	10.53	4	21.05	2	10.53	1	5.26
Wood	0	0.00	39	2.24	428	24.63	228	13.12	667	38.38	376	21.63

Before the flood analyzed in this scenario, the region had 2,006 hospital beds available for use. On the day of the scenario flood event, the model estimates that 1,834 hospital beds are available in the region. The difference in availability can be accounted for by the number of individuals in need after the event has occurred.

Table 20 Expected Damage to Essential Facilities (500 Year Return Period)

Expected Damage to Essential Facilities (500 Year Return Period)				
		# Facilities		
Classification	Total	At Least Moderate	At Least Substantial	Loss of Use
Fire Stations	42	2	0	2
Hospitals	10	0	1	1
Police Stations	37	1	0	1
Schools	208	8	1	6

8.10 Debris Generation

The model estimates that a total of 232,887 tons of debris will be generated for the 500 year return period. Of the total amount, Finishes comprises 25% of the total, Structures comprises 40% of the total. If the debris tonnage is converted into an estimated number of truckloads, it will require 9,315 truckloads (at 25 tons/truck) to remove the debris generated by the flood.

8.11 Shelter Requirements

The model estimates 4,703 households will be displaced due to the 500 year flood. Displacement includes households evacuated from within or very near to the inundated area. Of these, 10,484 people (out of a total population of 553,126) will seek temporary shelter in public shelters

8.12 Economic Loss

The total economic loss estimated for the flood is 959.39 million dollars, which represents 14.86% of the total replacement value of the scenario buildings.

8.13 Building Related Loss

The total building related losses were 954.07 million dollars. 1% of the estimated losses were related to the business interruption of the region. The residential occupancies made up 35.22% of the total loss. Table 21 provides a summary of the losses associated with the building damage.

Table 21 Building Related Economic Loss Estimates (500 Year Return Period)

Building Related Economic Loss Estimates (500 Year Return Period) (Millions of dollars)						
Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
	Building	210.55	102.02	52.89	12.20	377.66
	Content	126.88	237.32	122.02	49.35	535.58
	Inventory	0.00	10.33	30.06	0.43	40.82
	Subtotal	337.43	349.67	204.98	61.99	954.07
Business Interruption						
	Income	0.02	1.35	0.01	0.13	1.51
	Relocation	0.28	0.34	0.02	0.05	0.69
	Rental Income	0.07	0.21	0.00	0.01	0.30
	Wage	0.05	1.63	0.02	1.11	2.82
	Subtotal	0.43	3.53	0.06	1.30	5.32
ALL	Total	337.86	353.20	205.03	63.29	959.39

The final flood scenario ran for this report is the 1000-year event. Table 22 provides a summary of the building exposure by occupancy type for the scenario.

8.14 1000 Year Return Period

Table 22 Building Exposure by Occupancy Type for the Scenario (1000 Year Return Period)

Building Exposure by Occupancy Type for the Scenario (1000 Year Return Period)		
Occupancy	Exposure ($1000)	Percent of Total
Residential	$5,508,248	67.7%
Commercial	$1,544,678	19.0%
Industrial	$742,982	9.1%
Agricultural	$20,468	0.3%
Religion	$200,549	2.5%
Government	$56,973	0.7%
Education	$58,323	0.7%
Total	$6,540,655	100.0%

HAZUS estimates that about 2,385 buildings will be at least moderately damaged. This is over 71% of the total number of buildings in the scenario. There are at least 628 buildings that will be completely destroyed. Table 23 summarizes the expected damage by general occupancy for the buildings in the region. Table 24 summarizes the expected damage by the general building type.

Table 23 Expected Building Damage by Occupancy (1000 Year Return Period)

Expected Building Damage by Occupancy (1000 Year Return Period)												
	1 – 10		11-20		21-30		31-40		41-50		Substantially	
Occupancy	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
Commercial	2	7.41	9	33.33	8	29.63	4	14.81	1	3.70	3	11.11
Education	1	100.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Government	4	80.00	1	20.00	0	0.00	0	0.00	0	0.00	0	0.00
Industrial	0	0.00	9	47.37	3	15.79	5	26.32	1	5.26	1	5.26
Religion	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Residential	0	0.00	42	1.79	524	22.39	260	11.11	890	38.03	624	26.67
Total	7		61		535		269		892		628	

Table 24 Expected Building Damage by Building Type (1000 Year Return Period)

Expected Building Damage by Building Type (1000 Year Return Period)												
Building Type	1-10		11-20		21-30		31-40		41-50		Substantially	
	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
Concrete	1	14.29	2	28.57	2	28.57	1	14.29	1	14.29	0	0.00
ManufHousing	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	204	100.00
Masonry	1	0.88	2	1.77	21	18.58	9	7.96	55	48.67	25	22.12
Steel	1	5.56	8	44.44	3	16.67	4	22.22	1	5.56	1	5.56
Wood	0	0.00	42	2.04	511	24.85	256	12.45	848	41.25	399	19.41

Before the flood analyzed in this scenario, the region had 2,006 hospital beds available for use. On the day of the scenario flood event, the model estimates that 1,834 hospital beds are available in the region.

Table 25 Expected Damage to Essential Facilities (1000 Year Return Period)

Expected Damage to Essential Facilities (1000 Year Return Period)				
		# Facilities		
Classification	Total	At Least Moderate	At Least Substantial	Loss of Use
Fire Stations	42	2	0	2
Hospitals	10	1	1	1
Police Stations	37	2	0	2
Schools	208	7	1	5

8.15 Debris Generation

The model estimates that a total of 277,250 tons of debris will be generated for the 1000 year return period. Of the total amount, Finishes comprises 26% of the total, Structures comprises 39% of the total. If the debris tonnage is converted into an estimated number of truckloads, it will require 11,090 truckloads (at 25 tons/truck) to remove the debris generated by the flood.

8.16 Shelter Requirements

The model estimates 6,613 households will be displaced due to the 1000 year flood. Displacement includes households evacuated from within or very near to the inundated area. Of these, 14,016 people (out of a total population of 553,126) will seek temporary shelter in public shelters.

8.17 Economic Loss

The total economic loss estimated for the flood is 1,079.47 million dollars, which represents 13.27% of the total replacement value of the scenario buildings.

8.18 Building Related Loss

The total building related losses were 1,074.12 million dollars. Roughly 0% of the estimated losses were related to the business interruption of the region as shown in Table 25. The residential occupancies made up 40.18% of the total loss. Table 26 provides a summary of the losses associated with the building damage.

Table 26 Building Related Economic Loss Estimates (1000 Year Return Period)

Building Related Economic Loss Estimates (1000 Year Return Period) (Millions of dollars)						
Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss						
	Building	270.72	105.61	52.07	15.05	443.44
	Content	162.56	244.62	120.13	63.14	590.45
	Inventory	0.00	10.31	29.40	0.52	40.23
	Subtotal	433.28	360.54	201.59	78.71	1,074.12
Business Interruption						
	Income	0.02	1.32	0.01	0.16	1.50
	Relocation	0.33	0.31	0.02	0.07	0.73
	Rental Income	0.07	0.20	0.00	0.01	0.28
	Wage	0.06	1.53	0.02	1.23	2.84
	Subtotal	0.48	3.36	0.05	1.47	5.35
ALL	Total	433.75	363.90	201.64	80.18	1,079.47

This chapter presented the findings of the analysis of a regional flood event surrounding Hamilton County, TN. The total economic losses incurred by the region for the 100, 500 and 1000 year flood events are 611.77, 959.39 and 1,079.47 million dollars respectively. In the event that any of these simulations were to take place a federal disaster would be declared. There are several issues that need to be addressed to reduce the damages for each flood event. Chapter 9 discusses the case study in detail and how it relates to historical damages in Hamilton County as well as the State of Tennessee.

CHAPTER 9

DISCUSSION

Emergency preparedness plans are usually broken into several categories according to their phase within the system. The ability of a community's infrastructure to continue to function in the face of unexpected hazard events will determine the duration of recovery as well as its resilience as a whole. The following chapter regarding the discussion of the findings within the case study is broken into four categories: response, recovery, mitigation and preparation. Within each section the framework discussed in previous chapters will be implemented and discussed.

9.1 Determine the Question

The question or issue being raised in this thesis is how can determining the physical and economic effects of urban floods on critical infrastructure and surrounding communities help improve resiliency and preparedness to natural disasters. How can past occurrences as well as scientific based simulations of this type of phenomena bring attention to the growing issue facing the world? With climate change causing sea levels to be higher, temperatures to rise as well as warming ocean waters the scientific community is declaring the age of the super storm is imminent. Once the problem is understood in the broadest of terms the next question is what data is needed to address or support the claim. In other words the problem has to be analyzed with figures and numbers to support the claim. This is completed in chapter 7 with the case study for the Hamilton County area.

9.2 Problem Analysis

The concern surrounding emergency preparedness revolves around three important questions that were presented in the opening chapter: how much will it cost to fix the problem, how long will it take to fix the problem and how many people will be affected. Financial consideration is the main issue facing pre disaster mitigation because it is an issue that is easy to forget about until the unfortunate occurs. Before Hurricane Katrina hit the Gulf Coast there were numerous attempts by local experts as well as the Army Corps of Engineers to fix the issue of faulty flood defense systems but there was no room in the budget to do so. In the aftermath of the storm the government has committed $14.5 billion to flood protection improvements. The estimated total damages induced by the storm total $96 billion. There is no way to determine the amount of damage that could have been avoided as well as the avoided loss of life had there been earlier intervention. Although there are systems in place to help with pre-disaster mitigation there has to be more foresight given to these situations. The amount of time that it takes to fix the problem is directly proportional to the scale of the disaster as well as the level of recovery deemed necessary for future problems. As with the amount of time it takes to recover the community and numbers of individuals affected by the storm event are relative to the scale of disaster. It is up to government officials, the public and private sector, and experts in the required fields to alleviate this issue and come up with measurable goals and solutions.

9.3 Choose an Appropriate Turnaround Strategy

In business a turnaround strategy is applied to a company to determine the root cause of failure. Different analysis techniques are put to use and when the failure mechanism has been determined the evaluator proposes long term restructuring plans to forecast for future problems and ensure success. Flood management is a broad subject requiring experts from diverse fields to come together and solve its problems. There are vested interests in both the private and public sector in regulating this issue. When an area is flooded both sectors are affected with loss of business and damages. This is why they must work together to create public-private partnerships to mitigate this issue.

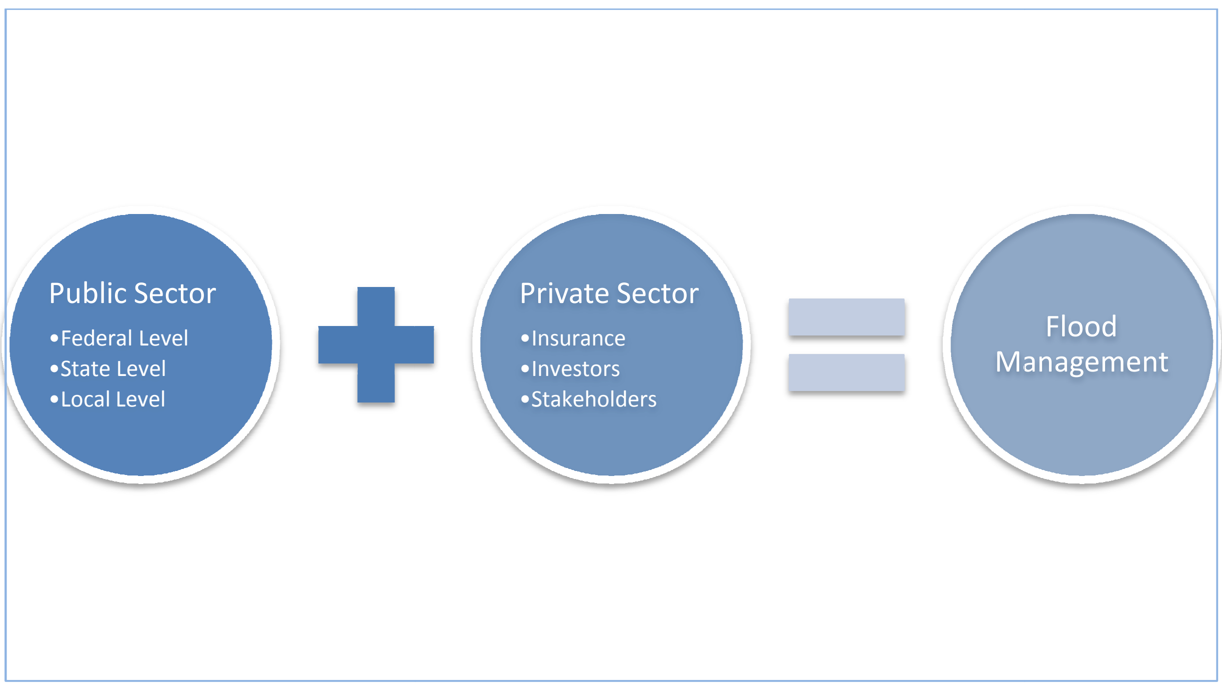


Figure 17 - Public Private Partnerships

The public sector must create the legislation at all levels of government to provide stricter regulations of flood control. At a local level emergency officials in vulnerable areas need to make an effort to inform residents of their level of exposure. People that have been properly informed have plans in place for adverse situations. Local governments have to make efforts to stop construction in dangerous areas within the flood plain through land use control. Historically floodplains have been an attractive site for new construction due to their proximity to natural bodies of water and aesthetically pleasing views, but poses high risk in the event of flooding. New construction should adhere to the guidelines presented in the National Flood Insurance Program (NFIP) in accordance with FEMA. A community that wants to be eligible for federal funds following a natural disaster has to adopt a floodplain management ordinance. The 100 year floodplains need to be reevaluated and updated based on changes to the floodplain as well as changes to the weather patterns. State and federal level contributions should include legislation, federal standards and improvements to infrastructure. Currently the United States only spends 2 percent of the GDP on infrastructure as opposed to the 5 and 9 percent spent by Europe and China, respectively. Although the amount of spending on infrastructure and its improvements is not a solitary indicator of the level of attention paid to development and protection efforts of a country the fact that spending has dropped by 50% since the 1960's does raise a disturbing issue [37]. Federal involvement usually only occurs after it has been established that the state is overwhelmed and in need of assistance by presidential declaration. Seeing that the federal government has spent $136 billion total from fiscal year 2011 to fiscal year 2013 on disaster relief efforts it would be more economically sensible to focus on pre-disaster mitigation [38]. According to FEMA every dollar spent on hazard mitigation provides the nation with about $4 in future benefits [38]. Pre-disaster mitigation will help save both money and avoid loss of life in the event of future hazards. This initiative is a large task to undertake but with help from the private sector it is feasible.

There is much the public sector can learn from the private in terms of financing large scale projects. Historically when the government gets involved with construction projects or even just large scale proposals there are overruns on both costs and completion dates. Political agendas and bureaucracy get in the way of the initial plan and generally ruins the outcome. Since the government is necessary for a plan involving the nation's well-being it is important to establish public-private partnerships. As previously stated the private sector has just as much at stake when it comes to losses associated with natural disasters. A study conducted by the Government Accountability Office found that approximately 85% of the nation's critical infrastructure and key resources are owned by the private sector [39]. So when disaster strikes not only do they have to worry about damages but also lost revenue due to system inoperability. The determination of the role each sector will play in emergency response can be resolved by forming a local response and resilience committee. The public sector element will be comprised of first responders such as the police, fire department, emergency planners, etc. They will work with the private sector stakeholders such as utility providers, voluntary agencies and other vested parties. Together both sectors can assess the risks facing their communities and determine the best course of action for mitigation. The comprehensive plan can then be given to larger entities such as the state government so they can review the needs on a larger scale and determine the amount of financial need in terms of immediate risk. When the smaller issues of immediate need are taken care of before disaster strikes it will improve overall resilience and alleviate future complications. This principle is similar to the "Fix it First" initiative suggested by congress. Instead of focusing on constructing new facilities the older facilities should be evaluated to determine the amount of repair necessary. If it is determined that repair is economically feasible renovation should take place otherwise proceed with new construction. In order to stay with the theme of resilient communities planning for new construction should include input from emergency planners so they can offer advice concerning building codes, land use, risks, and etcetera. This way all concerned parties are aware and their recommendations have been heard.

An additional way the private sector can help with disaster assistance is through private insurance. Currently the NFIP covers the majority of the nation's flood risk but it is now $18 billion in debt [40]. Due to the large debt owed by the NFIP and the overwhelming claims placed on the organization the insurance premiums are growing. The Biggert-Waters Flood Insurance Reform Act of 2012 calls on the various government agencies involved to change the way the NFIP is run. This act wants to raise rates based on the level of flood risk as well as change how floodplain mapping impacts policy holders. The major issue with this policy change is historically the population that is most vulnerable to floods happens to be poor. If these individuals can no longer afford flood insurance because of the rising premiums the costs to recover will fall squarely on the tax payers. The money that is paid out for disaster recovery from the government already comes from taxpayers so this will just add to the burden. If incentive is put in place for private insurance companies to also carry flood insurance competitive rates will help drive costs down.

9.4 Implement the Change Process

Formation of committees to assess risks for communities as well as determine comprehensive plans of action is the first step in emergency management. Implementation of the approved process determined is the next logical step. The following sections describe ways to respond, recover and mitigate the risks of urban flooding.

9.5 Vulnerability

The return periods explored in this thesis are based on annual probabilities of each of their occurrences. As explained previously, the 100 year return period does not necessarily mean that this event will occur once every 100 years. Historical accounts of each event are taken into context when predicting the probability of occurrence. When evaluating natural hazards according to the Hamilton County Emergency Management Agency (HCEMA) it is imperative to take three things into consideration: probability of occurrence, historical occurrence and likely extent/magnitude. Each of these categories are explained followed by Table 27 illustrating Hamilton County's vulnerability [41].

Probability of Occurrence

- ***High*****:** Greater than 20 percent probability each year, or at least one chance in the next 5 years
- ***Moderate*****:** Between a 5 and 10 percent probability in the next year, or at least one chance in the next 10 years
- ***Low*****:** Between a 1 and 5 percent probability in the next year, or at least one chance in the next 20 to 100 years

Historic Occurrence

- ***High:*** At least once every five years
- ***Moderate:*** At least once every 10 years

• ***Low:*** At least once in the last 20 to 100 years

• ***Unknown:*** Historic data was not available for evaluation

Likely Extent/Magnitude (one or more criteria may be met)

- ***Serious*****:** Severe injuries, loss of life, significant property damage, evacuations and provision of emergency shelter.
- ***Moderate*****:** Some injuries, property damage; disruption of area for more than 24 hours.
- ***Minimal*****:** Minor injuries, disruption of the area for less than 24 hours, minor property damage.

Table 27 Hamilton County Flood Hazard Probability [41]

Hamilton County Flood Hazard Probability				
Hazard	Jurisdiction	Probability of Occurrence	Historic Occurrence	Likely Extent/Magnitude
Flood	Unincorporated County	High (Valley) Moderate (Plateau)	High (Valley) Moderate (Plateau)	Moderate
	Collegedale	High	Moderate	Moderate
	Chattanooga	High	High	Serious
	East Ridge	High	High	Serious
	Lakesite	Low	Low	Minimal
	Lookout Mountain	Low	Low	Minimal
	Red Bank	High	High	Moderate
	Soddy-Daisy	High	High	Moderate
	Signal Mountain	Low	Low	Minimal
	Walden	Low	Low	Minimal
	UTC	High	High	Low
	HCDE	Moderate	Moderate	Moderate

The flood events on record for Hamilton County fall mostly within the 100 and 500 year return periods. There is no official record of a 1000 year flood event for Hamilton County. This is not to say that one has never or never will happen in this area. In May 2010 a 1000 year flood event occurred in Nashville, TN. Due to the recent increase rate and devastation of natural hazards it was deemed important to also explore possible damages related to that recurrence interval. The flood types that are frequently associated with Hamilton County fall into the categories of flash flooding and riverine flooding. The HAZUS-MH model utilized in the case study for this thesis used the riverine analysis tool. Flooding mainly occurs in valley areas flowing from higher elevations. Riverine floods often remain for weeks due to the nature of their occurrence while flash floods drain quickly. Flash floods tend to affect newly developed areas as the natural landscape has been altered and the natural drainage of these areas has been disturbed.

9.6 Damage Calculation

Flood damage functions are in the form of depth-damage curves which relate the depth of flooding, in feet, as measured from the top of the first finished floor, to damage expressed as a percent of replacement cost. Two of the main provisions used by HAZUS-MH to determine building related damages are the age and foundation type of the building. Damages to older buildings can be attributed to deterioration, out of date building codes and designs not up to NFIP specifications. HAZUS "damage states" are developed from damage percentages. The depth damage curves used were developed by the U.S. Army Corps of Engineers (USACE) and the USACE Institute for Water Resources (USACEIWR).

The model estimated building related residential economic losses of $210.38 million for the 100 year return period and $337.43 million for the 500 year return period. The Hamilton County Emergency Management Agency conducted studies for 100 and 500 year return periods and their residential building losses for both were $192.78 million and $422.00 million respectively. That is a difference of approximately $17.6 million for the 100 year period and -$84.57 million for the 500 year return period. The difference in losses can be attributed to the case study including five additional counties other that Hamilton County. Although the study is based primarily in Hamilton County there were additional reaches in the other counties to help preserve geological formations. Since 1994, the National Oceanic and Atmospheric Administration (NOAA) has recorded 582 riverine flood impacts in the State of Tennessee. Tennessee has 35 deaths and 1 injury relating to riverine flooding. These events have cost Tennesseans $4,245,763,300 in property damage [42]. For Hamilton County specifically, the National Climatic Data Center (NCDC) has documented 35 flood events from 1993 to 2010 that produce an annual average of $6.8 million in property damages [41]. The economic losses associated with flooding focus mainly on residential and commercial property damages. The records of losses associated with business interruption are usually on an individual basis so the numbers are difficult to summarize.

9.7 Repetitive Loss

Repetitive Loss (RL) and Severe Repetitive Loss (SRL) properties are a serious hazard related to flooding. RL structures are categorized by residential properties that have received 2 or more flood loss claims over $1000 each and SRL structures are properties that have received 4 or more claims over $5000 each. Structures that have flooded repeatedly in the past and have a high probability of future flooding are a major liability on the National Flood Insurance Program (NFIP). Hamilton County has 149 repetitive loss structures with losses totaling to $7,134,138 with an average claim payout of $19,373 [42]. Table 28 below shows the repetitive loss properties in Hamilton County by zip code.

Table 28 Repetitive Loss Structures by Zip Code [41]

Repetitive Loss Structures by Zip Code	
Zip Code	Total Loss (Building and Contents)
37343	$445,362
37379	$88,378
37401	$39,253
37402	$69,165
37403	$10,188
37404	$96,719
37405	$175,369
37406	$64,808
37407	$440,591
37408	$863,442
37409	$102,917
37410	$162,001
37411	$326,421
37412	$3,025,828
37415	$453,835
37416	$73,313
37419	$403,544
37421	$255,886
67412	$37,118
Grand Total	$7,134,138

9.8 Loss of Essential Facilities

Loss of services from essential facilities can happen throughout an extreme weather event. According to the Tennessee Emergency Management Agency's (TEMA) Continuity of Operations Plan (COOP), it is assumed that all essential services will be available between 24 to 48 hours after a hazardous event has occurred. However extreme weather events can cause extended periods without these services. Flooding can make roadways impassible, blackouts cause wastewater facilities to shut down and prolong emergency operations. Development of resilient infrastructure is crucial to decrease the impacts of natural hazards and increase the likelihood of continuity of services. Damages to essential facilities determined by HAZUS-MH are calculated on an individual site basis.

9.9 Shelter Requirements

Each scenario ran gave a significant estimate of the population in need of short term shelter. In addition to having adequate space for the displaced population there must also be a sufficient number of supplies as well as trained personnel.

Table 29 Shelter Requirements by Scenario

Shelter Requirements by Scenario		
100 Year Scenario	500 Year Scenario	1000 Year Scenario
3,120 households	4,703 households	6,613 households
7,180 people	10,484 people	14,016 people

Public buildings such as schools, religious institutions, and so on can be used to provide emergency accommodation after a disaster. These shelters are designated to provide a safe living place for individuals immediately following a disaster event. They are meant to reduce the vulnerability to health problems and future immediate danger. The assumption is that these dwellings are meant for the immediate period only, and any longer assistance after falls outside of the realm of the emergency contribution. Any other shelter is viewed as emergency housing which is a long term resolution after the event such as the FEMA trailers that were distributed across the South East region following the Hurricane Katrina event.

Like all of the other aspects of the response phase the type of shelter provided is dependent upon the scale of the disaster. The amount of damage caused is directly proportional to the amount of the displaced population. The costs of assistance are usually handled at the local level by companies, local government, non-profit organizations and the people of the community as no one entity has the resources to provide all necessary assistance. Studies have shown that people in developing countries as well as rural communities tend to be more self reliant and resourceful in disaster situations. This can be attributed to the fact that they tend to grow their own food and construct their homes. If the hazard is small enough that they can stay at their own place they are more likely to be self sufficient. However these individuals will be hit the hardest if a major disaster strikes due to their proximity to large scale disaster relief areas. Survivors tend to want to stay as close to their homes and places of business as possible unless compulsory evacuation takes place. Mass emergency shelters at community based buildings are temporary in nature and should only be viewed as an intermediate phase between evacuation and reconstruction. The resources provided at these shelters are in short supply and accommodations are usually on a first come first serve basis. The timeline for these shelters and the supplies only last up to a few weeks post-disaster and then evacuees must seek other means of refuge during the recovery period.

The case study performed for this thesis returned figures that are very alarming. Recent studies have proven that the costs associated with natural disasters continue to rise and the devastation causes the effects to prolong the recovery process. The HCEMA's current mitigation strategies rely heavily on the assumption that Federal funds will be available to fix existing issues. It is not enough to rely on national programs to help with local issues. Solutions to local issues need to start at the local level and use federal help as necessary due to the fact that there is no "one size fits all" for natural disaster mitigation. Local officials from all areas of interest must work together to establish guidelines for continuous improvement of disaster mitigation.

CHAPTER 10

CONCLUSIONS & RECOMMENDATIONS

10.1 Objectives of the Study

The objective of this study was to establish a framework to improve the impacts of physical and economical damages to critical infrastructure and surrounding communities. Validation of the framework was carried out by performing a case study to determine the damages inflicted on a community from a flood event. The framework included a six step pragmatic approach to research.

10.2 Summary of the Findings

The validation of the framework consisted of performing a case study of a series of flood events and how the physical and economic damages would impact a region. The city of Chattanooga is the most flood prone in the state of Tennessee so Hamilton County was at the center of investigation. To get a regional impact area additional counties in Tennessee Marion and Bradley were investigated also Dade, Walker & Catoosa counties in the state of Georgia. The economic damages were expressed as losses which totaled 611.77, 959.39 and 1,079.47 million dollars for the 100, 500 & 1000 year flood events respectively. The physical damages were represented by destruction to buildings, essentials facilities, transportation networks, etc.

Due to the amount of economic damages caused by all three scenarios, government intervention in the form of emergency aid would be necessary for repair. The urgency for intervention in addition to economic justification determines the type of flood control method put into operation. For more vulnerable areas subjected to large amounts of damage hard engineering tactics such as levees are necessary for protection. Soft engineering practices are used when there is enough time to let natural methods take place. In addition to physical flood control methods other means of warning include improving the warning time given to citizens of the community, proper preparation of shelters, increasing knowledge of vulnerability, and formation of committees at the local level to evaluate needs.

10.3 Conclusions

The need for a major overhaul of the protection of communities and critical infrastructure in relation to natural disasters is upon us. The rising costs and devastation is putting this and other countries around the globe in financial hardship. Pre-disaster mitigation has a greater effect on preparedness and reducing the destruction from these events. Financial considerations by far have the greatest effect on disaster relief and mitigation endeavors. Restructuring federal and state disaster aid based on vulnerability and risk analysis will decrease harmful impacts. There is a need for a formation of a committee of experts from relevant fields of interest to share their knowledge and structure a well-rounded approach to disaster management. These committees should be at both the federal and local level. Stricter federal standards should be put in place for structural flood protection. Overall awareness must be increased at all levels. When people are informed and prepared for disaster the loss of property and lives will be reduced.

10.4 Recommendations for Further Study

There are new technologies currently in the research stage for flood control that warrant a closer look. New sustainable infrastructure is being equipped with embedded sensors for environmental monitoring. These sensors include GIS data modeling to measure water levels and air pressure. In the event of water levels reaching dangerous heights these sensors send information to emergency operation centers to alert the public. GIS technology in general has proven to be an effective tool in flood risk management. Topics for further exploration include using GIS mapping to identify impacted locations and GIS based risk assessment for flood modeling.

REFERENCES

[1] T. O'Rourke, "National Academy of Engineering," 2007. [Online]. Available: http://www.nae.edu/Publications/Bridge/EngineeringfortheThreatofNaturalDisasters/CriticalInfrastructureInterdependenciesandResilience.aspx. [Accessed 17 January 2013].

[2] S. M. Rinaldi, J. P. Peerenboom and T. K. Kelly, "Identifying, Understanding and Analyzing Critical Infrastructure Interdependencies," *IEEE Control Systems Magazine,* pp. 11-25, December 2001.

[3] Federal Emergency Management Agency, "Hazard Mitigation Planning Overview," 2013. [Online]. Available: http://www.fema.gov/hazard-mitigation-planning-overview. [Accessed 22 March 2014].

[4] FEMA, "FEMA: Multi-Hazard Mitigation Planning," 12 September 2012. [Online]. [Accessed 17 December 2012].

[5] Federal Emergency Management Agency, "National Disaster Recovery Framework," September 2011. [Online]. Available: https://www.fema.gov/pdf/recoveryframework/ndrf.pdf. [Accessed 22 March 2014].

[6] The Department of Homeland Security, "National Infrastructure Protection Plan," 2009. [Online]. Available: http://www.dhs.gov/xlibrary/assets/NIPP_Plan.pdf. [Accessed 22 March 2014].

[7] Deparment of Homeland Security, "National Infrastructure Protection Plan: Partnering to enhance protection and resiliency," Washington, D.C., 2009.

[8] S. V. Croope and S. McNeil, "Improving Resilience of Critical Infrastructure Systems Postdisaster: Reconvery and Mitigation," *Transportation Research Board,* pp. 3-13, 2011.

[9] R. Mechler, "From Risk to Resilience: The Cost Benefit Analysis Methodology," IIASA, Nepal, 2008.

[10] J. D. Moteff, "Critical Infrastructure Resilience: The Evolution of Policy and Programs and Issues for Congress," Congressional Research Service, 2012.

[11] J. D. Moteff, "Critical Infrastructure Resilience: The Evolution of Policy and Programs and Issues for Congress," Congressional Research Service, Washington, D.C., 2012.

[12] National Research Council, "Sustainable Critical Infrastructure Systems - A Framework for Meeting 21st Century Imperatives," The National Academies Press, Washington D.C., 2009.

[13] R. Ferdous, F. Khan, R. Sadiq, P. Amyotte and B. Veitch, "Fault and Event Tree Analyses for Process Systems Risk Analysis: Uncertainty Handling Formulations," *Risk Analysis,* vol. 31, no. 1, pp. 86-107, 2011.

[14] X. You and F. Tonon, "Event-Tree Analysis with Imprecise Probabilities," *Risk Analysis,* vol. 32, no. 11, pp. 330-344, 2012.

[15] The Federal Emergency Management Agency, "The Stafford Act: Robert T. Stafford Disaster and Emergency Assistace Act, as Amended," April 2013. [Online]. Available: http://www.fema.gov/media-library-data/1383153669955-21f970b19e8eaa67087b7da9f4af706e/stafford_act_booklet_042213_508e.pdf. [Accessed 3 March 2014].

[16] FEMA, "HAZUS-MH Know Your Risk," January 2012. [Online]. Available: http://www.fema.gov/media-library-data/20130726-1629204909057/hz_overview _flyer_feb2012.pdf. [Accessed 1 October 2013].

[17] USGS, "Computing Erosion Modeling Inputs from a DEM," [Online]. Available: http://skagit.meas.ncsu.edu/~helena/gmslab/reports/CerlErosionTutorial/denix/Data /DEM_computing_erosion_modeling_input.htm. [Accessed 7 October 2013].

[18] FEMA, "So You Want to Use Hazus-MH," January 2012. [Online]. Available: http://www.fema.gov/media-library-data/20130726-1820-25045-1951/hz_scenarios_flyer.pdf. [Accessed 7 July 2013].

[19] M. Yan, "DIJKSTRA'S ALGORITHM," January 2010. [Online]. Available: http://math.mit.edu/~rothvoss/18.304.3PM/Presentations/1-Melissa.pdf. [Accessed 9 September 2013].

[20] B. Foltz, "Super Trooper Shortest Route Problem in Excel," 11 June 2012. [Online]. Available:

http://www.bcfoltz.com/blog/mathematics/super-troopers-shortest-route-problem-in-excel. [Accessed 22 September 2013].

[21] E. Dalziell and S. McManus, "Resilience, Vulnerability and Adaptive Capacity: Implications for System Performance," 4 December 2004. [Online]. Available: http://ir.canterbury.ac.nz/bitstream/10092/2809/1/12593870_ResOrgs_IFED_dec04_EDSM.pdf. [Accessed 12 September 2013].

[22] National Weather Service, "United States Flood Loss Report - Water Year 2012," 2012. [Online]. Available: http://www.nws.noaa.gov/hic/summaries/WY2012.pdf. [Accessed 28 September 2013].

[23] FEMA, "Chapter 11: Determining Site Specific Loads," [Online]. Available: http://www.humanitarian.net/cfpnet/hurricane/ref/ccm/vol2_ch11.pdf. [Accessed 29 September 2013].

[24] River Partners, "Levee Failure," 2013. [Online]. Available: http://www.riverpartners.org/resources/riparian-ecology/veg-levees/levee-failure/. [Accessed 1 October 2013].

[25] Science Daily, "Building Better Dams," August 1 2006. [Online]. Available: http://www.sciencedaily.com/videos/2006/0807-building_better_dams.htm. [Accessed 6 August 2013].

[26] Texas Department of Transportation, "Hydraulic Design Manual: Probability of Exceedance," 1 October 2011. [Online]. Available: http://onlinemanuals.txdot.gov/txdotmanuals/hyd/probability_of_exceedance.htm. [Accessed 20 July 2013].

[27] R. R. Holmes Jr. and K. Dinicola, "100 Year Flood - It's all about chance," April 2010. [Online]. Available: http://pubs.usgs.gov/gip/106/pdf/100-year-flood-handout-042610.pdf. [Accessed 20 July 2013].

[28] USACE, "Flood Problems," 12 September 2013. [Online]. Available: http://www.corpsnedmanuals.us/FloodDamageReduction/FDRID006FldProbs.asp. [Accessed 1 October 2013].

[29] FEMA, "Definitions of FEMA Flood Zone Designations," [Online]. Available:

https://msc.fema.gov/webapp/wcs/stores/servlet/info?storeId=10001&catalogId=10001&langId=-1&content=floodZones&title=FEMA%2520Flood%2520Zone%2520Designations. [Accessed 1 October 2013].

[30] S. Hallegatte and V. Przyluski, "The Economics of Natural Disasters: Concepts and Methods," The World Bank, 2010.

[31] SARRET Families of America, "Hamilton County Map," [Online]. Available: http://freepages.genealogy.rootsweb.ancestry.com/~prsjr/families/tn/index-e.htm. [Accessed 1 October 2013].

[32] S. L. Kurtz, "Hamiton County, Tennessee Natural Hazards Mitigation Plan," Chattanooga, 2004.

[33] B. W. Jackson, "Soil Survey of Hamilton County, Tennessee," United States Department of Agriculture Soil Conservation Service.

[34] RSS Weather, "Climate for Chattanooga, TN," 2013. [Online]. Available: http://www.rssweather.com/climate/Tennessee/Chattanooga. [Accessed 1 October 2013].

[35] TVA, "Valley Rainfall," [Online]. Available: http://www.tva.gov/river/flood/rainfall.htm. [Accessed 8 June 2013].

[36] Tennessee Valley Authority, "Flood Prone Areas," [Online]. Available: http://tva.com/river/flood/prone.htm. [Accessed 14 August 2013].

[37] The Department of the Treasury, "An Economic Analysis of Infrastructure Investment," Washington, D.C., 2010.

[38] J. Weidman and W. D. J., "Disastrous Spending: Federal Disaster-Relief Expenditures Rise amid More Extreme Weather," 29 April 2013. [Online]. Available: http://www.americanprogress.org/wp-content/uploads/2013/04/WeissDisasterSpending-1.pdf. [Accessed 10 October 2013].

[39] FEMA, "Critical Infrastructure: Long-Term Trends and Drivers and Their Implications for Emergency Management," Federal Emergency Management Agency, 2011.

[40] J. Liberto, "CNN Money," 12 October 2012. [Online]. Available: http://money.cnn.com/2012/10/31/news/economy/fema-flood-sandy/. [Accessed 11 October 2013].

[41] Hamilton County Emergency Management Agency (HCEMA), "Hamilton County Natural Hazards Reduction Plan," Chattanooga, 2011.

[42] Tennessee Emergency Management Agency, "State of Tennessee Hazard Mitigation Plan," State of Tennessee, Nashville, 2013.

[43] J. Moteff and P. Parfomak, "Critical Infrastructure and Key Assets: Definition and Identification," The Library of Congress, 2004.

[44] R. S. Kirk, "Emergency Relief Program: Federal Aid Highway Assistance For Disaster Damaged Roads and Bridges," Congressional Research Service, 2011.

[45] Federal Highway Adminstration, "Emergency Relief Manual (Federal Aid Highways)," Washington, D.C., 2009.

[46] J. D. Moteff, "Critical Infrastructure Resilience: The Evolution of Policy and Programs and Issues for Congress," CRS Report for Congress, Washington, D.C., 2012.

APPENDIX A

STEP BY STEP INSTRUCTIONS FOR THE SHORTEST PATH

Step 1: Enter columns into Excel for the following categories: Begin, Destination, On Route, Distance, Nodes, Net flow and Supply/Demand.

Step 2: In the Begin column put all of the beginning nodes with the number of destinations that they have. For example, node S has three destination nodes in A, B & C so it has three beginning nodes. In the Destination column put all of the destination nodes according to the beginning node column. The spreadsheet should now look like this:

Begin	Destination
Source	A
Source	B
Source	C
A	B
A	D
B	A
B	C
B	D
B	E
C	B
C	E
D	E
D	F
E	D
E	F
E	G
E	H
F	G
F	Emergency Center
G	F
G	H
G	Emergency Center
H	G
H	Emergency Center

Figure 18 - Step 2 in Shortest Route Calculation

Step 3: Make an On Route column but leave this column blank. This will be the variable column used in the analysis. Next to this column make the Distance column and put all of the corresponding distances for each begin to destination node. The spreadsheet should now resemble Figure 19 below:

Begin	Destination	On Route		Distance
Source	A	0		7
Source	B	0		5
Source	C	0		4
A	B	0		3
A	D	0		8
B	A	0		3
B	C	0		1
B	D	0		6
B	E	0		7
C	B	0		1
C	E	0		4
D	E	0		4
D	F	0		8
E	D	0		4
E	F	0		9
E	G	0		6
E	H	0		5
F	G	0		3
F	Emergency Center	0		7
G	F	0		3
G	H	0		2
G	Emergency Center	0		4
H	G	0		2
H	Emergency Center	0		6

Figure 19 - Step 3 in Shortest Route Calculation

Step 4: Make the columns for Nodes, Net flow and Supply/Demand. For each column created, highlight the information in each column and rename it after its title. In the On Route column add an extra cell at the bottom for the total distance of the travel. The final layout of the spreadsheet should look like this, in Figure 20.

Begin	Destination	On Route	Distance		Nodes	Net Flow		Supply/Demand
Source	A	0	7		Source	0	=	1
Source	B	0	5		A	0	=	0
Source	C	0	4		B	0	=	0
A	B	0	3		C	0	=	0
A	D	0	8		D	0	=	0
B	A	0	3		E	0	=	0
B	C	0	1		F	0	=	0
B	D	0	6		G	0	=	0
B	E	0	7		H	0	=	0
C	B	0	1		Emergency Center	0	=	-1
C	E	0	4					
D	E	0	4					
D	F	0	8					
E	D	0	4					
E	F	0	9					
E	G	0	6					
E	H	0	5					
F	G	0	3					
F	Emergency Center	0	7					
G	F	0	3					
G	H	0	2					
G	Emergency Center	0	4					
H	G	0	2					
H	Emergency Center	0	6					
	Total Distance	Enter						

Figure 20 - Step 4 in Shortest Route Calculation

Step 5: In the Net Flow column enter the following equation into the Source node space:

=SUMIF(Begin,H4,OnRoute)-SUMIF(Destination,H4,OnRoute)

Figure 21 - Step 5 in Shortest Route Calculation

This is the net flow for each node. This only sums the column if each requirement is met by the analysis. Drag this equation below for each node.

Step 6: In the total distance cell in the On Route column enter the following equation:

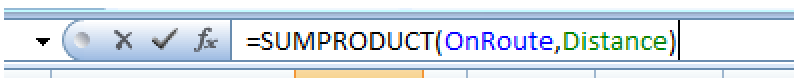


Figure 22 - Step 6 in Shortest Route Calculation

This product is the multiplication of the route optimal route taken and the distance of each route. The number in the cell is zero now because the analysis has not taken place.

Step 7: Open the solver in Excel. Set the target cell to the total distance cell. This is a minimization program so set the equal to portion to Min. Set the values for the "By changing cells" box to On Route. The constraints of this program are so that the net flow is equal to the supply and demand. Click on the options portion of the solver and check the boxes next to Assume Linear Model and Assume Non Negative. Figures 23 and 24 below show the results of Step 7. Once this is completed click OK.

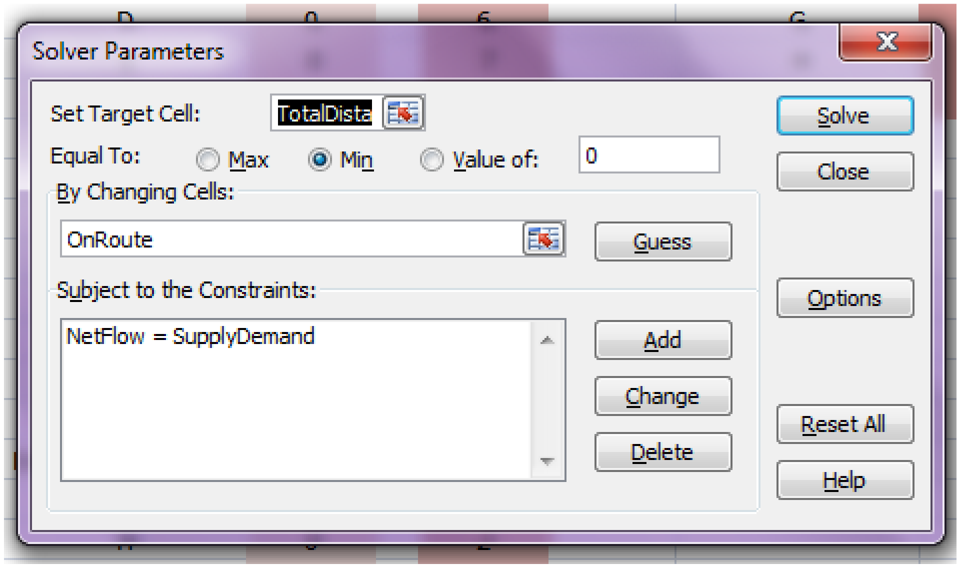


Figure 23 - Step 7 in Shortest Route Calculation

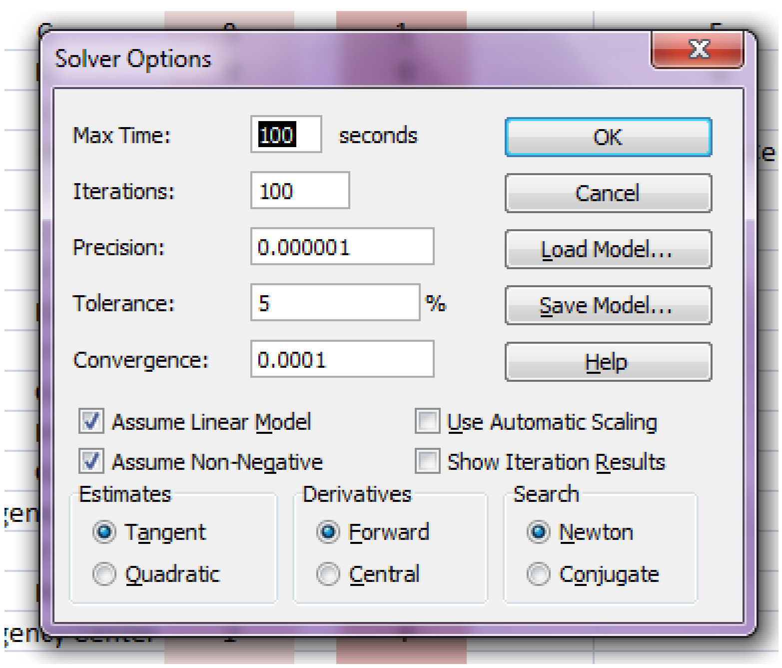


Figure 24 - Step 7 in Shortest Route Calculation

Step 8: The Solver has found a solution in the On Route Column. This column is now full of ones and zeros. The ones express the optimal route which is S-C-E-G-EC. This is the optimal route for the drive with a total distance of 18 miles.

Begin	Destination	On Route		Distance
Source	A	0		7
Source	B	0		5
Source	C	1		4
A	B	0		3
A	D	0		8
B	A	0		3
B	C	0		1
B	D	0		6
B	E	0		7
C	B	0		1
C	E	1		4
D	E	0		4
D	F	0		8
E	D	0		4
E	F	0		9
E	G	1		6
E	H	0		5
F	G	0		3
F	Emergency Center	0		7
G	F	0		3
G	H	0		2
G	Emergency Center	1		4
H	G	0		2
H	Emergency Center	0		6
	Total Distance	18		

Figure 25 - Step 8 in Shortest Route Calculation

VITA

Gloria Neal was born in Chattanooga, TN. She is the youngest of two children with one older brother. She attended Lakeside Elementary School and continued to Tyner Academy in Chattanooga, TN. After graduation, she attended the University of Tennessee at Chattanooga where she completed her Bachelor of Science degree in Civil Engineering in the fall of 2010. In the fall of 2011 she enrolled at the University of Tennessee at Chattanooga where she began to pursue a Master of Science in Civil Engineering. In the summer of 2012 she accepted an internship with BNSF Railway in Chicago, IL to work in their engineering services department as a Field Engineering Intern. Gloria will graduate in May 2014 with her Master's degree and she is currently working as a civil engineer with Barge, Waggoner, Sumner & Cannon, Inc. in Chattanooga, TN.