Iowa Research Online
The University of Iowa's Institutional Repository

University of Iowa
Iowa Research Online

Theses and Dissertations

Summer 2011

Assessing and augmenting emergency response: a study of the current methods and potential changes to flood response in the state of Iowa

Timothy James Middlemis-Brown
University of Iowa

Copyright 2011 Timothy James Middlemis-Brown

This thesis is available at Iowa Research Online: https://ir.uiowa.edu/etd/1163

Recommended Citation
Middlemis-Brown, Timothy James. "Assessing and augmenting emergency response: a study of the current methods and potential changes to flood response in the state of Iowa." MS (Master of Science) thesis, University of Iowa, 2011.
https://doi.org/10.17077/etd.0hta5vry.

Follow this and additional works at: https://ir.uiowa.edu/etd

Part of the Civil and Environmental Engineering Commons

ASSESSING AND AUGMENTING EMERGENCY RESPONSE: A STUDY OF THE CURRENT METHODS AND POTENTIAL CHANGES TO FLOOD RESPONSE IN THE STATE OF IOWA

by

Timothy James Middlemis-Brown

A thesis submitted in partial fulfillment
of the requirements for the Master of
Science degree in Civil and Environmental Engineering
in the Graduate College of
The University of Iowa

July 2011

Thesis Supervisor: Professor Witold F. Krajewski

Graduate College
The University of Iowa
Iowa City, Iowa

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

Timothy James Middlemis-Brown

has been approved by the Examining Committee
for the thesis requirement for the Master of Science
degree in Civil and Environmental Engineering at the July 2011 graduation.

Thesis Committee: ______________________________
Witold F. Krajewski, Thesis Supervisor

____
Larry J. Weber

____
David Bennett

One who knows the Mississippi will promptly aver--not aloud but to himself--that ten thousand River Commissions, with mines of the world at their back, cannot tame that lawless stream, cannot curb it or confine it, cannot say to it, 'Go here.' or 'Go there,'and make it obey; cannot save a shore which it has sentenced; cannot bar its path with an obstruction which it will not tear down, dance over, and laugh at.

Mark Twain
Life on the Mississippi

ACKNOWLEDGMENTS

I owe Professor Witold Krajewski my utmost gratitude for letting me explore my interests in flood research. My project represents an exploration into unfamiliar territory for both of us. Thank you for your guidance and faith.

I would like to thank Jerry Mount for his significant contribution to development in Augmented Reality. With his immense programming skills and vision, he made working in Junaio and Wikitude a far more approachable task. I would also like to recognize Professor Dave Bennett for his generosity in allowing me to distract Jerry with my many requests.

Professor Allen A. Bradley helped me begin my journey with solid encouragement and a paper on forecasting. Ray Wolf, Jeff Zogg, Tom Oswald and others provided me with their time and a willingness to answer my relentless questions. Gary Brown and Mark Tomb gave me a voice to contact county emergency managers and city officials across the state. My parents contributed a consistent source of encouragement, redirection, and guidance. Kaitlyn Clark was most generous with both time and understanding as I struggled to balance writing and the rest of life. Finally, I want to extend a thank you to everyone else who helped make my research possible, including the many nameless emergency managers and city officials who took the time to answer my questionnaire.

ABSTRACT

This study represents a review of existing flood response, exploration into potential improvements, and possible enhancement technologies. Research includes gathering information from individuals associated with response, searching for and testing emergent technologies, and gauging interest in possible improvements. National Weather Service and Iowa Homeland Security and Emergency Management Division staffers contribute details, unavailable through published literature, on forecast development and dissemination, and coordination of flood response in Iowa. These details help influence the design of questionnaires distributed to emergency managers and city officials. The questionnaire respondents provide a real-world base for speculation in the usefulness of map and communication technologies. Augmented Reality, spatial triggers, dynamic routing, and social media are all primary focuses of literature research and experimentation within the study. Developmental problems in Augmented Reality, spatial triggers, and dynamic routing are also described. Based on the results of this research, future work should include a focus on development of these map technologies, a survey of private citizens, and experimentation in social media. Involving private citizens is an especially important consideration due to the blurring line between data sources and outputs in forecasting, and the increasing ability of officials to provide efficacy to an information aware public.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 : INTRODUCTION

1.1 Inspiration

In the summer of 2011, floodwaters along the Mississippi River, in the United States, crested multiple times outside of the channel from the state of Missouri to the Gulf of Mexico (Sainz 2011). Residents throughout southern and Gulf Coast states, such as Tennessee and Louisiana, evacuated and watched homes become inundated with water flowing from the Midwest (Associated Press 2011). This scenario was by no means unique to the Mississippi River and has been repeated throughout history and across the world.

The 2011 floods followed severe flooding throughout Iowa in 2008 and 2010. Iowans were already very familiar with flooding and the devastation floodwaters can cause. In fact, Iowa is known for being a part of Tornado Alley, but, as Figure 1-1 and Figure 1-2 illustrate, many more disaster proclamations have been issued for floods than tornados during the last fifty years. However, until recently, no cohesive group of flood researchers existed in Iowa. The 2008 floods changed this situation by inspiring development of the Iowa Flood Center, a research group at the University of Iowa (UI), the need for which had been reaffirmed by the 2010 and 2011 flooding. One objective of the research center was to conduct a reassessment of the best methods for a general theme of *living with floods*. Evaluation of these methods included components of flood response.

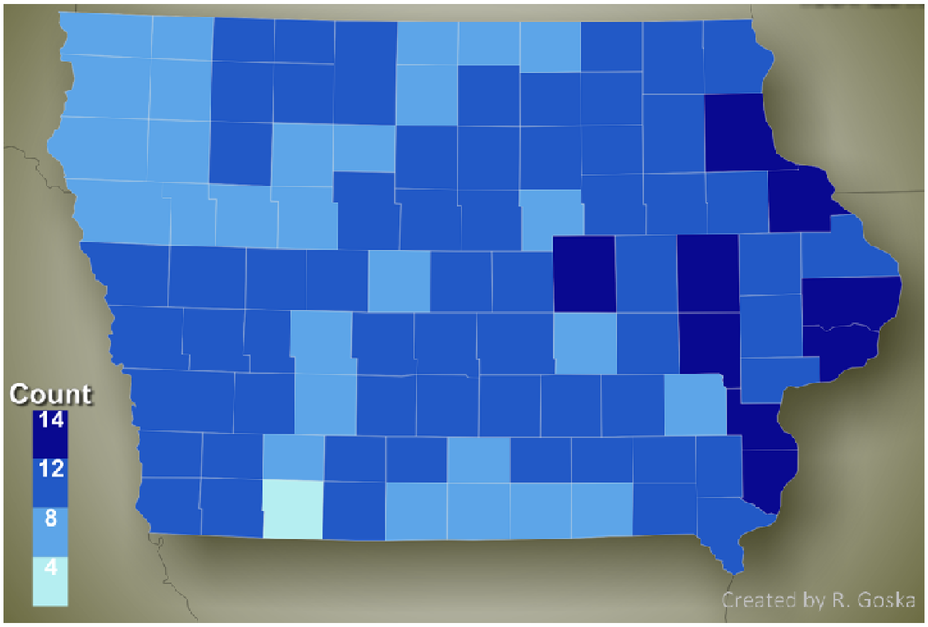

Figure 1-1. A color-coded map of Iowa, indicating the number of Presidential disaster declarations due to flooding for each county from 1964 to 2010. Courtesy of Iowa Flood Center.

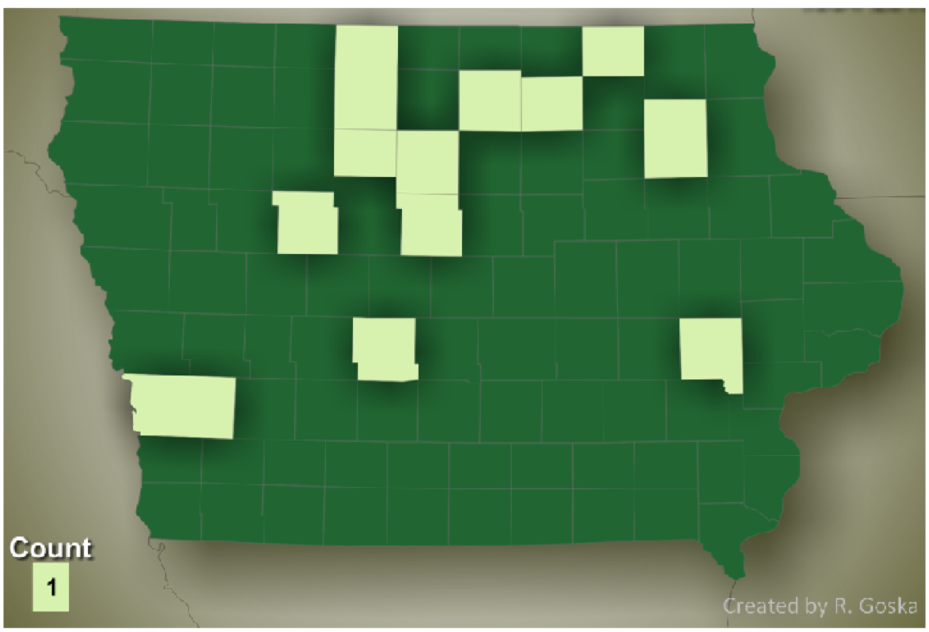

Figure 1-2. A color-coded map of Iowa, indicating the number of Presidential disaster declarations due to tornados for each county from 1962 to 2010. Courtesy of Iowa Flood Center.

1.2 Objectives and Scope

The proceeding report details a survey of both currently operational processes within and potential technologies for emergency response during flood events. The results are intended to outline typical procedures associated with emergency flood response in the state of Iowa and provide guidance toward new technologies to develop for implementation in future flood events. As such, this research included analyzing historical events and mitigation techniques, cataloguing current systems for flood response in the State of Iowa, evaluating potential improvements to flood response, and suggesting future technologies for development and implementation.

I began with a consideration of historical events in both Iowa and across the world. The resulting methods for mitigation of these events correlate along three distinct, but heavily intertwined, themes. First, historically flood-prone areas tend to correlate directly with the development of culture, which can result in the construction of flood control structures (Ludlow 1998) (Shu and Finlayson 1993). Second, some cultures have also adapted to flooding; leading to coexistence with floods. Third, while control structures and flood-friendly designs built for coexistence exist as planned mitigation, action is also taken during flood events as short-term emergency response.

I chose to focus this study on the emergency response aspect of flood mitigation. I considered forecast development and dissemination to be the first key steps of flood response. This meant ensuring an accurate forecast provides emergency managers, other officials, and the general public a chance to react before an event begins. Therefore, analysis included available forecast hardware, operational forecasts, and dissemination techniques used by the National Weather Service (NWS), a Federal agency tasked with meteorological and hydrological forecasting.

I scrutinized current forecast dissemination methods and investigated possibilities from both the public user and emergency manager perspective. Dissemination included software platforms intended for visualizing and communicating forecasts, and led me outside the forecast realm to consideration of how emergency managers communicate with the public. For example, social media and networking were both examined as potential new candidates for engaging the public.

The expanding popularity of mobile devices justified consideration of two and three dimensional mobile mapping software (Lenhart, et al. 2010). A constant connection to web-based information systems provides previously unknown potential for personal efficacy (Yi and Hwang 2003). Therefore, each mobile device-based georeferencing possibility; alerting stakeholders, providing routing services, and creating digital overlays of pertinent information in local environments; underwent assessment within current software and hardware constraints.

Publications, interviews, and surveys helped determine interest in new technologies and gather information on current systems. Interviews consisted of meetings with various government personnel, including staff from the NWS, The University of Iowa (UI), and Iowa Homeland Security. Questionnaires, distributed via email to emergency managers and city officials throughout the state of Iowa, returned results concurrent to the other parts of the study. Thus, the surveys shape the course of the recommendations more than the actual content of the study. However, the final results of the study represented an interesting mix of procedures, needs, and desires with the potential for further study and recommendations for development of various technologies.

CHAPTER 2 : HISTORICAL PERSPECTIVE

> It takes about three generations for people to forget. Those that experience the disaster themselves pass it to their children and their grandchildren, but then the memory fades.
>
> Jay Alabaster, Tsunami-Hit Towns Forgot Warnings from Ancestors

Studying flooding and flood response in Iowa requires historical background of human interaction with floods. In fact, while the floods most prominent in contemporary Iowan minds have all occurred in the last twenty years; people throughout the world continuously live with the duality of rejuvenating benefits and scouring destruction caused by floodwaters. Biblical accounts include floodwaters cleansing the earth and destroying almost all life. Ancient reference points along the Nile River show frequent floods replenishing localized agriculture. Ancient Chinese and Japanese histories include stories of a multitude of devastating floods with a few, in the 20^{th} century, killing hundreds of thousands (Markus 2002). Yet, society often has only short-term memory, forgetting about historic disasters as new ones occur (Alabaster 2011) (Gruntfest and Handmer 2001).

The constant cycle of destruction and rebuilding between flood events has continued throughout history due to the economic benefits of riverine environments and need for space in overcrowded communities. Instead of simply moving outside the floodplain, inhabitants rebuild near rivers due to the low costs of and accessibility to water-based shipping (Duranton January 1999). This leads to an assortment of often intermixed approaches to living with floods as individuals choose to move, are unable to leave, or rebuild once the threat of flooding has been forgotten.

Flood control can be a very costly approach to living with floods and translates into expenditures of billions of dollars in flood control structures. The concept of control is intended to avoid evacuating people and destructive loss of capital. Flood coexistence harnesses the ability of floodwaters to rejuvenate local soils, reconnect rivers to floodplains, and recharge alluvial aquifers. This corresponds to a paradigm shift from flooding interpreted as a purely destructive force, to a natural process. Regardless of the capabilities of flood control and designs for coexistence, properly designed and executed flood response provides additional opportunities for mitigating human and capital loss.

2.1 Control

The attempt to control flooding is common among industrialized nations. Industrialized countries often view floods as dangerous to citizens and as crippling to economic growth. Unfortunately, floodplains are often the most productive areas of a country. Floodplains provide access to waterways for commercial trade, a water source for industry, rich agricultural land for farmers, and close proximity to jobs for housing.

Any analysis of flood control methods has to include the Netherlands. A low elevation, coastal European country, the Netherlands has a rich history of dependence on flood control structures. Flood control structures are vital in a countryside resting at average of only 11 feet above sea level and no options for eastward expansion into the interior of continental Europe (Rosenburg, Polders and Dikes of the Netherlands 2011).

Building control structures allows the Netherlands to expand and exist as a country. Accordingly, the history of flood control in the Netherlands began almost 2000 years ago. Today, the natural landscape has all but disappeared with the advanced development of these structures.

The local productivity of floodplains is a second common reason for populating floodplains. The Netherlands exemplifies this richness by having the highest gross domestic product (GDP) per square kilometer in Europe (Associated Programme on Flood Management 1956). Furthermore, some of the most productive working areas of the country exist purely because of flood control structures. These areas sit as low as 23 feet below sea level, making them extremely vulnerable to tidal and river flooding (CIA Factbook 2010).

Despite their extensive investment in flood control structures, the Dutch have admitted the term “flood prevention” could be a misnomer (van Dantzig 1956). Not all floods can be prevented because the cost of every project has to be weighed against the benefits (Green 2000). Therefore, the goal of a flood control structure is to maximize protection versus monetary, logistical, and spatial constraints (Costa 1978). For example, raising a levee an extra meter may change the exceedance probability from one in 1000 to one in 1500, but may be cost prohibitive by doubling the total structure cost. Thus monetary constraints play a significant role in protection afforded by flood control structures.

Operational constraints also represent an issue with reliance on protection from control structures. The Coralville Dam and Reservoir; outside Iowa City, Iowa; exemplifies a localized control structure with a regional operating standard. The structure, commissioned by the Flood Control Act of 1938, continues to provide flood protection since being built in the 1950s. However, the primary flood protection mission is regional, instead of local (Castle 2010).

The Coralville flood control structure is one element within a flood protection system in the Mississippi River basin. Other elements include various locks along the main channel and dams throughout the basin subwatersheds. These operate in unison intending to mitigate flooding along lower reaches of the Mississippi River. Thus operational decisions are made based on regional needs, without a primary concern for local flood control (Castle 2010).

Two other operating constraints on the dam are stage and capacity. The structure stands 1400 feet long, 100 feet tall, and 650 feet wide at the base. A spillway is also included in the structure with an elevation of 712 feet at the crest, which is 31 feet lower than the top of the dam and capable of handling a 244,000 cubic feet per second of overflow discharge. These design considerations combine with a normal operational elevation of 683feet to translate into a 21.7 mile long impacted zone, a surface area of approximately 5400 acres, and an estimated 28,400 acre-feet of stored water (Castle 2010).

The original capacity of any dam decreases substantially with time due to sediment collection. Therefore, sediment trapping efficiency is a typical design-life constraint (Csiki and Rhoads 2010). The capacity of the Coralville reservoir progressively decreases every year due to sediment trapping. Espinosa-Villegas & Schnoor (2009) estimates the sediment trap efficiency from 1973 to 2005 at approximately 80 percent, which resulted in an estimated annual sedimentation rate of 5.3 x 10^8 kg per year. Bathymetric data confirms an 11 percent loss of flood storage capacity and 62 percent loss of the normal pool capacity since 1958 (Espinosa-Villegas and Schnoor 2009).

The original maximum capacity, equal to only 2.6 inches of runoff from the entire 3,115 square mile Iowa River watershed, indicates that the Coralville dam has never had the capacity to fully control all flood events within the near downstream proximity, regardless of regional operational requirements. Instead, the primary local objectives are to level off ends of the flow duration curve by reducing instances of high flow conditions and augmenting low flow conditions, as demonstrated by Figure 2-1; induce sediment deposition, which increases water quality; provide recreation opportunities; and create wildlife habitat (Castle 2010).

Despite these very real constraints on the Coralville dam capabilities, the results of floods in Iowa City since 1958 demonstrate the false sense of security associated with the dam. Starting in 1959, one year after the dam was inaugurated; the Parkview Terrace subdivision was approved by the Iowa City council. Developers argued that the new dam protected the area, which lay in the floodplain. The UI followed in the footsteps of the city in 1960. Buildings were added to the Arts Campus and have since been added to other areas of campus within the Iowa River floodplain (Sayre 2010).

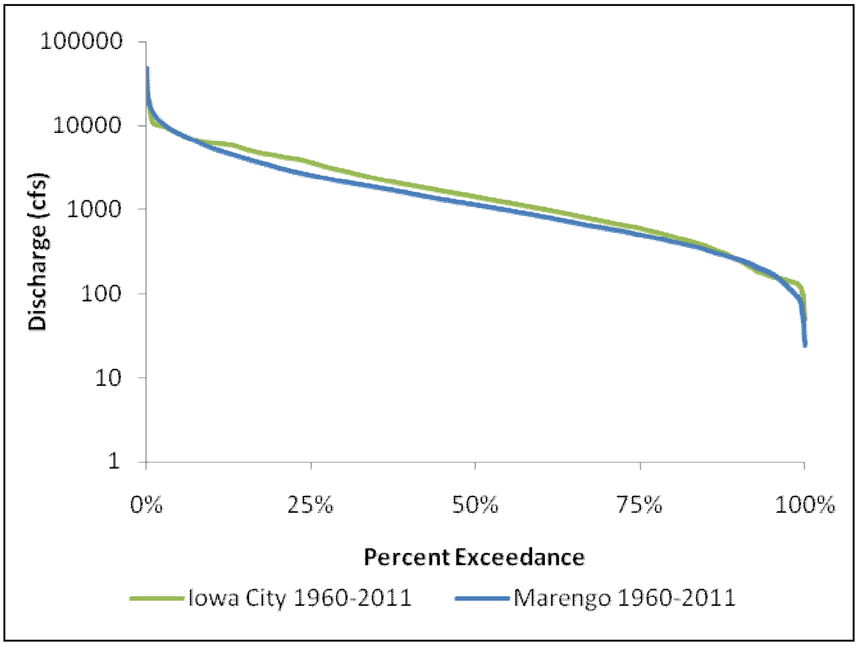

Figure 2-1. Two flow duration curves for the Iowa River at Marengo and Iowa City, which are above and below the Coralville dam, respectively. These curves are based on mean daily discharge data from USGS gaging stations at each location. The two lines demonstrate the expected artificial flattening of the discharge curve and normalization of extreme discharge events caused by a dam.

The false sense of security, provided by the dam, extended beyond both officials and developers. In 1985, one Iowa City historian, Irving Weber, declared that the Iowa River fully controlled and unable to flood Iowa City. Eight years later, in 1993, the Iowa River crested over the Coralville dam spillway and inundated communities all along its route to the Mississippi River (Sayre 2010).

Irving Weber and others failed to realize the operational and spatial constraints of the Coralville dam. Even the primary outflow from the dam; three vertical slide gates, 8.33 feet wide and 20 feet tall; allows a maximum, fully-open discharge above bankfull capacity (Castle 2010). This means that discharge from the dam can cause flooding in Iowa City, Coralville and on the UI campus before cresting the spillway.

The potential for local flooding due to regional planning policies became readily apparent during the 2008 floods. The Army Corps of Engineers (ACE), the agency in charge of regulating Coralville reservoir discharge, began fluctuating discharge during March of 2008. These fluctuations spanned from 1000 to 10,000 cubic feet per second, depending on the downstream and reservoir levels. Water level at Wapello, Iowa, at the confluence of the Cedar and Iowa River, represented an especially important consideration to avoid major flooding along the Mississippi River.

The NWS, ACE, and other governmental agencies continuously work to predict unusual hydrologic events, such as the floods of 2008. These agencies attempt to guide the operations of flood control structures to simultaneously maintain minimum pool requirements while minimizing flood-level discharge. However, exceedance probability is estimated using local historical data, which can be severely limited. Flood control and prevention is therefore a moving target and uncertainty is a continued reality.

Unfortunately, regardless of flood forecasts, some structures suffer catastrophic failure due to numerous reasons, including inadequate design and construction. In 2010, a dam failure on the Maquoketa River in Iowa illustrated issues with flood exceedance and control structures inducing false security. The Lake Delhi dam incurred inordinately high flow after intense rainstorms on an already swollen river (Downstream Residents Dodge Bullet After Lake Delhi Dam Fails 2010). Waters rose 15 feet higher than the dam outlets and eventually wash over the dam. The overtopping waters cut a hole in a weak section; thus causing catastrophic failure. The flooding impacted residences and businesses downstream, and emptied an important recreational lake (Downstream Residents Dodge Bullet After Lake Delhi Dam Fails 2010).

Another recent example of failed flood control comes from the Mississippi River in 2011. Flooding along the Mississippi River, coming from snowmelt along the Red River and precipitation throughout the south-central United States, is pushing officials to create intentional levee breaches, including a breach along the river banks in Missouri discharging 396,000 cubic feet per second of floodwater onto 200 square miles of farmland, and pushed Army Corps of Engineering managers to reduce output from reservoirs along Mississippi tributaries (CNN Wire Staff 2011). Emergency managers used levee breaches as a flood response tool intended to alleviate downstream flooding. However, the destruction of flood control devices demonstrates the problems with perceived security from these structures.

Ultimately the side effects of trying to control water movement may influence a policy shift (Sayre 2010). In fact, in some ways, policies in countries such as the United States have already begun to change. Dam removal and consideration of usable dam lifetimes have both become common practice. Instead of considering all floods in terms of control, consideration of coexistence and response is gaining prominence.

2.2 Coexistence

Overcrowding from population growth generally pushes communities toward water bodies. Also, industry and agriculture relying on water sources for transportation, power and supply crowd waterways. This close proximity to potential flooding often creates the need for flood control structures. Unfortunately, these structures disrupt natural processes by disconnecting a river from its floodplain and subject control structures to potential failure. Therefore, engineers and planners consider the possibility of living with limited flood control structures.

From a historical perspective, Egyptian cultures along the Nile River also thrive because floodwaters brought fresh, nutrient-rich floodwaters and sediment on a yearly basis. The Egyptians begin tracking the flood patterns approximately 5000 years ago. A variety of devices are initially used to record inundation levels, including stationary marks on quays (Bell 1970). Culture grows around seasonal flooding and was able to sustain agriculture with limited artificial irrigation (Takeuchi 2002).

Floodwaters, while generally declining in effect with contemporary protective barriers, can be harbingers of death. Preponderance of levee breaches corresponds with lives lost, but water levels stay similar with each flood event while precipitation amounts decreased. Unfortunately, population growth in areas previously used for ponding and offsetting floodwaters causes the increase water levels for similar precipitation events (Takeuchi 2002).

Another solution to avoid residential flooding is transplanting. Rezoning flood prone areas as parks and recreation areas eliminates risk to businesses and residences. The park structures can be built for flooding using impervious, easily washable materials. An example of transplanting residential neighborhoods after flooding can be found in Iowa City, Iowa. In the years following flooding in 2008, the City of Iowa City purchased and demolished homes in the 100-year floodplain using the Federal Emergency Management Agency's (FEMA) Hazard Mitigation Grant Program (Smith 2009). These areas now both reduce local flood prone residences and provide additional green space as neighborhood parks.

Barring the ability to transplant residents, flood friendly building designs are one way for people to live and work in flood prone areas. These structures can include buildings with floodable concrete parking areas on the first level, floating houses, and homes built on pedestals. In fact, floating houses (Even Construction 2010) are not a new technology (Shaman 1981) and include recent construction in New Orleans. One prototype house is built to primarily rest on the ground until floodwaters arrive, when the houses can float in up to 12 feet (Floating House Makes Debut in New Orleans 2009).

Accepting flooding, attempting to build accommodating structures, and deciding where to locate displaced people requires a variety of contemporary tools. One such tool is accurate mapping of flood prediction zones based on Light Detection and Ranging (LiDAR). These maps are currently being created in Iowa for the State Department of Natural Resources by the Iowa Flood Center, housed in IIHR-Hydroscience &

Engineering, which is located in Iowa City and affiliated with the University of Iowa. The maps will illustrate 100- and 500-year flood zones across the state in both rural and urban areas. Such maps, based on high-resolution LiDAR data, ensures accurate data are available for various tasks related to planning for floods, including flood insurance selection, flood-capable design work, locating escape routes, and other flood-related mapping needs. Yet, these maps also have potential for use during a flood response and especially during flash floods.

Weighing the cost and accurate benefit value of flood control versus working with floods is gaining popularity among policy planners. Integrated Water Resource Management (IWRM) principles support the change. The IWRM principles promote receiving and using input from all stakeholders. For example, the real costs of losing local natural resources.

2.3 Response

Floods can be caused by anything from snowmelt to a single storm. The response to these events ranges from short-term emergency coordination to long-term planning. Often emergency response is needed to keep people alive and out of harm's way. Emergency responders, therefore, are given the responsibility of determining the best course of action during a flood. A multitude of tools are available to emergency managers, however, every flood event guides the development of new technologies and methodologies.

Floods familiar to Midwesterners, from 1993 to 2011, do the most to shape current flood response on both official and individual levels. Despite almost twenty years passing, people continue to remember the effects of flooding in 1993 throughout Iowa and the Mississippi River corridor. Floods create something akin to a cultural memory, which has a profound effect on flood response and planning. However, these memories tend to fade with time as a population ages. The major flood disaster declarations during the 1950s and early 1960s in Iowa (Iowa Disaster History 2011) provide an excellent example of the short-term memory of flooding, because homes and businesses were still built in floodplains affected by 1993 floodwaters.

The results of flooding in 2008, 2010, and 2011 differs from the disaster in 1993. People, before the 2008 floods, built to the flood levels from 1993 and many, before 2008, built to that flood level, presuming 1993 floods represented peak floodwaters. City planners, developers, and individuals often follow this paradigm of building to the highest flood; especially from a historical context (van Dantzig 1956) (Sayre 2010).

Interestingly, the idea of superimposing historical flood perceptions onto long-term flood response, such as planning and construction, spills over into techniques for short-term response. During the 2008 floods, individuals and businesses affected by the 1993 floods typically built temporary flood protection barriers and performed other preparatory measures at an unnecessarily high level (Oswald 2011). Conversely, those unaffected by previous flooding presumed that they will again be safe. This turned into disaster for those in the path of floodwaters.

The IFC has the task of both preserving this cultural memory of floods and prepare the state of Iowa for future flood response. The State of Iowa provides funding for the IFC, as a long-term response to the 2008 floods, and tasks the researchers involved with providing support for State agencies. This mission has expanded into the development of tools for individual citizens. These tools include forecasting services and improvements in dissemination of water-related information (IFC 2011).

Information is important during short-term response, especially when citizens are looking for answers. However, disseminating information to the public represents a significant challenge for both the IFC and NWS. Furthermore, emergency managers, often untrained in water sciences, need forecasts explained in understandable terms and, potentially, through a combination of methods. To reduce these issues, the NWS and IFC have developed both graphic and mobile forecast dissemination methods.

Emergency response to flash flooding, in Iowa, could most use the new mobile forecasts and alerts. This is especially true as flash floods gain increasing significance due to human loss and catastrophic, geomorphologic change. The number of flash floods and impact of events on society becomes increasingly apparent and prominent with increases in the length of historical record, the expertise related to meteorological and hydrological forecasting, and the rate of reporting for flood events (Gruntfest and Handmer 2001).

Flash floods have become particularly prominent due to human activity and geophysical factors. Human activities are often most vulnerable due to location, type, and value of infrastructure. For example, recreational and leisure activities include visiting natural areas along riverways, which are generally relatively flash flood prone areas. Furthermore, the incremental expansion of urban areas puts human life and infrastructure in harm's way within floodplains (Gruntfest and Handmer 2001).

Individuals, at risk for flash flooding in recreational areas, are generally located away from information sources. The typically remote locations of occupied environments make them particularly susceptible to flash flooding. Recreational campgrounds next to a river, for example, are especially dangerous in areas prone to flash flooding. This is particularly true in an area lacking permanent infrastructure and emergency communication devices, such as sirens. Hampered distribution of weather warnings to stakeholders can thus result loss of life (Curtis 2010).

Flash flooding during June of 2010 represents a recent example of disaster due to inadequate ability to inform unsuspecting visitors (Mayerowitz 2010). During the event, the Caddo and Little Missouri Rivers, in southwestern Arkansas, rose 20 feet, peaking between one and two in the morning. The Albert Pike Campground, operated by the US Forest Service, was inundated by water rising at 8 feet per hour. The water level and debris flows resulted in 20 deaths, approximately 24 hospitalizations, and another approximately 60 people requiring rescue (Yancy 2010).

In an article explaining the situation, authorities noted a lack of warning likely exacerbated the devastation. The article pointed out that the Little Missouri went from 3 feet in depth to 23.5 feet during the flood. Rainfall during the night, approximately eight inches, caused the increased discharge (Yancy 2010).

The cause of the flooding and result are directly linked, but missing key was pre-emptive emergency response. To avoid this situation in areas with cellular signal, social networking websites and services, such as Facebook, Twitter, SMS text messages, and email may represent new possibilities for communication with the public and are being adopted by a new generation of US government officials (Rein 2010).

2.4 Summary

Living with floods, as a concept, varies by design and function. Societies require water for commerce, agriculture, and general development. Consequently, floods are a part of human history and appear throughout historical text in terms of both disasters and mitigation attempts. Floods will become increasingly common as populations grow and encroach on water sources, which will lead to an increasing development of control structures, methods for coexistence, and flood response. As control structures and protective designs cannot be available everywhere, improvements of the tools and techniques associated with flood response; such as enabling high-speed, reliable communication and increasingly accurate forecasts; are especially important. Equally important is proper action based on this information to avoid either under- or over-responding to a flood event.

CHAPTER 3 : LITERATURE REVIEW

Disasters, for the purposes of this research, occur when the in situ system fails to cope with unexpected, sudden-onset situations. This can primarily be considered as breakdown in institution or infrastructure (Perry 2007). Furthermore, the institutional tools of flood response are analyzed in three parts: forecasting, mapping, and communication.

Forecasting entails the currently deployed hardware, software, and expertise used throughout the process from precipitation to forecast dissemination. Mapping primarily considers potential methods for employing two- and three-dimensional georeferencing tools. Communication focuses on the addition of mobile devices and social media to existing information distribution and response coordination methods.

The actual distinctions between each component are somewhat ambiguous. Using the three part structure is purely intended to create a sense of logical progression from the forecaster to the stakeholder. In fact, a linear path typically represents the progression from data sources through forecasters to consumers. However, as new communication technologies blur the lines between data sources and stakeholders, the presumption of a single path from originator and consumer will become obsolete.

3.1 Forecasting

Hardware begins the forecasting process with raw data collection. Remote sensing hardware faces limitations from temporal resolution; for example, radar sweeps; and spatial resolution; radar has a four kilometer by four kilometer grid cell size. In situ sampling gages are also subject to temporal and spatial resolution constraints, due to the spacing of gages across a landscape.

Software processes remote sensing and in situ data from sources; such as satellite, radar, gage stations, and human spotters. The software utilizes models, employing various algorithms, to estimate precipitation and subsequent hydrological events. These models estimate precipitation between in situ gages using radar data. Ultimately, expertise can contribute to these steps by filtering the resulting forecast and choosing methods for dissemination to stakeholders.

3.1.1 Forecast Hardware

Runoff caused by rainfall is a key component in flooding. Therefore, precipitation measurements are important for hydrologic and hydraulic forecasting. Remote sensing and physical gages are the two precipitation measurement methods employed by the NWS. Physical gages include automated tipping buckets and manually read gages used by human weather spotters. These gages provide relative accuracy at the collection point, but require estimation between each point.

Common estimation methods for physical gages include the Thiessen Polygon, Isohyetal, Kriging, and IDW approaches (Bastin, et al. 1984). Each method utilizes areal, distance or contour weighting to create a precipitation map. This works very differently from remote sensing, which measures readings at a given resolution across the entire map and then can be calibrated to physical gages.

3.1.1.1 NEXRAD

In 1988, agencies from the Departments of Defense, Commerce, and Transportation created the Weather Surveillance Radar –1988 Doppler (WSR-88D) Radar Operations Center (ROC) in Norman, Oklahoma. Commonly referred to as NEXRAD, the associated network consists of 159 radars. This network is ultimately intended to provide an accurate source of weather data for advanced warning models (About the ROC 2011).

Radar detects two meteorological conditions: wind and precipitation. To do this, energy waves emit from a radar station in a beam, which projects into a conical shape with the apex at the origin and circular terminus. The conical beam sweeps through a circular pattern, thus limiting temporal resolution of data collection, at any given point, to the time required to pass through each revolution (National Research Council's Board on Atmospheric Sciences and Climate 2005).

Radar energy waves scatter upon contact with solid and liquid materials. Most of the energy striking solid objects tends to be absorbed, and the energy encountering liquid objects generally continues traveling. A small fraction of the total energy reflects back to the radar detector. For water droplets, the reflected energy is proportional to the sixth power of the droplet diameter. This relationship provides the basis for measurement of droplet size and spatial distribution (National Research Council's Board on Atmospheric Sciences and Climate 2005).

The Doppler phase shift within the outgoing and incoming energy ways, along with travel time and return signal strength, assists in the measurement of droplet size and motion. Knowing the size and motion of droplets translates into estimation of where atmospheric droplets will fall, causing precipitation, and the direction and speed of any associated wind. However, large, solid objects can interfere with measurement due to radar wave opacity (National Research Council's Board on Atmospheric Sciences and Climate 2005).

Reflected signal can come from both atmospheric and ground-based objects (Seo, et al. 2011). Therefore, solid objects can shrink the operating range of radar in varied topography. Conversely, relatively flat regions, such as Iowa, have very little interference by landforms. These regions encounter problems with the minimum 0.5 degree angle pitch required for all NEXRAD stations (National Research Council's Board on Atmospheric Sciences and Climate 2005). Instead of a constricted radar path, the radar in Iowa typically reaches the full 200 kilometer operating extent.

The range and pitch of NEXRAD stations causes bias at the farthest extent, before attenuating. Data collection near the top of cloud structures catches a mixture of liquid and solid water. These regions can cause overly bright spots within a radar map due to density differences between a water droplet and a ball of ice coated with melting water.

The melting water sends the same signature as a water droplet, but has disproportional volume due to the ice, which is less dense than liquid water. The disproportionally large volume ice and liquid water mixtures return a much stronger signal than the liquid water droplets due to the power regression relationship between droplet diameter and reflected energy.

Energy wave absorption and overestimation are among several current issues with radar. Other primary problems include no cross-calibration among radar stations, which correlates to a general lack of published information regarding procedures and schedule (Seo, et al. 2011). One known additional known bias is in the radar-based estimation of hourly precipitation within multisensory products (Young, et al. 2000).

Precipitation estimations from NEXRAD have typically been biased toward lower estimated values than those created through areal estimation based on rain gauges. Combining radar and gauge data should improve precipitation estimates in both quality and spatial resolution, and when compared to either source alone (Young, et al. 2000). The expertise component of forecasting can provide the ability to recognize bias and tweak forecasts as needed, but can also introduce subjectivity into forecasts (Johnson, et al. 1999) (Young, et al. 2000).

Therefore, problems with validating multisensory areal precipitation estimations continue to exist. Size difference in sampling area creates a problem when comparing measurements from sampling points to areal estimations. Furthermore, few independent precipitation gauges exist outside of the multisensor estimation network. Finally, limited records of the original data, methods used, and manual changes, made to model outputs, exist (Young, et al. 2000).

3.1.1.2 GOES

Geosynchronous satellites with infrared capabilities are used to estimate rainfall. In the US, the National Environmental Satellite Data and Information Service (NESDIS) operates the Geostationary Operational Environmental Satellites (GOES) system. The satellites provide larger-scale cloud cover maps than radar and avoid having a ground-based system (Vicente, Scofield and W. 1998).

Some other differences exist between radar and satellite-based meteorological measurements. For example, radar, unlike satellites, can encounter problems with ground clutter over the circular radar sweep and cloud over-topping at the longest ranges. Conversely, GOES typically collects hourly radiances from above cloud formations, but images are sometimes available only once every couple to several hours (Schmit, et al. 2002) (Vicente, Scofield and W. 1998).

Many of the derived products from satellite data differ from NEXRAD. Some examples include atmospheric temperature profiles, moisture profiles, total precipitable water vapor, atmospheric stability indices, lifted index, cloud-top properties, total column of ozone, and midlevel motion (Schmit, et al. 2002).

Satellite monitoring uses infrared light (IR) to track cloud progression and growth. Cloud-top temperatures tend to have an indirect relationship with storm intensity and, ipso facto, precipitation rate. Tracking finite differences in temperatures and shape through periodic image returns and stills allows for estimation of growth and decay in cloud formation. Simultaneously, spatial gradient analysis is applied to disregard cirrus clouds releasing no precipitation (Vicente, Scofield and W. 1998).

3.1.1.3 Output

The final product, used by forecasters, is a multisensor precipitation estimate, which includes a mixture of remote sensing and in situ data collection. Neither system alone represents a perfect methodology for gathering data. Instead, merging remote sensing and precipitation gauge data based on weighting regions according to variance estimations minimizes uncertainty for detailed hydrological forecasts (Grimes, Pardo-Igúzquiza and Bonifacio 1999) (Young, et al. 2000).

3.1.2 Operational Forecasting

Two of the most difficult aspects of accurate forecasting are the scalability and uncertainty of estimations. The Office of Hydrologic Development (OHD) coordinates NWS progress toward reducing uncertainty and increasing accuracy in hydrologic forecasts. This executive commission directs the integration of new hydrologic principals from the research science realm, modifies scientific concepts into working methodologies, oversees growth within NWS field offices, and helps ensure the congruent progression of NWS outputs with stakeholder needs (OHD 2011).

The OHD responsibilities and activities are distributed to and abetted by five operation systems and organizations. The Advanced Hydrologic Prediction Service (AHPS) integrates burgeoning hydrologic assessment methods into new forecasting systems for flood warnings and water resource availability assessments. As of fiscal year 2005, AHPS had 1,376 operational locations and river forecasts at 3400 locations. The AHPS plans to reach a total of 4,011 operational forecast locations by 2013 (Committee to Assess the NWS AHPS 2006).

The Planning, Programming, and Coordination Group (PPC) pursue various analyses for hydrology programs within NWS and the rest of NOAA. The Hydrology Laboratory (HL) considers, chooses, and offers training in new scientific methods and software technologies for forecasting. The River Forecast Center Development Management (RDM) is a program run by a single manager, who ensures efficient application of new science and software within River Forecast Centers (RFCs). The Community Hydrologic Prediction System (CHPS) combines and facilitates data sharing between NOAA and other federal-level water agencies, academic institutions, and other stakeholders throughout the nation (OHD 2011).

A NWS recent report, the “Strategic Science Plan” (SSP) for the HL, enumerates the current and proposed processes and models for forecasting. The authors broke up each subject into three ideas. First, “where we are,” which explains the techniques currently used by NWS personnel. Second, “where we want to be,” which outlines either a new or reaffirmed goal. Third, “what are the challenges to get there” provides an explanation of the anticipated problems for reaching each goal (Strategic Science Plan 2010).

The current methods illustrated in the SSP include the hydrologic forecasting process for the NWS River Forecasting System (Total River and Hydrologic Forecasting System 2011). The forecast methodology begins with data inputs from observation infrastructure, such as the remote sensing and in situ hardware detailed in the previous section, 3.1.1 Forecast Hardware. Forecasts have specific data input needs to satisfy the algorithms used within the model.

Forecast data input requirements fall within two basic lists: primary and secondary needs. Primary needs include the height of the planetary boundary layer, soil moisture and temperature profiles, high-resolution vertical profiles of humidity, measurements of air quality and related chemical composition above the surface layer. Secondary measurement needs consist of direct and diffuse solar radiation, vertical wind profiles, subsurface temperature profiles, incidents of icing near the surface, vertical temperature profiles, and surface turbulence parameters (Committee on Developing Mesoscale Meteorological Observational Capabilities to Meet Multiple National Needs 2009).

Some of the data collection networks for the meteorological and hydrological models fall outside national agency dominions. For example, mesonets, or mid-level networks, provide additional data available in limited regions of the country (Committee on Developing Mesoscale Meteorological Observational Capabilities to Meet Multiple National Needs 2009)The Iowa Environmental Mesonet, provided by the Iowa State University Department of Agronomy, hosts information on atmospheric temperature, wind speed, precipitation, atmospheric pressure, soil moisture and various other local parameters (Iowa Environmental Mesonet 2011).

Soil moisture, in particular, represents a particularly important and under-sampled parameter for hydrological forecasts, which can be sampled using an optimal number of sensors (Brocca, et al. 2010), or modeled using observed precipitation, temperature, and runoff (Huang, van den Dool and Georgakakos 1995). Soil moisture estimations come from presumed initial conditions with fluctuations estimated by temporally continuous radar-rainfall models (Villarini, et al. 2010). The NWS uses the Sacramento Soil Moisture Accounting model (SAC-SMA) to estimate basin-scale antecedent soil moisture conditions for flood forecast models. The SAC-SMA has no explicit inclusion of measurable physical characteristics or processes for model basins, which limits estimations to watersheds with a gage for river stage observation (Committee to Assess the NWS AHPS 2006). A second model, SNOW-17, developed to estimate snow accumulation and ablation, tracks the water content in snow to predict spring runoff and available soil moisture during spring thaw. (Frozen Ground Modeling 2001) (Anderson 2006).

Non-stationarity creates a problem with predicting both long- and short-term hydrological events (Lima and Lall 2010). A properly calibrated model can still incorrectly forecast an event due to assumption of stationarity (Refsgaard, et al. 2006). A growing realization of climate instability and uncertainty stemming from limited empirical data has instigated a movement toward non-stationarity when developing probability distributions and models based on historical data (Milly, et al. 2008) (Peel and Blöschl 2011).

Changes in surface coverage can impact more than runoff rates by directly affecting the stage height of floodwater. As floodwaters leave the river channel, velocity profiles change with the newly encountered friction values. Plants and other objects in the floodplain impede local flow and decrease velocity magnitudes, causing a hysteresis effect (Perumal, Shrestha and Chaube 2004). The inversely proportional relationship between velocity and flow-path area then causes an increase in stage height to accommodate the fixed discharge value.

3.1.2.1 Long-Term Floods

Long-term flooding generally occurs along rivers. These major waterways correlate to large basins with substantial baseflow. Single-storm events typically have little impact on streamflow (Committee on Developing Mesoscale Meteorological Observational Capabilities to Meet Multiple National Needs 2009). Long-term flooding instead originates in a series of precipitation events, the effect of which becomes compounded when basin travel times, for runoff, coincide with additional precipitation events. Thus hydraulic equations and open channel flow characteristics; such as slope, width, bottom, and bank roughness; govern long-term flood forecasting.

Forecasts for these multi-event, basin-scale events originate at the regional River Forecasting Center (RFC) and are distributed to local offices. The forecast is top-down in nature, but model data inputs are funneled through the local NWS offices to the RFC from intra- and inter-agency resources. NWS Weather Forecasting Offices (WFOs) gather the data from United States Geological Survey (USGS) gages, United States Army Corps of Engineers (USACE) gages, and local NWS sources; such as spotters, radar, and precipitation gages. RFC estimations are also compared to USACE models before final results are released to stakeholders (Wolf 2010).

The NWS River Forecast System (NWSRFS) governs NWS software for hydrologic, hydraulic, and data management operations (NWSRFS Overview 2011). A combination of three systems performs the necessary tasks within the NWSRFS. Model calibration is the key part, and uses a historical time series of streamflow and mean areal estimations of precipitation, temperature, and other raw data from the National Climate Data Center (NCDC). The Ensemble Streamflow Prediction System (ESP) utilizes a combination of hydrologic models, hydraulic models, and statistical analysis. The

Operation Forecast System (OFS) incorporates real-time observed and projected data, hydromet analysis, hydrologic models, hydraulic models, and no provision for run-time adjustments.

Traditionally, a suite of model parameters have been fed into algorithms based within RFC-specific application program interfaces (APIs). Models then estimated surface runoff based on an index of the stored basin moisture, physical basin characteristics, time of year, storm duration, rainfall amount, and rainfall intensity. More recently, models have begun including increasingly fine spatial and temporal scales, and physically based processing equations, instead of traditional parametric equations.

The local forecasting software programs compose the Weather Forecast Office Hydrologic Forecast System (WHFS) part of the Advanced Weather Interactive Processing System (AWIPS) (AWIPS 2011). The system is designed to compile all hydrologic information needs on the same workstation as the meteorological program (WFO Hydrologic Forecast System 2011).

The WHFS software includes HydroView, HydroBase, and RiverPro. HydroView is a hydrologic data viewing system, which enables users to view hydrologic situations through a geographical view, temporal graphic, tabular display and cross-section profile. An available menu also enables access to flood category, historic crest, impact potential, and contact individuals at each river forecast point. Users can also access detailed information at locations of dams along waterways (WFO Hydrologic Forecast System 2011).

HydroBase acts as a database manager for all of the information related to hydrology. There are no operational uses for HydroBase during an event. Instead, the importance of HydroBase is to ensure other operational software has access to accurate and relevant data (WFO Hydrologic Forecast System 2011).

RiverPro creates the final output form HydroView and HydroBase. Whereas HydroBase controls the inflow of data and HydroView provides a forecasting platform for the forecast, RiverPro automates the outputs for public consumption. These products are based on customized templates, which are designed separately by each office. The program also, by default, recommends the most severe scenario based on maximum observed stages. Forecasters can then select data points and products as desired before issuing the forecast (WFO Hydrologic Forecast System 2011).

Text-based forecasts are outputted to the public and media through the WarnGen system. The standardized format allows for automated reuse on multiple media. News outlets are familiar with the standardized system and computers digitize the words into spoken text for weather radio. The text is also available for consumption via the NWS local forecast website (Wolf 2010).

The ease of use provided by WarnGen allows forecasters to produce and output simplified forecasts. However, the system has problems with clarity for inexperienced users. The structured output works well for computers, but has approachability problems (Wolf 2010). Changing over to a graphics-based or mixed text and graphics system is suggested to potentially alleviate these comprehension problems. Users may find interactive graphics with pop-up explanations more intuitive and comprehensible than the separated text and map forecasts currently in existence.

In addition to forecast dissemination methods, the strain put on forecasters to act as scientists and coordinators places potentially too many needs on one individual. Forecasters, when working with county-level emergency managers, attempt to address local needs and coordinate with the RFC to fulfill those needs. This includes some of the coordination facilitated by the IHSEMD EOC and WebEOC. For example, NWS local WFOs can become involved in finding volunteers from various agencies for sandbagging activities and pinpointing the crucial locations to protect during a flood event.

The coordination role of WFOs establishes them as a liaison for the regional RFC. This is especially true due to a lack of direct interaction between RFCs and public entities. Therefore, WFOs inherit the task of communicating forecasts to local officials, such as the county-level emergency managers (Wolf 2010).

Forecasters use a qualitative scale to communicate forecast urgency to stakeholders. These qualitative statements turn forecasts into action statements (Gruntfest and Handmer 2001). For example, the long-term flood forecast process begins one week in advance of an event with the *outlook* stage. At this stage, the forecast is not tailored directly for emergency managers and is disseminated passively through the website. The forecast is also based on 20 percent occurrence probability likelihood (Wolf 2010).

Forecasts transition from *outlook* to *watch* at a two to three day lead-time. The *watch* designation is associated with 50 percent occurrence probability likelihood. This is also when the local WFO contacts pertinent emergency managers via a conference call (Wolf 2010).

Emergency managers gauge response based on the tone of the forecaster. This personal forecast issuance helps managers determine level of concern among forecasters and the uncertainty in the forecast. Furthermore, forecasters often change working language as necessary. For example, forecasters often refer to uncertainty as *confidence level* when working with emergency managers (Wolf 2010).

Personnel at the WFO continue to stay in direct contact with emergency managers as occurrence probabilities increase. Figure 3-1 illustrates the interplay between forecasters, data sources, and stakeholders during the decision making process to establish a *warning*. This level corresponds to the highest qualitative probability measure for a forecast and is the next increment after *advisory*. The two forecasting terms represent 80 and 60 percent occurrence likelihood probabilities and forecasters only issue them when the expected arrival time is imminent (Wolf 2010).

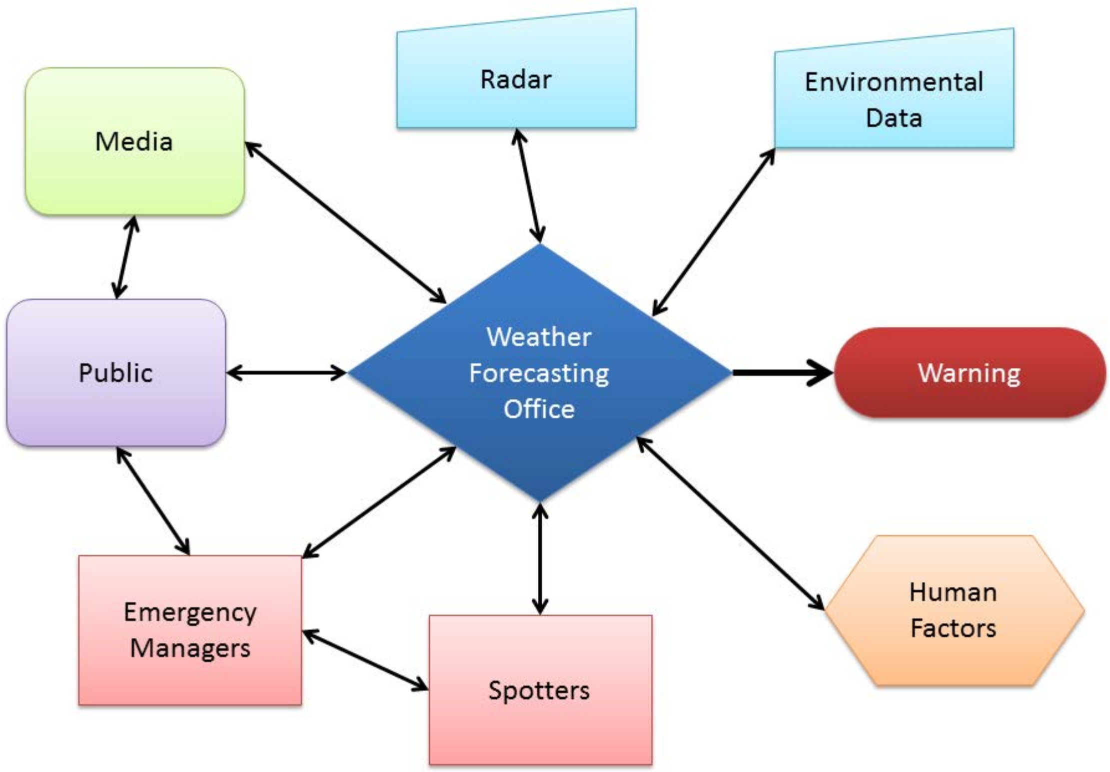

Figure 3-1. Reproduction of forecast decision making flowchart provided by Ray Wolf.

Phone calls during the lead up to an event provide a simple method for forecast clarification. Emergency managers can ask forecasters for explanations through direct questions. This is often also used during flood events to help managers assess needed changes. NWS Forecasters are currently developing a podcast system to verbalize forecast explanations in an automated and constantly available platform. Ultimately, these and a variety of other techniques are employed in disseminating forecasts, including "warnings," as illustrated in Figure 3-2.

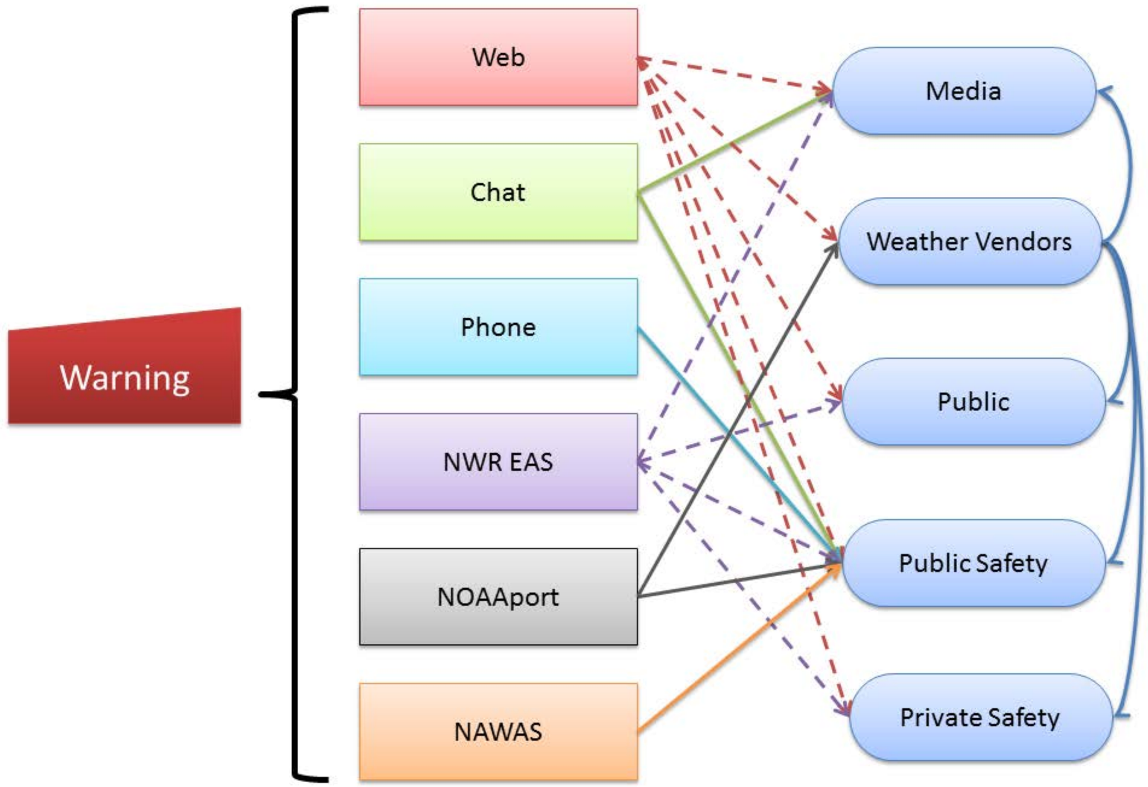

Figure 3-2. Forecast dissemination through multiple portals leads to a multitude of interconnected stakeholders.

3.1.2.2 Short-Term Floods

Short-term flood events, referred to as flash floods, are precipitation event driven. Discharge spikes quickly, generally in 10 to 30 minutes, and significantly. Localized rainfall totals and topography, which determine runoff travel time, are two key characteristics for approximating the predicted discharge increase. Basin water storage capability, based on soil moisture content, is also important for estimating the total runoff potential (Committee on Developing Mesoscale Meteorological Observational Capabilities to Meet Multiple National Needs 2009). These parameters make flash floods especially challenging to forecast in terms of occurrence likelihood and magnitude (National Research Council's Board on Atmospheric Sciences and Climate 2005).

Flash flood forecasts are handled differently from long-term and major flooding. The NWS defines, for working purposes, a flash flood as lasting less than six hours (Weather Terms and Warning/Advisory Criteria 2011). As such, short-term forecasts for flash floods originate from local NWS offices due to the localized nature of the flood potential (Wolf 2010). These forecasts represent warnings for a geographical area and lack specific quantitative stage estimations (Weather Terms and Warning/Advisory Criteria 2011).

Forecasters at WFOs in Iowa use Flash Flood Guidance System (FFGS) to model flash flood potential and provide guidance on issuing flash flood statements. The FFGS operates as a deterministic system with watches and warnings being issued based on set exceedance thresholds (Villarini, et al. 2010). Three values are synonymously modeled to return a deterministic prediction of a higher than bankfull discharge: estimated precipitation, soil moisture, and runoff.

The model processing algorithms incur uncertainty due to reliability of the input data. As noted in section 3.1.1 Forecast Hardware, areal rainfall estimation contains inherent uncertainty. However, the uncertainty of Quantitative Precipitation Estimations (QPEs), created from multisensory precipitation estimation, is not quantified. Similarly, Quantitative Precipitation Forecasts have application issues within FFGS due to the intended designs. The QPFs match meteorological needs better than hydrological purposes because the verification of accuracy and performance is neither consistent nor calibrated with other hydrological models (Committee to Assess the NWS AHPS 2006).

Soil moisture estimations, based on a continuous model, also have associated uncertainty, which combine with rainfall uncertainty when estimating runoff. Simultaneously, the discharge model uses Snyder’s synthetic unit hydrograph; which is based on effective rainfall duration, peak direct runoff rate, and basin lag time; and 2- to 5-year return period flows to back calculate the threshold runoff. However, Ntelekos, et al. (2006) argued that 2-year return period events may not equal bankfull discharge return period, and suggested a range of 1- to 32-year return period discharges with an average 1.5-year return period more closely matched the actual bankfull conditions than the current FFGS methodology (Ntelekos, Georgakakas and Krajewski 2006).

The deterministic output from FFGS fails to detail the uncertainties within a flash forecast. Therefore, a potential exists for poor quality inputs without explicitly apparent poor quality outputs. Villarini, et al. (2010) analyzed the possibility of converting to a probabilistic system. Thus uncertainty within radar-rainfall estimation and FFGS would be clear (Villarini, et al. 2010).

FFMP; a collaboration between NWS, National Severe Storms Laboratory (NSSL), and the National Center for Atmospheric Research (NCAR); works within AWIPS to illustrate flash flood forecasts and provide warning guidance. This software allows forecasters to rapidly queue model outputs as a graphic depiction of local conditions. Forecasters use information from both a map and a table with names, rates, QPE, FFG, rates of QPE divided by FFG and absolute difference between QPE and FFG (FFMP Frequently Asked Questions 2011).

Regardless of the forecast modeling and dissemination methods, flash floods are sudden occurring, typically violent and terrifying, located in unexpected places, localized scale, rare, and short in duration. Ensuring an accurate and well disseminated forecast with significant lead time can potentially save lives and reduce community disruption. This includes either under- or over-estimating hydrological events. An appropriate early warning system should then properly interpret flood predictions, have meaning for target audiences, communicate messages through appropriate methods, be based on user requirements, and undergo continuous review as local needs change.

3.1.3 Forecast Output

Daily forecasts from the NWS are output to the public as media releases to local news, postings on the website, and weather radio broadcast. Emergency forecasting changes the dynamic of disseminating the forecast with emergency broadcasts on weather radios and phone calls to emergency managers. The NWS Weather Forecast Offices (WFOs) enlist the entire staff during an event to contribute to forecasting and communication via HAM radio, TV stations, weather radio, websites, and telephones (Wolf 2010).

The entire group is necessary to continuously staff the office during each 24-hour cycle with forecasters and a dedicated communications officer. Multiple forecasters are also needed because each forecaster focuses on only one element of the event. This single-task approach is intended to ensure each forecast is produced in a timely manner (Wolf 2010).

From there, a smooth transition between information and action is one of the key parts of managing any emergency event. According to Ray Wolf, Science and Operations Officer for the National Weather Service (NWS) in Davenport, Iowa, county-level emergency managers, in Iowa, receive forecasts directly from the NWS local offices (Wolf 2010). Emergency managers next must try to convert these forecasts into action. However, as Tom Oswald of the Iowa Homeland Security and Emergency Management Division (IHSEMD) noted, few county-level emergency managers in Iowa have any formal training in hydrological or meteoroligical forecasting.

Forecasters are obliged to translate forecasts into common terminology and present forecasts in a simplified format. Ideally, managers would prefer definitive answers and this need manifests itself as a request for advice from the forecaster. NWS WFOs act strictly as information sources and may not provide advice to emergency managers (Wolf 2010).

The NWS employs a variety of methods to disseminate forecasts for the public. These include text, audio, and graphical representations. Audio broadcasts via weather radio are the most proactive form of communication from the NWS. Text and graphical forecasts are both available via the Internet and require active consumption.

The AHPS provides a web-based source of information for all stakeholders. The NWS, intending to modernize available forecast products, uses AHPS to illustrate satellite and radar data, graphical forecasts, and regional maps (AHPS 2011) (Committee to Assess the NWS AHPS 2006). The website provides maps for a graphical interface to select and illustrate ascertain local conditions (Water: River Observations 2011).

The NWS uses AHPS to distribute minimized gage information to the public. Other information, such as detailed station and flood history, is formatted for in-house use during hydrologic event prediction. Keeping these detailed records are important, especially flood history, because the NWS is expected to correctly forecast every event, including low probability occurrences.

AHPS also provides a singular location for everyone to access information available from and through the NWS. Users have information compiled for them and regional predictions are clearly marked on maps. This system, which includes the USGS streamflow gage data network, shows river gages throughout the United States (USGS 2011). The gages are color-coded based on a comparative flooding scale, ranging from no flooding to major flooding. The color-coding, only applied to gages with data less than 24 hours old, enables users to visualize regional flooding patterns in relative real-time (AHPS 2011).

Iowa Flood Information System (IFIS), a recently introduced product from the Iowa Flood Center (IFC), is another map-based forecast dissemination platform encompassing only the state of Iowa. Similar in function to the AHPS platform, IFIS provides users with an interactive map containing color-coded gaging stations. These stream gages include IFC bridge sensors and USGS gages, each station host indicated by the color. Unlike AHPS, IFIS indicates flooding rivers with a separate icon, which only appears when the waterway is either at or approaching flood stage (IFC 2011).

The two systems, AHPS and IFC, both provide hydrographs with mapped locations and clear flood level indicators for each gage. Yet, the systems contain some differences in the presentation of the hydrographs. AHPS presents a multi-day, static hydrograph with stage height and estimated discharge (AHPS 2011). Long-term, the NWS plans to upgrade these static hydrographs to include forecasted river levels, weekly flow probabilities, and monthly flow probabilities (Committee to Assess the NWS AHPS 2006).

IFIS contains an interactive hydrograph showing the conditions for each day of the hydrograph and corresponding gage heights. Users can move a tool along the hydrograph with a popup snapshot of the selected stage and a visual of the stage level within a basic river cross section (IFC 2011).

Another difference between AHPS and IFIS is the map hosting. AHPS uses a static map without a scrollable zoom function, which confines user selection to specific political regions, demonstrated by Figure 3-3. The IFIS map runs on an embedded Google Map with scrollable zoom capabilities and the ability to host layer selection, as shown in Figure 3-4. Users can select which layers to make visible and, once a community is selected, are provided with a graphic of the upstream watershed boundary. This also limits the visible gages to those within the watershed for the selected community (IFC 2011). Thus IFIS operates on a basin presentation method.

The watershed limiting system creates an environment in which a user can select a community and receive a filtered response from the system. These filters thus act to tailor information provided to a user based on familiar landmarks, instead of requiring users to choose pertinent gages from a nationwide map.

Another localized feature is available through IFIS and differentiates IFIS from AHPS. IFIS users can interact with municipality-level inundation maps. These maps are available for six Iowa communities and demonstrate the relationship between stage, discharge, and inundation area (IFC 2011). AHPS also has been planning to add this feature to municipalities nationwide since 2005 (Committee to Assess the NWS AHPS 2006). A continuous of these maps would potentially allow individual users throughout the nation to visualize flood risk with previously unknown clarity as predicted inundation maps.

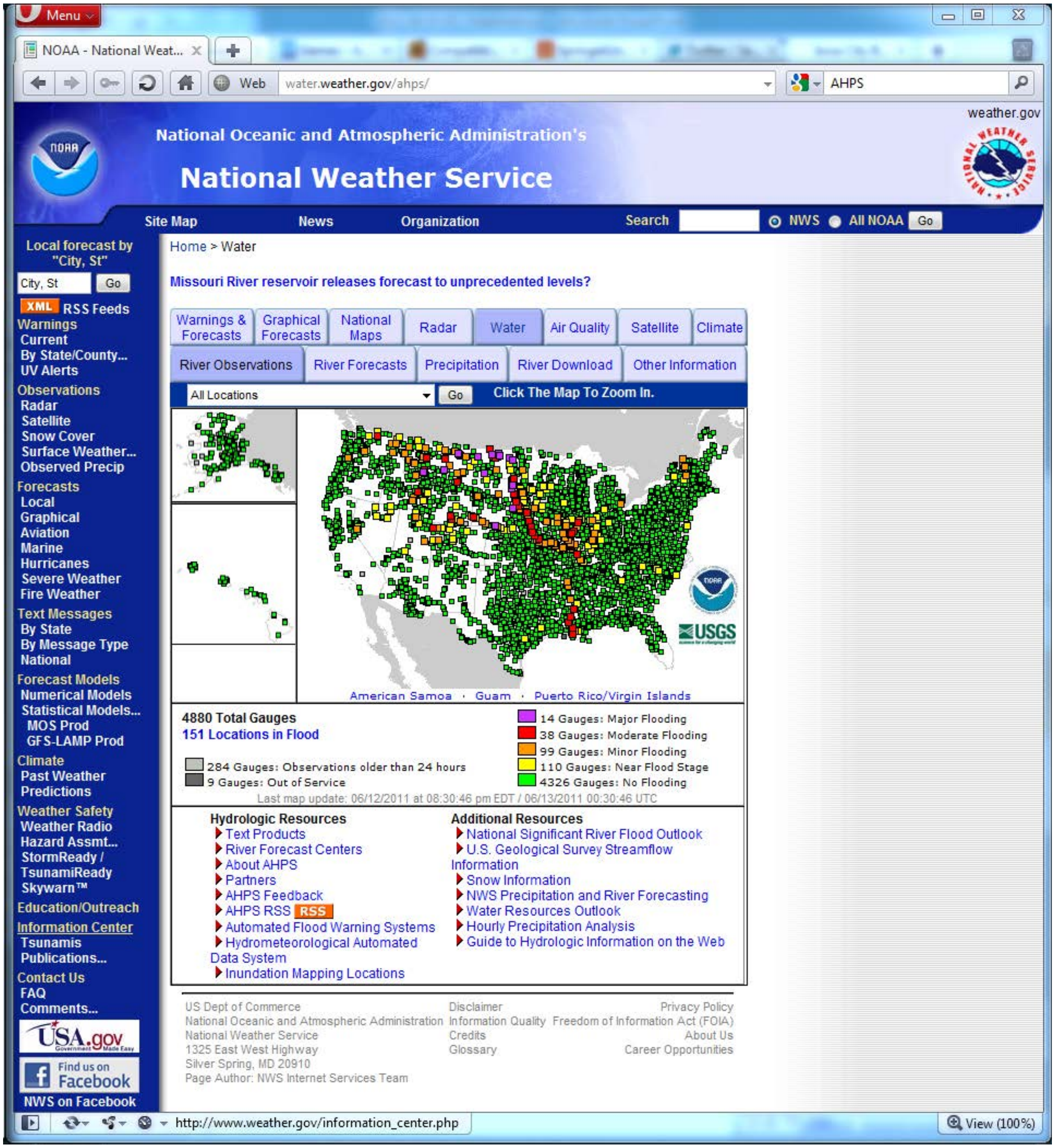

Figure 3-3. The AHPS interface provides users with a graphical representation of current conditions and forecasts through symbolic color coding.

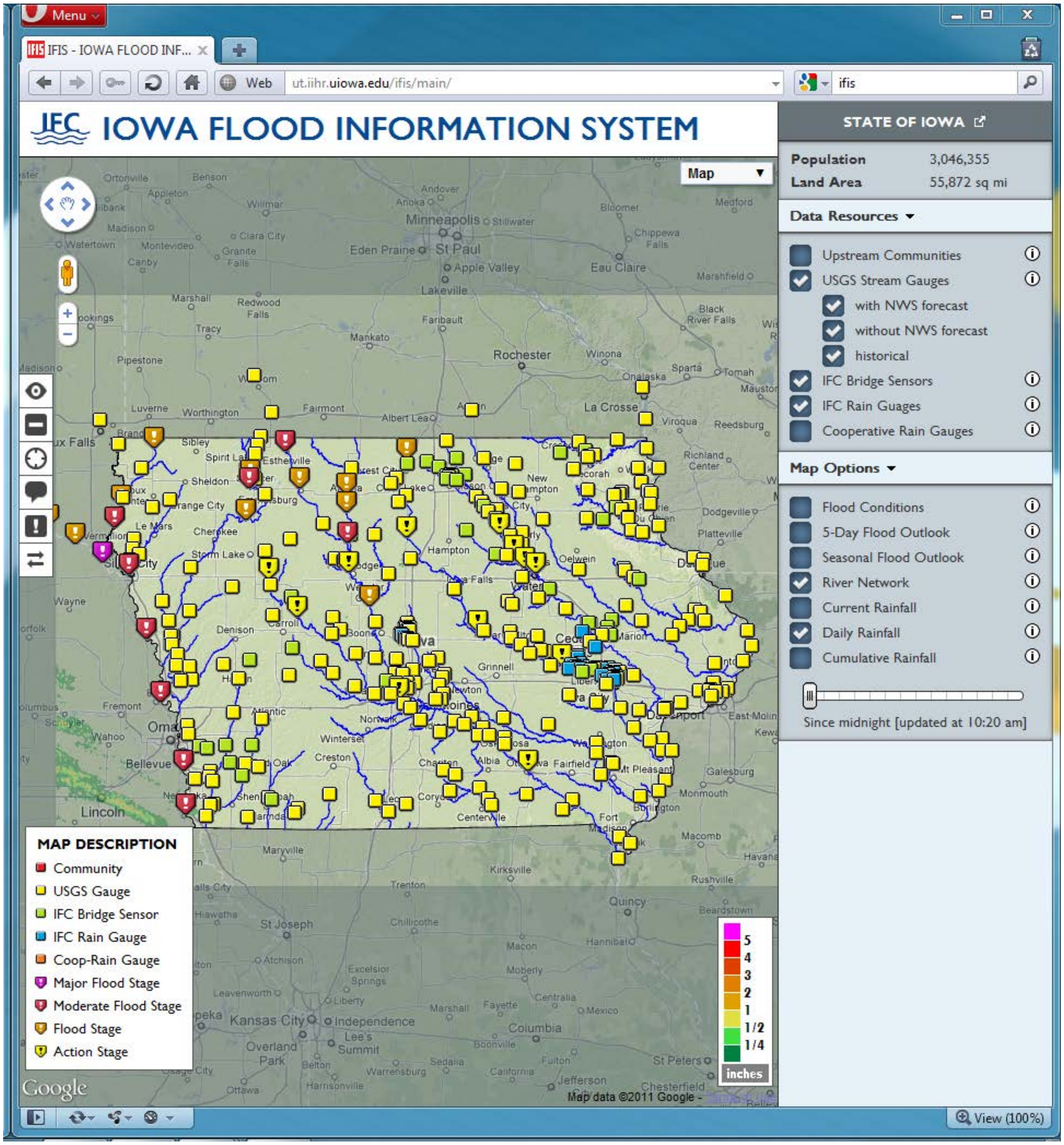

Figure 3-4. The IFIS website allows users to dynamically zoom on regions of the state and focus on specific watersheds to filter information based on personal need and relevant locale.

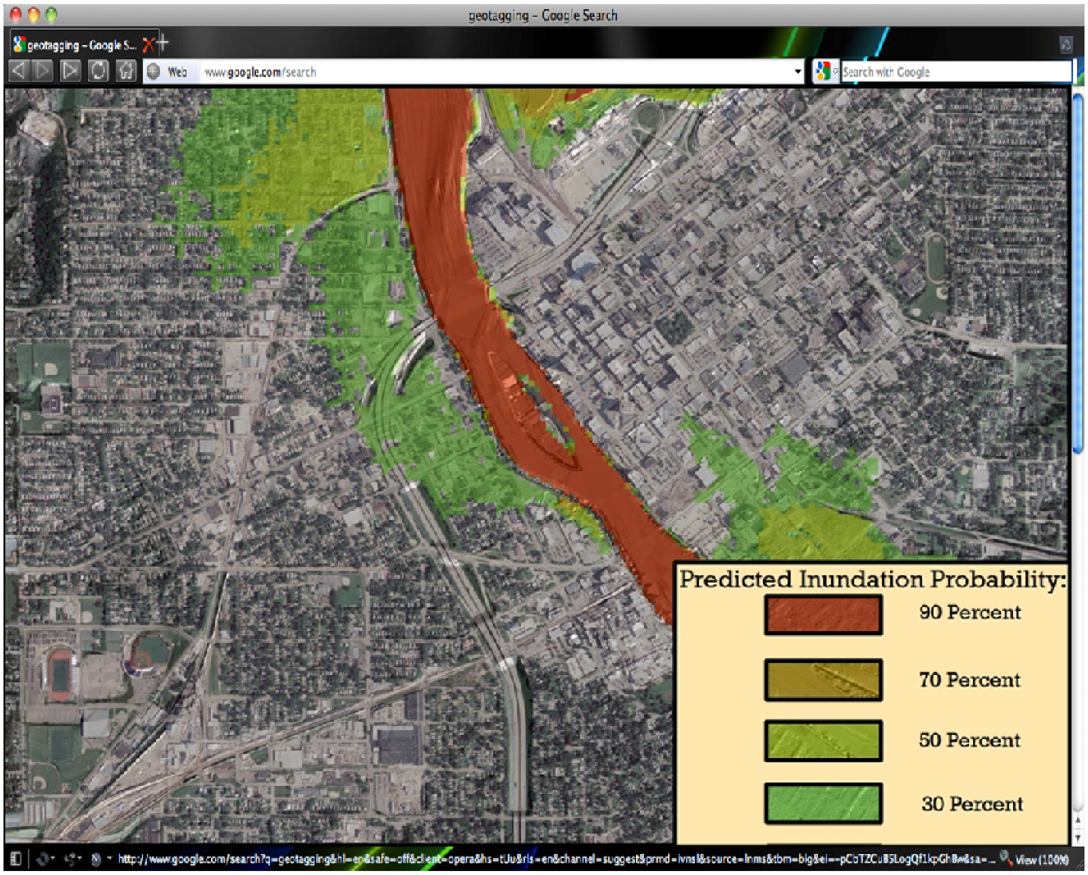

Figure 3-5. A mock-up of a probabilistic inundation forecast displayed as a 2D map within a Google Map interface in a web browser.

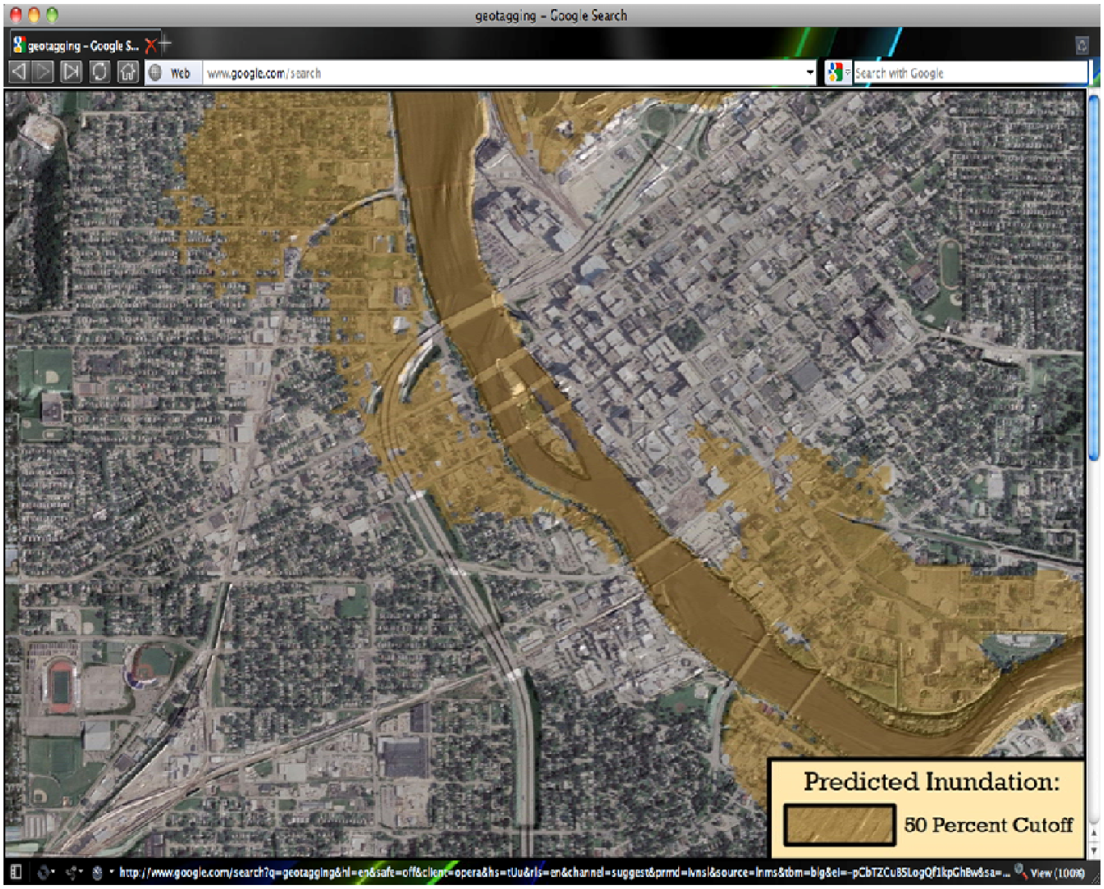

Figure 3-6. A mock-up of deterministic inundation forecast displayed as a 2D map within a Google Map interface in a web browser.

3.2 Mapping

3.2.1 Two Dimensions

Spatial triggers and dynamic routing represent two potential methods for minimizing external stresses during flood response. These two services, provided to individuals by a centralized source, could both increase awareness of potential dangers within a geographical region and help reduce or prevent the paralysis caused by hypervigilance during an emergency event. The stress caused by attempting to determine the shortest escape route or a safe location during an emergency can often overwhelm an individual. This is especially true while trying to process information about an unfamiliar locality (Ozel 2001).

3.2.1.1 Spatial Triggers

Regardless of familiarity with a local area, individuals can be caught unaware during a flood event. Flash floods are a prime example of this scenario and lack of communication, as demonstrated by the flash flooding along the Little Missouri in June of 2010, can result in lost lives (Mayerowitz 2010). Designing a system automatically to notify people within a flash flood warning area would bring up to date information to people and, potentially, save lives.

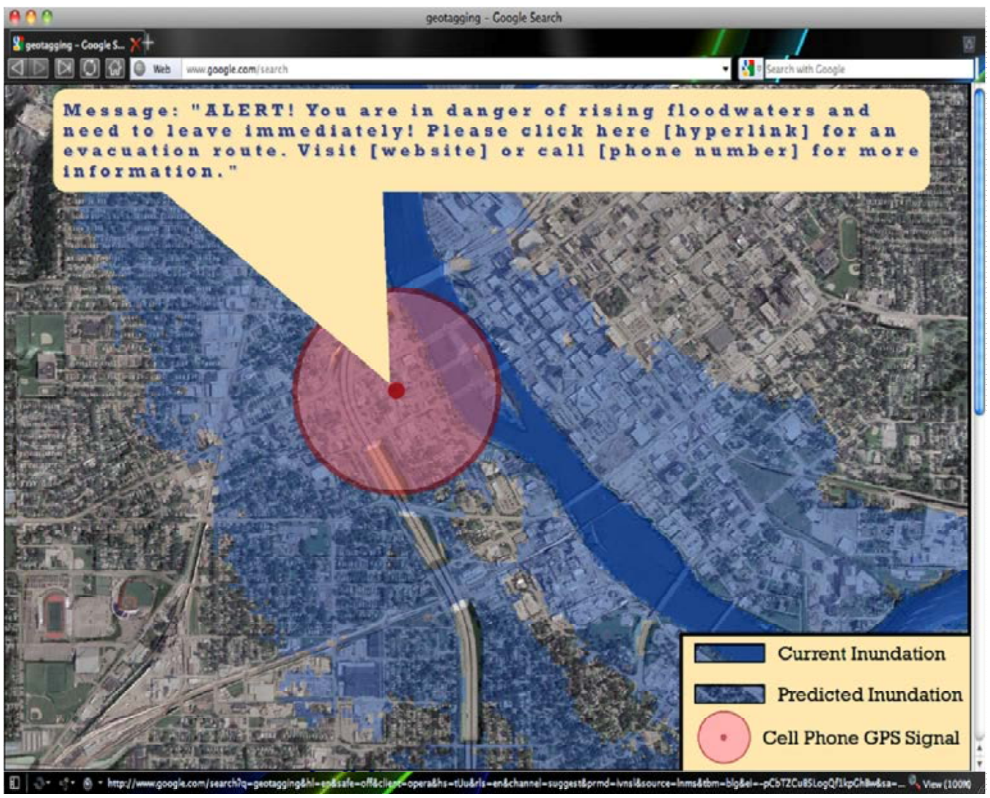

Figure 3-7. A mock-up of a spatial trigger based on predicted inundation, displayed as a 2D Google Map interface in a web browser.

Spatial triggers consist of various query functions, each of which activates a response depending on the proximity of the user. Any individual carrying a GPS and web-capable device can act as a user. The spatial trigger system automatically follows the user and reacts when the user GPS signal moves into a triggered area (Bennett, Armstrong and Mount 2007).

Evacuation notification provides a perfect application for spatial triggers. People within a geographical region slated for evacuation could be notified based on their location. This location-based notification system is demonstrated in Figure 3-7. The evacuation route could also be tailored for the individual with consideration for variables, such as chokepoints, threatened bridges, and unsafe roadways.

Spatial triggers could also be used to positively identify individuals within predicted inundation zones. Differing from a simple evacuation announcement or warning system, such notifications would provide additional information to the individual. This would be applicable for both flash and long-term flood events, satisfying the need for warning during a flash flood and providing accurate information during long-term flooding (Contributor 2011). Furthermore, the notification could include location-relevant information, such as a predicted inundation map with estimated depth at the given coordinates, which reduces the need for individuals to filter pertinent data themselves.

A final application for spatial triggers is in task distribution. Emergency responders carrying a mobile data capable device could instantly receive tasks and task updates when entering an area. The packets of information could contain a list of local tasks, the corresponding skills and resources needed, and a link to an Augmented Reality service containing additional information, including to-do lists tagged to each building.

3.2.1.2 Smartphones

Smartphones have the most potential to facilitate spatial triggers and dynamic routing as new flood response technologies. These are uniquely capable devices with built-in capabilities, such as GPS, mapping services, powerful processing hardware, radio signal, and expandable software applications. Cell phones usage among young adults has also become nearly ubiquitous at 93 percent ownership, which translates into the capability of emergency managers to instantaneously reach nine out of every ten young adults during an emergency event (Lenhart, et al. 2010).

Mobile and wireless Internet use, required to tap all of the potential in smartphones, is less common than standard cell phone usage. However, 81 percent of young adults use wireless Internet and may be ideal candidates for mobile-based forecasting, mapping, and communication services. An additional 63 percent of the mid-age adults, 30 to 49 years old, and 34 percent of the oldest age group, 50 and above, use wireless Internet. Racial demographics show another usage disparity; wireless data use is also more popular among African Americans than white and Hispanic adults. Therefore, care should be taken when designing services to address the varying needs of users spanning diverse demographical backgrounds (Lenhart, et al. 2010).

3.2.1.3 Mapping Services

Combining the communication ability afforded by smartphone proliferation with geospatial referencing creates the potential for a broadcast warning system capable of issuing personalized information and response details. Furthermore, the features available in mobile phones enable use of new mapping technologies, including navigation and tracking. Crowdsource technology, the use of pooled tracking data from anonymous users, already has a variety of applications. For example, Google Maps, a mainstay of mobile mapping services with 200 million users, utilizes crowdsourcing to report traffic patterns to users (Sanglap 2011) (Barth 2009). Figure 3-8 illustrates color-coded traffic patterns within Google Maps, which are displayed within the mobile interface using the colors as an intuitive qualitative scale.

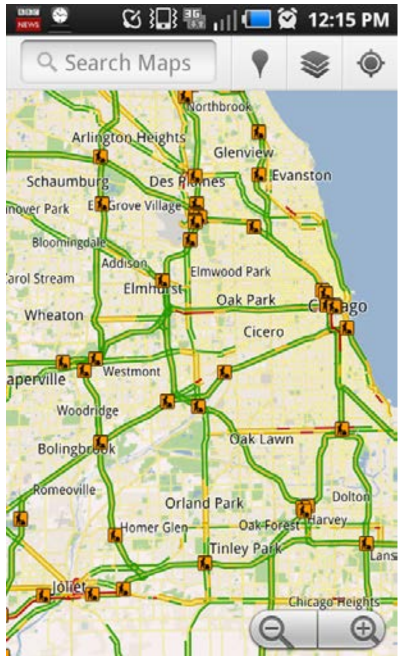

Figure 3-8. Screenshot of mobile Google Maps illustrating traffic congestion within the Chicago area.

The GPS capabilities of smartphones provide a potential platform for spatial triggering. An application, such as Google Maps, with widespread use could include emergency-related layers, which would include polygons corresponding to predicted inundations, evacuation zones, and flash flood warning areas. The Google Maps application, or a third party application with embedded Google Maps, could automatically push and obtain information based on location of the user in conjunction with emergency-related layers. This has the potential to help individuals realize actual risks during events, which could reduce actions taken due to perceived, and possibly false, risk (Rogers 1997) (Hayes 2009).

The spatial trigger concept has already begun to develop commercially in areas outside of emergency response. Apple will be introducing a mobile application called Reminders for the fifth generation of the iOS mobile operating system. The application will allow users to set event and task reminders with both temporal and geographical referencing. For example, users can type in a list of groceries and set the list to pop up automatically on their phone when they enter the grocery store (Reminders 2011).

3.2.1.4 Dynamic Routing

Once spatial triggers alert users to potential danger, dynamic routing can be used to move them out of danger. Dynamic routing would be based on Dijkstra's algorithm, which could map efficient routes for smartphone users during a flood event. The algorithm plots nodes and pathways iteratively from the beginning point to the destination. Every pathway around each node is analyzed and the shortest path is chosen between each node. A software program on a server could host and compare all of the routes to minimize travel times based on the entire user set.

A method currently being studied by Jerry Mount, a PhD candidate in the Department of Geography at the University of Iowa, tabulates routes to create dynamically changing routes. The scripts that he has designed have the potential to work on a large-scale for routing, and rerouting, individuals as needed. The routes are developed based on two different premises, depending on local constraints.

3.2.1.4.1 Time Constraint

The first type of routing is a set number of pathways and a compilation of all routes between two points along the available pathways, which have been constricted by a set amount of total time. This method compiles every possible route with no restrictions along the pathways. The only constriction is the total amount of time available to traverse the route, which is illustrated in Figure 3-9 and Figure 3-10 illustrate the reduction of pathways as total available time is constricted. Currently, mapping the entire queue of routes takes approximately 100 milliseconds to compute with the inclusion of time constraints.

Figure 3-9. An outline of every route possible between two points within a given time span. Courtesy of Jerry Mount.

Figure 3-10. An outline of every route possible between two points after reducing total time from Figure 3-9. Courtesy of Jerry Mount.

3.2.1.4.2 Physical Constraint

Obstacles to evacuation are important considerations when designing evacuation routes for citizens. This is especially true in large metropolitan areas, exemplified by two major traffic jams caused by evacuations for Hurricanes George, in 1998, and Floyd, in 1999. These inspired a survey of evacuation plans throughout the United States and a review of the inclusion of transportation officials in designing evacuation plans (Urbina and Wolshon 2003).

Despite retooling of evacuation plans in the early 2000s, evacuation related disasters occurred again in 2005. Deaths and injury caused by Hurricane Katrina, which killed 1800 people, were blamed partially on the Mayor of New Orleans delaying a mandatory evacuation. The Mayor of Houston, responding to Hurricane Rita approximately one month after Hurricane Katrina, acted in the opposite manner with an early evacuation of all residents. This response clogged roadways and blocked in citizens located in the highest risk areas (Harris 2011).

The problem of evacuation gridlock extends beyond occurrences to plans. During the Three Mile Island event in 1979, the Governor of Pennsylvania reviewed evacuation plans for local counties. The review found that two counties planned on evacuating the entire population of each over the same bridge in either direction. This plan, while appropriate on a county level, disregarded the potential for multi-county or regional emergencies (Harris 2011).

Dynamic routing has the potential to circumvent the problems faced during large-scale evacuation. Total space available on roadways is an unavoidable problem, yet, dynamic routing can reorganize traffic flow patterns to alleviate gridlock. The concept utilizes one starting location and end location, for each vehicle-based user, with sensitivity to obstructions.

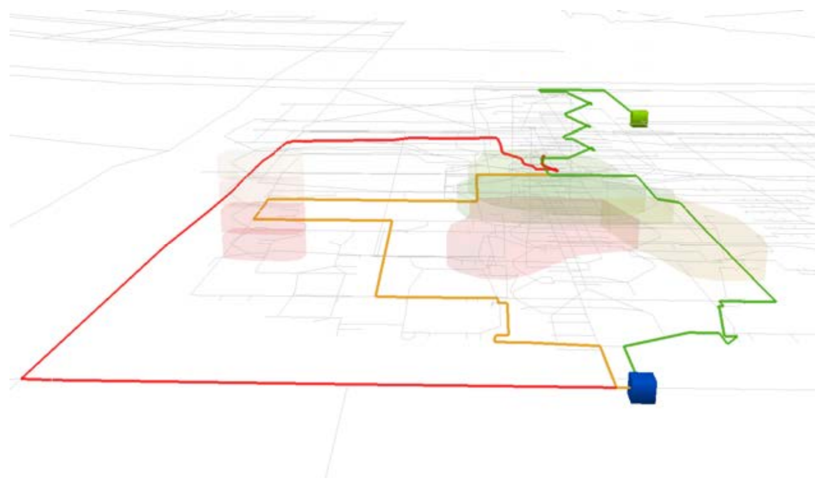

Figure 3-11. A 3D view of various escape routes from a burning building. The inclusion of a stairwell is notable due to the required elimination of elevators as an option during a fire. Such details must be considered when designing similar routing systems for flood events. Courtesy of Jerry Mount.

The routing method begins with the selection of the shortest route for each user between the origin and a safe location. Rerouting occurs every time an obstacle blocks one of the pathways. These obstacles are shown as shaded regions in Figure 3-11. In the figures, the obstacles represent a fire spreading through a building. During flood response, obstacles could include dangerous bridges, traffic jams, washed out roadways, etc. These result in a dynamically changing route intended to keep every individual user moving within the system, regardless of physical constraints.

3.2.2 Three Dimensions

Augmented Reality (AR) represents a user interface meshing together technologies related to virtual environments and mobile computing to augment the real world. Unlike standard virtual reality, which creates an entirely new environment, augmented reality enhances the landscape with information and illustrations. These digital overlays are commonly referred to as layers, services or channels. To plot these layers, mobile devices need a GPS, compass, camera, accelerometer, Internet connection, and optional gyroscope. The applications for flood response would utilize this graphically displayed information to distribute geospatially pertinent data to users in a three-dimensional environment.

3.2.2.1 Early Applications

A simple way to describe AR is as the intermediary between Virtual Reality (VR) and telepresence (Azuma 1997). Virtual Environments, the experiential part of VR, completely immerse the user, whereas a user of telepresence technology, while working remotely, loses sense of distance. Video conferencing and remote controlled aircraft are prime examples of telepresence technologies. AR is intended to keep the user rooted in the real world, unlike VR, and interacting with localized media (Azuma 1997).

The definition of AR technology can be delimited by three criteria. First, AR must combine real and virtual in the visual display. Second, real time interactivity is required to separate AR from static video. Third, objects exist in a three-dimensional (3D) environment, which creates a realistic portrayal of real-world objects (Azuma 1997).

An AR tour of Columbia University, in New York City, New York, created in 1997 by researchers in the Department of Computer Science and Graduate School of Architecture, Planning, and Preservation, , exemplifies an early attempt at goereferenced AR. Photographs, such as Figure 3-12, illustrate a tour designed to introduce visitors to various campus landmarks through the use of two visual displays and a global positioning system (GPS) tracking device. In the description, a set of transparent 3D display goggles, with GPS tracking, combine with a two-dimensional (2D) handheld, tablet-style device utilizing stylus and trackpad input. Significant advances in electronics make the separate 2D device and 3D goggles unnecessary because handheld devices now incorporate both a camera and higher screen resolutions than were available in 1997 (Feiner, et al. 1997).

Figure 3-12. Columbia University researchers use a set of transparent 3D display goggles, a GPS tracking device, a portable computer, and a two-dimensional (2D) handheld tablet with stylus and trackpad input (Feiner, et al. 1997).

Graphics in contemporary AR applications include a sense of depth unavailable in rudimentary AR devices. Furthermore, the original devices separated viewing and input with menu items appearing as selections on the goggles and input available through a track pad on the handheld. Users can now directly select from various menu choices, on the display, to receive additional information or remove augmentation graphics (Feiner, et al. 1997).

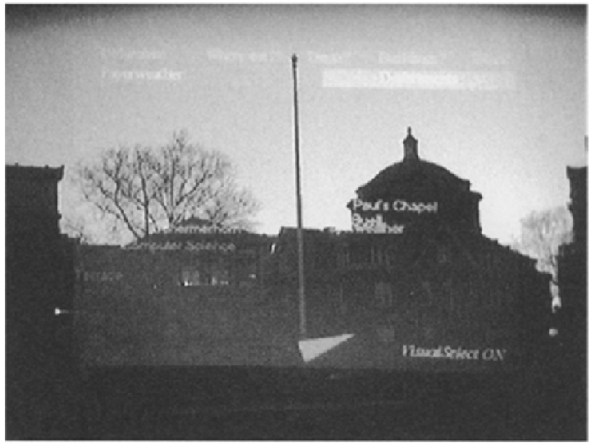

Figure 3-13. The view through goggles from a 1997 study by Columbia University in AR applications (Feiner, et al. 1997).

Navigation to points in the 3D AR world is possible. Figure 3-13demonstrates the usage of AR navigation as early as the tour created by the researchers at Columbia University. The photo shows an arrow being used for navigation to a building outside of direct visual contact by what the researchers explain to be green and red color indicators. The arrow stays green while the building is within the forward-facing viewing angle, but becomes red to indicate the user turned at least 90 degrees away from the building (Feiner, et al. 1997). Contemporary smartphone AR applications have similar features allowing for navigation and highlighting points within the viewing area.

The major limitations of the portable augmented reality systems are typically related to hardware. Published research includes mostly late 1990s era LCD displays and computing power available. Traditionally, the handheld quality of displays and tracking are two of the biggest problems researchers. Sunlight also exposes limitations from low resolutions on goggle-based systems. GPS technology is also dramatically improved in mobile devices with the inclusion of triangulation from cell signals (Feiner, et al. 1997) (Roxin, et al. 2007).

Incorporating underground objects and hidden infrastructure could also be useful for flood response (Feiner, et al. 1997). For example, devices could display a digital representation of basement structures, underground tunnels, stormwater drainage systems, and terrain-based flood control structures. Individuals unfamiliar with the surrounding terrain then use this information to change tactics as needed, such as adding sandbags around a stormwater drain connected to inundated areas and with the potential to allow backup behind a barrier.

Mobile interfacing in 3D, compared to 2D desktop computing, is also an excellent method for dealing with modern multi-tasking requirements (Fuhrmann, et al. 2002). This is becoming especially true as mobile devices have begun to support many abilities of desktop computers while adding collaborative capabilities. Mobile devices allow cooperation through the cloud concept supported by Google App Engine and other web-based application services (Buyya, Yeo and Venugopal 2008).

Collaboration via cloud-based data enables mobile device users to geotag specific locations. This process is essentially akin to placing virtual sticky notes throughout a landscape or local environment (Rekimoto, Ayatsuka and Hayashi 1998). Mobile device users thus add text, photos, audio, video, etc. to specific geospatially referenced locations. Previously only considered on a conceptual level or available as only a very rudimentary design, these personal annotations and dedicated geospatial services are now available through various mobile AR programs.

Personal annotation possibilities include ideas such as pop-ups moving into an AR device-wearing user’s field of vision in real time based on location and chronological order. For example, users could look through an AR enabled device at a piece of equipment, as shown in Figure 3-14, and see annotated comments created by other users. These comments could include problems discovered and tasks tried during troubleshooting. A similar concept is currently in production by Metaio, an AR software maker, who suggests digitizing operation manuals into 3D objects for simplified visualization of parts and troubleshooting ideas (Rekimoto, Ayatsuka and Hayashi 1998).

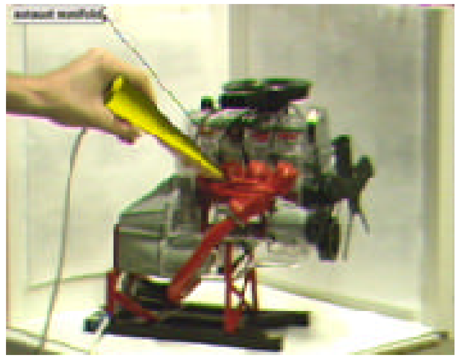

Figure 3-14. Individuals can use AR in a variety of work-related applications; especially during surgeries and repair work where important features are concealed. (Azuma 1997). Individuals can use AR in a similar context during floods to visualize infrastructure hidden by floodwaters.

Another potential used of geotagged AR is viewing restaurants and other commercial establishments through a mobile AR device (Rekimoto, Ayatsuka and Hayashi 1998). The user could view comments and reviews uploaded in real time by other users. This is a prime example of crowdsourcing dependent on new, instant access social media, such as Twitter, which allow users to instantaneously share thoughts and ideas with a wide audience (Twitter: About 2011).

Each geotagged comment, shared through a mobile device, has an associated location. This information from geo-referenced resources, such as Google Maps, can be made available in the AR environment. Users can thus access reviews, business hours, and other important details about any building before entering (Rekimoto, Ayatsuka and Hayashi 1998). These two types of information sources also have the potential to provide local, crowdsource-based, and static information about an individual user's surroundings during a flood event.

3.2.2.2 Crowdsourcing

Individuals, in the augmented response, act as information sources and sinks. Private citizens, broadcasting information regarding their current status, act as a source of information. These sources can provide a diverse network of data with very little individual burden. This could act through either an organized reporting program or the collection of anecdotal references throughout social media.

An organized program could directly invite the public to participate. A drop box for specifically requested information would be made available. Users would upload physical data or photographs as needed. This pooled data from volunteered sources could reduce demand on resources during a flood event and maximize data collection sites.

The IOWATER Program, run by the State of Iowa, is an existing example of a volunteer-based data collection program (DNR IOWATER Staff 2011). Volunteers are trained in data collection procedures and submit work via a website. A flood response program would have similar goals and function, but use social media to spread awareness and gather information while providing instructional videos on a video hosting website.

The second approach could avoid engaging data sources directly. Instead, computer software trolling for various keywords on social media websites can essentially work as impromptu survey data collectors (National Weather Service 2010). Polling in this method represents a non-scientific estimation of public needs during a flood event. The respondents would be limited to individuals using social media and not a representative sample. However, software, tallying instances of various words and phrases, could be used to provide emergency responders with an estimation of local citizens' current conditions, anxieties, and needs.

The purpose of the various information sources is to satisfy the information sinks. Everyone, in some capacity, acts as an information sink by looking for direction and information. Thus, social media can act as a tool to host information coordination between sources and sinks (Goecks and Mynatt 2004).

Social media provides a platform for interpreting raw data and results while also offering users redirection to primary, website-based information sources. Essentially, the social networking website acts as an intermediary to reach previously untapped audiences. Furthermore, unlike a standard website, social media, such as Facebook, allow organizations to actively reach out to stakeholders while providing a forum for discussion and feedback (Facebook 2011). Facebook members who have *liked* the organization's webpage receive constant updates on any activity the organization posts to the webpage, thus providing the organization with the ability to be proactive and approach users (Facebook 2011).

Social networks also allow circumvention of traditional, centralized data distribution. Each user can use social media to glean anecdotal information from other users. For example, an individual using Facebook or Twitter has access to live updates from anyone they choose. This potentially translates into instant, georeferenced messages providing information concerning local conditions. Furthermore, using social media, such as Flickr, enables individuals to bear direct witness to graphic depictions of local conditions with built-in geotagging capabilities (Flickr 2011).

Visual referencing can be used in conjunction with georeferencing or as a standalone system (Rekimoto, Ayatsuka and Hayashi 1998). In fact, visual references could easily work as a redundancy to geospatial cues. The visual cues are unaffected by any GPS inaccuracies and could easily be based on Quick Response (QR) codes, which are two-dimensional (2D) matrix barcodes. QR codes, illustrated as Figure 3-15, are already widely used and look very similar to the familiar Maxi codes used by the UPS for tracking packages (Denso Wave 2011).

Figure 3-15. A demonstration of QR codes. Left: the text "Iowa Flood Center." Right: a link to the Iowa Flood Center website.

A simple method of adding visual references to buildings could be on the building information signs. Printing a QR code to these signs, at a large enough scale to be easily scanned, enables users to have direct access to a dynamic database of building information. In fact, this allows access to more than text-based responses with websites, 3D objects, local AR channels, video, audio, 2D maps, photos, and other media all readily available via a QR code link.

A prime, implemented example of digital markers exists at the Augusta Canal National Heritage Area. A trail, following the original canal towpath, has three inch by seven inch markers denoted locations of historical significance, at approximately every half mile, along its route. Each marker has a QR code printed on it, which automatically directs users' handheld devices to the corresponding web address. This allows for minimal local signage and interpretation needs and enables administrators to change content with relative ease, compared to replacement of static displays (Augusta Canal 2011).

The usability of AR-capable devices is as important as the practicality of designing an AR system. Early iterations, such as those used in the Studierstube project and Columbia University, consist of a portable computer, head-mounted goggles, camera set, a GPS tracking device and a power source, which, combined, create a particularly complex assemblage. These devices are, as noted by Wagner, et al., inherently cumbersome and unwieldy for the average user. Furthermore, such complex appliances inhibit mass-scale testing of AR suitability for public consumption (Wagner, et al. 2005).

Cellular phones, personal digital assistants (PDAs), and tablet personal computers (PCs) are all potentially AR-capable. PDAs are an example of a device previously chosen due to their ubiquitous presence in society and expectedly flat learning curve. This can be proven exceptionally true when cataloguing public response to AR games, such as the *invisible train* game created for and hosted on PDAs (Wagner, et al. 2005).

Most users require little to no instruction when playing an AR game via touch interface. In fact, everyone, from computer science professionals to small children and senior citizens, can learn either by looking over another individual's shoulder or from being instruction by fellow users. This is true in a variety of situations from controlled environments to an uncontrolled exhibit at a museum (Wagner, et al. 2005).

The most promising feature of AR applications is the surprisingly intuitive interface. People with very little preconceived notions of technology, such as children, are some of the most receptive to this new technology (Wagner, et al. 2005). The biggest problem, outside of potential bugs in software interface, is generally battery life while maintaining GPS signal, running the camera and downloading data. However, AR capable devices for distributed to the public and responders should be as cohesive and indestructible as possible because of the fragility inherent in electronic hardware, especially in regards to wet environments.

3.2.2.3 Visualization

Augmented reality has the potential to help people visualize 2D maps in 3D. The possibilities include multi-user interactive geographical software environments. Users have the potential to interact with 2D, physical maps, with corresponding 3D components. Various triggers can be used, including hand gestures and symbols, to enable display of various map sections in 3D (Hedley, et al. 2002).

Zoom interactivity can allow a viewer to see increased detail, in a digitized and refreshable format, upon close inspection. Annotating a map in real time and make the annotations visible to other users adds a layer of communication unattainable through phone or text-based conversation. This real-time editing ability would be the most potent combined with streaming capabilities. Such maps could be used, as noted by the Hedley, et al, to illustrate inclement weather in 3D environment and aid in visualizing the resultant impacts on infrastructure. Including additional variables, these maps could also include the location of various emergency resources, known population movements, and illustrate the dangers of flood prone topography (Hedley, et al. 2002).

3.2.2.4 Summary

Many of the AR features previously hypothesized by researchers are now becoming possible for mainstream use. Smartphone hardware technology provides users with important capabilities to fully utilize AR, such as GPS, compass, camera, accelerometer and Internet connectivity (The Layar Platform 2011). This provides a host of mobile opportunities, such as georeferenced notes, 3D images of predicted flood inundation, georeferenced instruction videos, interactive building information overlays, and digital representations of infrastructure covered by floodwaters.

3.3 Communication

Clear communication is crucial during an emergency event. This includes communication both within and outside the emergency response team. The public needs information from managers, especially in the areas most at risk. Simultaneously, responders need updates from management and the ability to cross-communicate between peers.

The Incident Command System (ICS) requires that top-down communication be available during an emergency response. In fact, the ICS 205 form was created and made available by the Federal Emergency Management Agency (FEMA) for developing common communication plans (Emergency Management Institute 2011). FEMA considers clear links between operational and support units to be critical facilitate clear organization and execution of plans during the dynamic environment of an emergency event.

Tom Oswald, of the Iowa Homeland Security and Emergency Management Division (IHSEMD), confirmed the use of the ICS by county-level emergency managers in the State of Iowa and the reliance on clear communication channels (Oswald 2011). County emergency managers, according to Oswald, act as the Incident Commander, top administrator, of every emergency operation. The county-level manager has the final say for anything within the county and is the highest level of response for emergencies in Iowa. This fact becomes most important during multi-county floods, which require cross-county collaboration and coordination.

State and Federal agencies always act in a support-only role during flood events in Iowa. The IHSEMD never seizes control of response management. Instead, the division provides a support system for counties, which includes an instant messaging tool for communication between counties, state entities, federal agencies, and other resource providers.

The instant messaging tool is hosted by WebEOC, a Crisis Information Management Software (CIMS) tool, and enables connections between various agencies for efficient resource distribution (WebEOC 2011). Yet, this communication network is merely a platform without any oversight for coordinating resources. From discussions with Oswald, there appears to be no centralized distribution database tracking the movements of resources or ensuring maximized efficiency. Thus WebEOC creates a forum for communication, but, for county emergency managers in Iowa, lacks provisions enabling centralized coordination.

3.3.1 Internet and Mobile Connectivity

Internet usage has become prevalent in the US population. Among adults, 74 percent use the Internet in some capacity. Young adults are especially frequent Internet users with 93 percent online. The new ubiquitous of the Internet has led to various new usages, which promote social connectivity (Lenhart, et al. 2010).

Social media and networking options are beginning to permeate society and shift within various demographics. The percentage of blogging Young adults, defined as 18 to 29 years old, decreased from 24 percent, among Internet users, in December 2007 to 15 percent in 2009. Conversely, blog usage by Older adult Internet users, defined as age 30 and above, has increased from seven percent to 11 percent (Lenhart, et al. 2010).

General social networking usage among all adults, Internet users above 18 years old, also has increased from 37 percent in November 2008 having a profile to 47 percent in 2010. Among all adults, Young adults have the highest usage rate at 72 percent and Older adults maintained 39 percent immersion (Lenhart, et al. 2010).

Not every user is on the same social network. In fact, adults can have multiple profiles. For example, 73, 48, and 14 percent of adults have a profile on Facebook, MySpace, and LinkedIn, respectively. Due to the lack of mutual exclusivity among social networks, users overlap between each service and create a total usage greater than 100 percent (Lenhart, et al. 2010).

Social networks exhibit disparate usage across the age spectrum. Young adults tend toward MySpace usage at 66 percent of profile owners versus 36 percent of Older adults. Conversely, LinkedIn accounts for 19 percent of profile owners among Older adults and a sparse seven percent of young profile owners. Facebook diverges from the age split with approximately the same profile ownership rate, at 75 and 71 percent, among Older and Young adults, respectively (Lenhart, et al. 2010).

Twitter usage, like LinkedIn, is biased toward adults. Among all adults, 19 percent of Internet users are associated with Twitter or a similar microblogging service for status updating and reading. Young adults use microblogging at an exceptionally high rate, with approximately one-third involved. This suggests microblogging has potential for interfacing with all adults, and, especially, young adults (Lenhart, et al. 2010).

3.3.2 Coordination via Social Networks

Increased Internet and social media usage suggests a similar increase in usefulness of social networking platforms, such as instant messaging systems, for collaboration during a response. Social networks provide a potential platform for communication with the public and a secondary ability to enable conference between peers within an emergency response. This is especially true now, because adults have become increasingly familiar with computers, the Internet, and social media (White, et al. 2009).

At least one disaster response entity, the Department of Homeland Security (DHS), has tapped a social network for disaster notification. DHS asked MySpace to create a fast-track disaster notification system. This widget links users' profiles to federal information sources, provides an online tracking system, and assists the local response in various other ways (White, et al. 2009).

During the same disaster, a Community Emergency Response Team (CERT) encountered volunteer staffing problems. Evacuees were entering Arkansas in the early morning, and call list group members were not answering their phones. A CERT official next tried to use email, but the system was malfunctioning (White, et al. 2009).

The CERT official had exhausted the planned methodology and, therefore, chose to deviate from protocol by incorporating the existing Facebook group as an alternative communication tool. The official updated her Facebook status bar with the necessary information. This action triggered a notification to be sent to every group member's personal Facebook account (White, et al. 2009).

3.3.3 Information Distribution via Social Networks

The use of social networks for information, according to Sutton, et al., is already happening. A study conducted on the 2007 Southern California wildfires showed that individuals used social networks to collaborate. However, information content concerned officials due to the lack of controlled dissemination. Arguably, this suggests that officials should become involved in the distribution of information via social media to help provide filtering of misinformation (Sutton, Palen and Shklovski May 2008).

External inflexibility of the Incident Command System (ICS) reduces the ability of responders to incorporate interaction with outside entities (Sutton, Palen and Shklovski May 2008). The internal structure of ICS scales as needed from a single responder to a complex, region-scale emergency response. Yet, the ICS lacks flexibility for direct interaction between responders and the public (Sutton, Palen and Shklovski May 2008).

Individuals cope with the communications disparity by circumventing official channels. Citizens acquire information informally due to a lack of sufficient dissemination from official warnings and messages. Essentially, the decision support needs to come from somewhere, whether from either officials or other individuals (Sutton, Palen and Shklovski May 2008).

The new arena of integrated Information and Communication Technologies (ICT) is generally being referred to as Crisis Informatics (CI). This represents the shift, especially among young adults, from receiving news via television and radio reports to exploring news on Internet news websites to pursuing information via social networks.

The transition is from passive observation, watching a disaster unfold on television, through active capture of knowledge, searching for news on websites, to assertive communication, sending text messages, emails, Facebook messages, and other communications directly to those involved (Byrne and Whitmore 2008).

Accepting the usability of CI requires a paradigm shift in assumptions of accuracy. Instead of the expected inaccuracy of unofficial communications, the public collaboration actually resolves into a self-policed, accurate representation of reality. In fact, victims of the Virginia Tech shooting, in 2007, were identified correctly on Wikipedia first, before the university released a communiqué listing the victims. Furthermore, individuals use social networks, such as Facebook, to communicate their personal status which can reach a larger audience than individual phone calls and works faster than moving through official university channels (Byrne and Whitmore 2008).

Individuals can use the social capital built between peers to form groups and facilitate action during a crisis. Official emergency responders can do the same and some city officials already have. In the summer of 2011, the City of Los Angeles asked four celebrities with huge Twitter followings to tweet a message regarding an upcoming Interstate-405 closure. The celebrities included Lady Gage, 11.3 million followers; Ashton Kutcher, 7 million followers; Demi Moor, 3.7 million followers; and Kim Kardashian, 8 million followers. This unorthodox method of information dissemination was used in conjunction with other non-traditional methods, such as messages in Google Maps, MapQuest, and GPS devices. City officials also used traditional methods, such as news conferences, advertising, email blasts, and warning messages on electronic freeway signage (Blankstein 2011).

Emergency manager using social networking to strengthen ties in the community and with peers between emergency events can leverage the established trust during a crisis. Emergency responders and managers, whom community members trust, will receive a positive response to official communiqués, such as evacuation requirements.

Congruently, as information flows easily out of an Emergency Operation Center (EOC) to a receptive public, information also flows into the EOC from every technologically connected individual. This turns individuals into points for crowdsource data mining. Furthermore, informal groups, who connect via social networks, could obtain guidance from official sources through social networks with minimal time requirements from officials.

3.3.3.1 Within Emergency Management

The IHSEMD website is a prime example of the modern usage of social networks to distribute the official message. The website has links to Facebook, Twitter, a blog, podcasts, and video (IHSEMD Home 2011). These forms of media reach out to a relatively diverse body of Internet users and help propagate the IHSEMD messages. The blog offers suggestions to maximize utilization of emergency services while the Twitter feed provides relatively constant updates for ongoing responses.

The NWS is also considering the applications of social media and mobile services, including use of YouTube, Facebook, Twitter, and an in-house project called Interactive NWS (iNWS) (Interactive NWS 2011). In fact, the NWS has a YouTube channel to provide video dissemination of forecasts, explanation of scientific concepts, and debriefs on responses to weather events (NOAA's National Weather Service 2011). Video briefings are one of the YouTube video types available from the NWS. These videos include explanations of risk maps, forecast symbology and causes for upcoming conditions. The videos are available on the NWS websites and Facebook with links from Twitter (Multimedia Weather Briefing 2009) (Multimedia Weather Briefing Product Description Document 2011). The combination of a YouTube channel, Facebook websites for WFOs, and crowdsourcing research via Twitter represents NWS embracement of social media as tool for both data collection and spreading official information.

The Iowa Flood Center could potentially create similar videos to the NWS and include instructional videos teaching hydrology and flood concepts. These videos, hosted on an external website, such as YouTube or Vimeo, could include demonstrations of concepts related to flooding and explain how predictions are made. Properly formatted, the videos could appropriately simplify and teach concepts to a wide audience (Duffy 2008). Additionally, interactive games may, in fact, be even more useful than video for teaching flood response and hydrology concepts (Rieber 1996).

The United Nations Educational, Scientific, and Cultural Organization (UNESCO) is also promoting education as a method for reducing risk and increasing preparedness. UNESCO, which blames disasters for the deaths of approximately one million people and 570 billion dollars worth of financial losses since 2000, is currently developing education programs, including interactive games (Education for disaster risk reduction, a growing priority for UNESCO 2010). One game, a rudimentary development, allows users to act as emergency managers trying to minimize damage and loss of life during a variety of natural disasters (Stop Disasters! 2011). This game provides a solid foundation for future possibilities; including AR-based games similar to those currently available for non-flood related themes, and realistic training simulators for emergency managers (Cameron 2010).

3.4 Survey Use for Data Collection

Gathering information directly from the source is the best mode for collecting data on flood response methods in Iowa. Therefore, data collection for the study comes from government publications, interviews, and questionnaires. These information sources are primarily used to assess the current practices of emergency managers and support staff.

Surveys are an exceptionally important tool for market research, and especially to ensure that academic research is grounded in the reality of current methodology. Market research is an imperative for companies and organizations looking to properly serve stakeholders. The Iowa Flood Center, a government-sponsored entity is charged with pursuing flood science in Iowa and thus fulfilling the flood science needs of Iowa citizens.

The usability of survey data can be explained by three factors. First, questionnaires are designed with the intent to ascertain facts, attitudes, and behaviors within a given population. Second, a standardized survey can be circulated at a low price to garner information from a significantly large population, provided a reasonable response rate. Third, survey creation and analysis involves a null hypothesis, which is intended to be confirmed or refuted, dependent on the results (Hart 1987).

3.4.1 Mail Surveys

Typically mail surveys are chosen as the lowest cost per issued survey. Furthermore, the passive nature and potential anonymity of a mail survey helps reduce influence on respondent answers caused by a number of factors during telephone and personal interviews. However, major problems with mail surveys exist, such as potentially low response rates, question wording and only partial completion of the questionnaire.

A few techniques exist to improve mail survey response. Preliminary notification and follow-ups are two key methods for ensuring respondents both notice and remember to return a questionnaire. Other factors affecting response rate and speed include the questionnaire length, sponsoring agency, simplicity of returning completed forms, use of a cover letter, monetary incentives, and deadline dates (Kanuk and Berenson 1975) (Fox, Crask and Kim 1988).

3.4.2 Electronic Surveys

Similar to mail surveys, two new forms of questionnaires, email and website, are low-cost and far-reaching electronic alternatives to paper mailings. Use of email surveys began in 1986 and declined subsequently (Sheehan 2001). Website-based surveys are a newer phenomenon than e-mail questionnaires. Unlike e-mails, these surveys can be designed based on multiple pages with progression through the survey contingent on question response (Couper, Traugott and Lamias 2001).

Electronic surveys can be especially useful when sampling populations with known access to the Internet, such as government professionals. However, response rates can be exceptionally low for electronic questionnaires, which is in part due to concerns for Internet security and spam. Furthermore, many of the incentives employed for mail surveys are less applicable to web surveys, but hard copy notifications preceding electronic surveys do tend to improve results (Kaplowitz, Hadlock and Levine 2004).

CHAPTER 4 : METHODOLOGY

4.1 Questionnaires

Data collection for the study came primarily from government publications, interviews, and questionnaires. These information sources were used to assess the current practices of emergency managers and support staff. The questionnaires were especially useful as a dual method for determining the local perceptions of emergency managers and gauging interest in modifying the existing paradigms of flood response. I issued the questionnaires congruently with my work in exploring technology possibilities, which negated much of the potential for collected survey data to guide the direction of my research.

4.1.1 Emergency Managers

I drafted the first questionnaire using a platform of multi-part, essay-style questions. Each question had several components, which required a complex set of answers. This draft, intended for email distribution due to low associated costs, was subsequently discarded due to the complexity of each question and the intimidating format of the questions.

SurveyMonkey, a questionnaire hosting website, was chosen for a second draft of the questionnaire. The questionnaire was redesigned based on the SurveyMonkey platform. Each questionnaire was shortened into simplified, multiple choice or binary questions. This format was intended to help ensure uniformity among individual answers and to allow for statistical analysis.

During redesign, I scrubbed the questions for problems with wording. This scrubbing was based on guidelines found in a chapter on survey design found in Marketing Research, a textbook by Aaker, et al. (Aaker, et al. 2011). These guidelines included determining whether questions use familiar vocabulary, contain words with vague meanings, are "double-barreled", are leading or loaded, are potentially confusing, are applicable to all respondents, and are of appropriate length. The questions were then designed to minimize response bias caused by such wording problems and with concern for total time commitment to reduce respondent fatigue error.

I split the questionnaire into three primary sections for clarity. These sections, as shown in Figure 4-1, consisted of Forecasting, Mapping, and Communicating with the secondary Justification, Technology, and Demographics sections. Before the Forecasting section, the initial justification question asked respondents whether they felt any improvements could be made to flood response. Respondents who were interested in providing feedback for possible changes were then directed to the rest of the survey. Those uninterested in providing feedback were rerouted to the Demographics section at the end of the survey. This question was deemed important to determine the interest level among emergency managers for augmenting flood response.

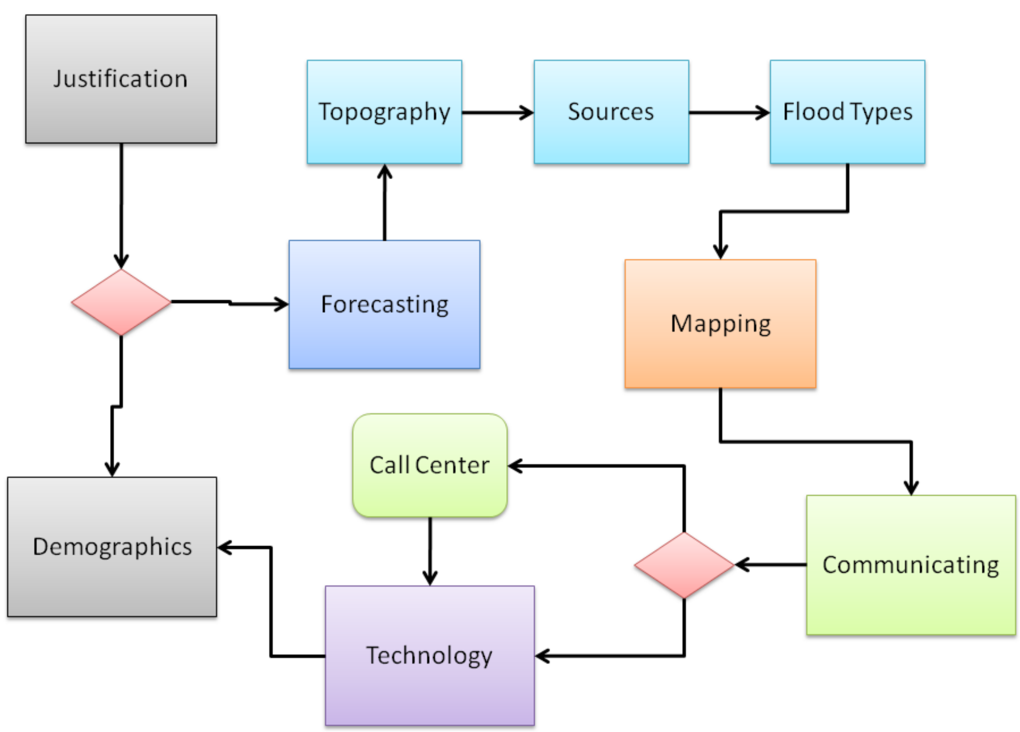

Figure 4-1. A map of the general flow and question logic built into the questionnaires.

4.1.1.1 Forecasting

The first section consisted of questions discussing aspects of forecasting and forecast dissemination. The first three questions covered local topography and the next two questions asked about common sources of flooding and forecasts. These five questions were intended to be simple and approachable normalizing questions, which follows suggested questionnaire design guidelines (Aaker, et al. 2011).

One of primary purposes of the Forecast section was to ascertain the perception of forecasts by emergency managers. Questions six through nine were, therefore, designed to gather information on perceptions of available NWS forecasts and preferences between deterministic and probabilistic forecasts. Perceptions of scientific terms, such as *uncertainty*, among emergency managers were also of specific interest.

The last questions in the Forecast section were intended to gauge the interest of emergency managers in changes in forecaster services. Question ten inquired about partnership opportunities and desires with both the NWS and IFC. With these potential partnerships and services in mind, question eleven focused on the issue of funding sources, which was designed to create a scale with a willingness to use county funds corresponding to the highest level of interest.

4.1.1.2 Mapping

The second primary section of the questionnaire delved into mapping applications during flood response. Like the forecasting section, the initial questions covered map usage. The survey questions were designed to recognize that emergency managers may not use mapping software for flood response. Furthermore, no expectation was made that emergency managers were trained in the use of 2D map orientation.

Questions one and two asked about whether the respondent used maps during a response and, if so, how the maps were used. These questions included well known software, such as Google Maps, and less known GIS software being used for everything from routing to hydrologic computations. Building on this concept, the next questions included potential future map applications, such as high-resolution inundation forecast maps, and, matching the forecasting section, an inquiry into willingness to pay for related services.

4.1.1.3 Communication

The third primary section of the questionnaire covered communication tools and methods. These methods included both traditional media, such as radio and television, and new schema, such as microblogs and Internet videos. Inclusion of Internet- and mobile-based services was intended as a means to validate presumptions regarding social media usage among emergency managers.

The second communication question segregated counties with and without access to a call center for public interface during an event. Responses indicating access to a call center automatically directed the respondent to an extra question pertaining to the call center. All other respondents automatically skipped these questions, and proceeded to a question about shared resources and emergency broadcasting.

4.1.1.4 Secondary Sections

A secondary section, following the communication section, discussed potential technologies for implementation into flood response. Each response was intended to garner interest in developing the technologies. The questions included flood simulation software, uses for AR, dynamic routing, and geotagging. The anticipated answers to these questions were intended to shape future work and, potentially, validate current direction of research.

Demographics constituted the last section. This included questions concerning staff numbers and roles. Also, a question on county population size was included to normalize responses and determine correlations between county size and available services.

4.1.1.5 Distribution and Data Collection

The questionnaire was released for data collection once it was vetted for potential wording and structure problems. SurveyMonkey was used as the host platform with a direct link available for respondents. This link was sent out to a list of county emergency managers through the President of the Iowa Emergency Management Association (IEMA), Gary Brown, with an attached invitation to participate in the survey. A copy of the cover letter invitation and original questionnaire are available in Appendices A and B.

4.1.2 City Officials

I developed a second questionnaire for city officials. This survey followed the short-answer and multiple choice format of the first questionnaire. The second survey also was hosted on SurveyMonkey, similar to the first questionnaire. Hosting both questionnaires on SurveyMonkey helped create congruity between the formatting of each questionnaire and the method for collecting responses.

Contrary to the first questionnaire, the second one lacked a specific target audience. Therefore, the questionnaire began with a question intended to filter respondents based on involvement during flood response. The question asked whether respondents were directly involved in emergency response during flood events.

Respondents who indicated a direct involvement in flood response were directed to a second preamble question. The second question asked respondents what their flood responsibilities entailed. Answers to this question were for use in categorizing responses.

A justification question was included in the second questionnaire. This question was similar in format to the corresponding question contained in the first survey. Once again, a negative response redirected users to the demographics section and skipped the primary sections of the survey.

4.1.2.1 Forecasting

The same primary sectional format was repeated for the second questionnaire. The first section, Forecasting, began with basic questions involving local topography. These questions were revamped to focus on municipality scale geography. This included questions on local levels of urbanization, which were presumed potentially correlated to hydrological residence times and predisposition toward flash flooding. Therefore, the follow-up questions included the typical local flood types.

The remaining questions dealt with forecast sources, forecast dissemination, and agency partnerships. Several forecast sources were provided along with adjectives to describe the quality of forecasts received from these sources. These questions were intended to determine where forecasts typically originated and how pleased officials were with the forecasts. This analysis also included a question regarding desired subjectivity in forecasts and a second inquiry into terminology, such as *uncertainty*.

The agency partnership questions included questions related to current and potential future partnerships. Respondents were asked whether relationships already existed and, if not, whether they were interested in created any partnerships. This was followed by a funding question, taken from the first survey, determining respondent interest in using various levels of government as funding sources for services.

4.1.2.2 Mapping

The mapping section began with questions related to map usage during flood events. These questions were designed to find correlations between map usage and respondent interest in new map technologies, such as high-resolution inundation maps for use during a flood event. Respondents were also asked whether they would use inundation maps given as probable forecasts, which was followed by a question about interest in funding sources.

4.1.2.3 Communication

The communication section was designed to determine understanding of flood response coordination and communication among city officials. This included beginning with a question asking which level of government and agency coordinates emergency response. The question was intended to determine awareness among city officials of the role of county-level emergency managers.

The next questions were intended to gauge any problems with coordination at county jurisdictional and political boundaries. The first question asked where the respondent's city was in relation to the county border. The wording included specific mileage distances with the intent of correlating proximity to county borders and perceptions of problems with flood response.

The second question asked whether respondents encountered any problems between county-level emergency managers during flood events spanning multiple counties. This question was included to explicitly ascertain the perceived problems among emergency responders during a multi-jurisdiction event and need for possible regional and statewide EOCs used for direct coordination of response. These centers, unlike the current state EOC, would act in a management function, instead of as coordinators of resource distribution.

The last communication questions covered interface with the public. Information distribution potentially represents an important challenge, especially when considering the various communication methods employed by each demographic. Therefore, a question was added to ask respondents whether their duties included involvement in official notifications to the public. The next question, which would only be offered in the case of a positive response to the previous question, built on this idea by asking what methods are used to notify the public during events.

4.1.2.4 Secondary Sections

The last two sections, similar to the emergency manager questionnaire, included questions on technology and demographics. Likely the most though intensive questions, the technology section asked respondents to consider a variety of potential new technologies for future use in flood response. Finally, the demographics section was intended as a relaxing set of simple questions to correlated respondent roles and municipality sizes to respondent answers.

4.1.2.5 Distribution and Data Collection

The second questionnaire was released on SurveyMonkey after editing. Respondents were sent an invitation to participate with a direct link to the questionnaire, which are located in Appendices D and E. This invitation was distributed to a sample of cities. The exact list is unknown because the distributor, Mark Tomb of the Iowa League of Cities (ILC), cannot release the list, which contains email information, due to privacy policies related to spam email precautions.

4.2 Two Dimensional Mapping

Due to time and technology constraints, exploration of the use of spatial triggers and dynamic routing failed to move past the conceptual stage. The presumed steps for each of these concepts were discussed and outlined in the proceeding sections.

4.2.1 Spatial Triggers

The concept of spatial triggers was based on the GPS and radio capabilities of smartphones. The basic premise involved comparing points, representing cellphone locations, to regions overlaid on a map (Bennett, Armstrong and Mount 2007). These regions could be anything from predicted flood inundation zones to flash flood warning zones.

The most basic method would be to trigger a system anytime the point crosses into a set polygon or radial distance from a reference, such as a river. This proximity relationship was envisioned with the system defaulting to a no response status. The system then have activated when a comparison between the point and polygon results in an intersection. These spatial queries would have a set refresh rate with the intersection variable denoted as a *false* or *true* value, depending on negative or positive response.

4.2.1.1 Spatial Queries

The intersection variable would be based on three spatial queries. One possibility is an overlap between the cellphone signal and the warning zone. A second potential intersection would be the cellphone signal being completely contained within the warning zone. The third would be based on how far the cellphone signal is from the warning zone.

All three spatial queries would be important to contact everyone within the at-risk zone, due to the nature of cellphone GPS units to be potentially inaccurate. Using all three queries ensures every phone would be contacted, despite weak GPS signals, demonstrated by the blue circle in Figure 4-2, or signal quality. This would include phones located both inside homes and in relatively remote locations, such as parks located near rivers.

Phones identified within local areas would be sent both a warning message and any additional, pertinent information. For a long-term flood, these could be pushed once to twice per day and include the local forecast with an inundation warning, predicted water depth at the location, 2D map of projected inundation, invitation to an AR channel with a 3D map, and a navigation service for evacuation. Flash floods, differing in length and onset time, would need information packages with every forecast change. Initially the service would require users to opt-in due to privacy concerns and lack of access to individual GPS signals.

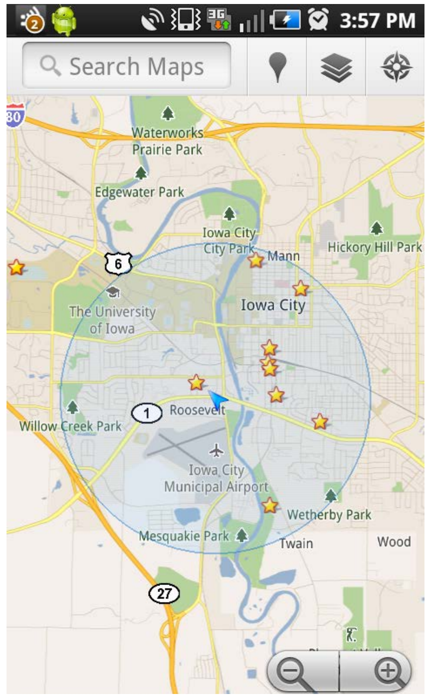

Figure 4-2. A screenshot of Google Maps. Technology developed for Spatial Triggers may encounter issues with weak GPS signals.

Phones identified within local areas would be sent both a warning message and any additional, pertinent information. For a long-term flood, these could be pushed once to twice per day and include the local forecast with an inundation warning, predicted water depth at the location, 2D map of projected inundation, invitation to an AR channel with a 3D map, and a navigation service for evacuation. Flash floods, differing in length and onset time, would need information packages with every forecast change. Initially the service would require users to opt-in due to privacy concerns and lack of access to individual GPS signals.

4.2.1.2 Privacy Concerns

There were potential methods considered to circumvent privacy concerns. Traditionally, systems have been designed to send a location to a server, compare coordinates to a database and return a result. Turning this concept around would allow the phone application to pull all the warning zones in a given region and discard non-intersecting warning zones in situ. This would mean the server never knows where the user is located.

Processing the data within the cellphone would translate into a system similar to a weather radio. An entire suite of warnings, including forecasts and other optional information, could be broadcast for a region and picked up by cellphones with an application tuned to that specific region. The service would circumvent using phone location to determine the region by having the user select a region within the mobile application. Unnecessary warnings would then be filtered out and discarded by the phone, which would compare pertinent warnings to phone location on the device, before final consumption by the cellphone owner.

4.2.2 Dynamic Routing

Mapping routes during a flood emergency would need to include both the time and the physical constraints. Nodes and pathways, available in a database, would be analyzed based on x, y, and z coordinates. The route would factor in all three dimensions to ensure elimination of potentially inundated roadways.

Usage rates would have to be included to avoid choke points, particularly at bridges; considering the proximity of flooding to waterways. Given the complete implementation of a perfect routing methodology, vehicle ponding would be completely eliminated. However, non-users, either following users or simply choosing their own routes, could prematurely cause vehicles to reach capacity on a given pathway within the routing system.

A method following individual GPS signals would introduce potential for rerouting individuals once capacity has been reached at a given pathway. The system could recognize users delayed at specific choke points and redirect en route users as needed to avoid compounding the problem. Yet, this would require personalized tracking of smartphone locations, which may meet resistance due to privacy constraints, similar to those associated with spatial triggers.

4.3 Three Dimensional Mapping

I considered four different mobile AR applications for use in developing flood response tools. These applications included Tagwhat, Wikitude, Layar, and Junaio. Junaio ultimately was chosen for experimentation and implementation of test products.

Tagwhat, an AR platform available for Android and iOS, had a focus on social connections. As described on the website, Tagwhat was based around users, instead of developers creating *layers*, *channels*, or *worlds* for consumption by target audiences. This translated into an application primarily intended for mobile geotagging at individual locations, which allowed users to instantly share text, URLs, photos, or videos with GPS coordinates (The Tagwhat Team 2011).

A second AR application, Wikitude, was considered partially based on availability for Android, iOS, Symbian, and Bada operating systems. Wikitude was designed for developers with a software developer kit (SDK) and an application programming interface (API) key. These were part of a structured development procedure, which differed from the user-oriented and instantaneous nature of adding content within Tagwhat.

Similar to Wikitude, Layar was an open platform application based on developer-created layers with support for animations, 3D models, audio, video, and sharing to social media. Layar also allowed for addition of the Layar Player to already existing mobile applications. For example, an Iowa Flood Center mobile application could contain the Layar Player for use of AR directly within the application.

Layar was also a prime candidate based on popularity. On the Android market, there were one to five million downloads as of March 2011, compared to 100 to 500 thousands downloads of Wikitude and 50 to 100 thousand downloads of Junaio (The

Layar Platform 2011). This translated into 1.4 million active users across four mobile operating system platforms and 15 languages. These users rated Layar at 4.1 and 2.5 out of five stars on the Android market and iOS iTunes App Store, respectively (Layar Reality Browser - Augmented Reality software 2011) (Layar 2011).

Junaio, the least popular AR application for Android OS devices, was available from a German AR company named Metaio. Junaio operated similarly to Wikitude and Layar with worlds designed by developers. One significant difference between Junaio and the other available applications were the two supported channel types. Junaio supported both georeferenced and image-referenced, or *Glue*, channels.

4.3.1 Wikitude

The first worlds were designed for Wikitude. Two methods were used to build the channels. Each method required a developer account, an in-house server, and experience with a programming language. Therefore, most of the programming was conducted by or with significant assistance from The University of Iowa Department of Geography.

4.3.1.1 Method One

The first method began with preparation of georeferenced points. These points were initially created in ArcGIS, and automatically associated each point with a specific X and Y coordinate, representing longitude and latitude. A Python script then gleaned the attributes for each of these points from the database file (DBF). Simultaneously, the script wrote a Keyhole Markup Language (KML) file containing all of the files and attributes. The KML file was uploaded to the developer section of the Wikitude website along with a working title, status, and other world details.

4.3.1.2 Method Two

The second method for Wikitude internalized some of the functions. This time, the *layer to KML* function, located in the *Conversion Toolbox* of ArcGIS, was used. The tool was capable of converting features or rasters to KML files, which were then compressed into ZIP file format as a KMZ file (Layer to KML 2008). The compressed files were then submitted to the Wikitude website, along with additional details, for integration into a new Wikitude world.

4.3.2 Junaio

Junaio replaced Wikitude for AR work after the development of two worlds. The primary reason for switching from Wikitude to Junaio was limitations within the framework of Wikitude. Each application could host POIs, but Wikitude was unable to incorporate 3D objects, video, audio and animation into the world display. Conversely, Junaio allowed for developers to include all of these components into an AR channel. This flexibility was deemed important for potential flood response applications, which may include either video or audio instruction, or 3D images overlaid on real world objects.

Two methods were used to build georeference channels in Junaio. Both required the creation of a server to host the information for the Junaio channel. Next, the files to be hosted were moved into the server folder for recall by Junaio users. After these first two steps, the process differentiated between a manual method for coding 3D objects and an automated method for developing informational POIs.

4.3.2.1 Method One

The first method was used almost exclusively for creating channels containing 3D objects and text. The next step in this method was to prepare 3D object files in an either MD2 or OBJ format. These were the only two supported formats and also had to be both encrypted and zipped via the Junaio website.

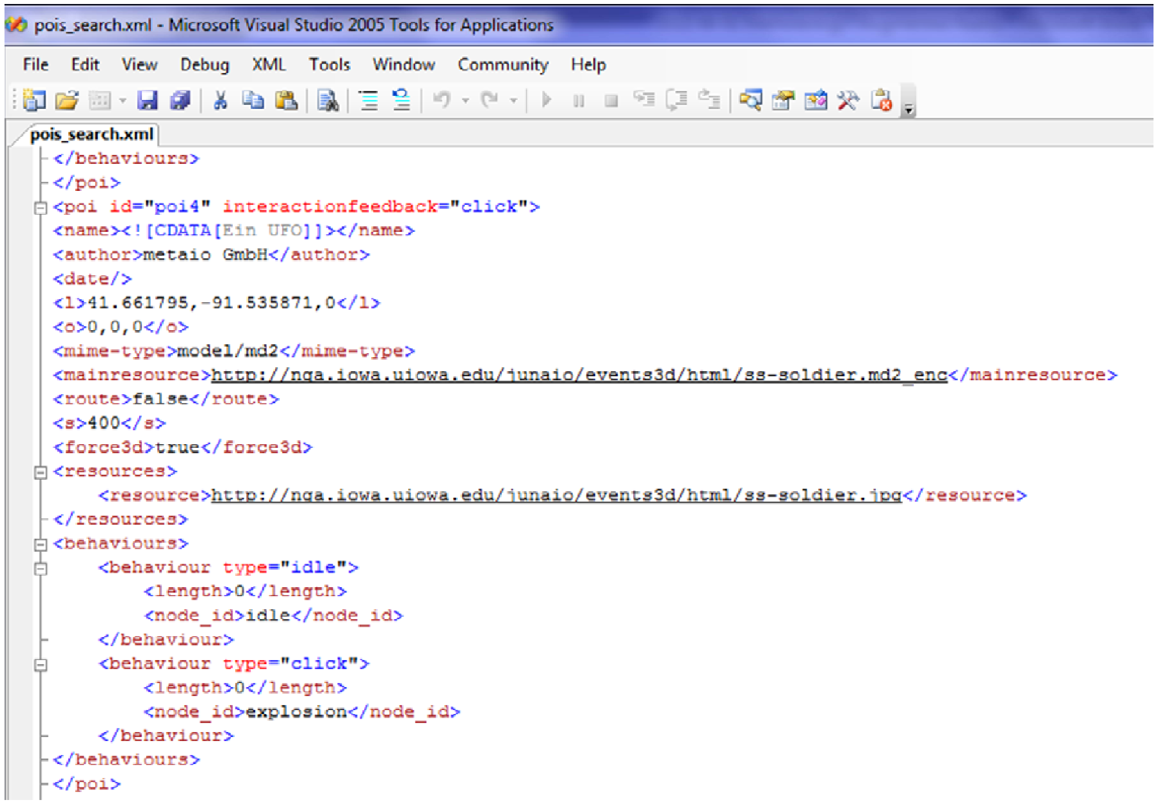

Figure 4-3. A screenshot of the code used for location-based object channels in Junaio

The query for the first method was written in the file, *poi_search*, as shown above, in Figure 4-3. The general model for this scripting originated in the developer section of the Junaio website and was modified as necessary. This format called for each POI to be written individually, beginning with a simple name and the application author. These, including a blank spot for the date, are illustrated as the first four lines above.

The proceeding lines of code assigned physical characteristics and behaviors to the POI. The lines beginning in <*l*> and <*o*> described the location, in decimal degrees, and orientation, in radians, of the object. The <*mainresource*> called up the path to the object, defined as MD2 in the previous line, on the server and <*route*> determined whether a user could choose to navigate to the object using map software. The size was ascribed by the value associated with <*s*>, and <*force3d*> required the model to appear as a 3D object. The last lines of code, <*resources*> and <*behaviours*>, point to the model texture and actions caused by user input.

4.3.2.2 Method Two

The second method for developing a location-based channel in Junaio was based on an automated process, conducted by a Python script. First, the script accepted an input, from Junaio, containing the user's GPS coordinates. Python then converted the location into GIS coordinates and issued a query, which pulled attribute information from points contained within a DBF. This query was limited, by the Python script, to points with coordinates falling within a set radius, or radii, of the user. Python was chosen for this step to bypass an antiquated language, utilize the built-in spatial functions, freely available modules, and, primarily, the close association between the scripting language and ArcGIS technologies (Butler 2005).

The database query function, located in the Python script, began with a POI counter to keep track of the number of POIs created. This looped function contained script to write all of the PHP components described in the first methodology. (Diagram of Python script) The only differences from the first methodology were the object type, and inclusion of a thumbnail, webpage, and icon for display within the channel graphic.

4.3.2.3 Necessary Files

Regardless of developer methodology, Junaio claimed to require two primary files to exist when loading a channel for a user. The first file, entitled *poi_search*, contained code relating to the search query. The second file, entitled *poi_event*, contained code for action to be taken after receiving input, such as selection, from the user. This file was left out of the second methodology for simplification.

Predefining these files was deemed unnecessary after developing the second methodology for channel creation. The first methodology consisted of both files being fully written in PHP scripting language before receiving a query from Junaio. The second methodology was designed to initially fake the existence of each file and then build the *poi_search* file when requested. This file was therefore tailored to the user location with a set geographical boundary around the user.

4.3.2.4 Finishing Steps

The finals steps for implementing each channel were done manually through the Junaio website. First, a channel was created on the website via the developer account. Information was filled in via a graphical user interface (GUI).

The channel status, available as a dropdown menu, and type, available as a multiple choice bubble, were selected as *new* and *location based*, respectively. The channel name was provided and a thumbnail was selected for display within the list of channels in the Junaio application. The callback Uniform Resource Locator (URL) was given for the server, and selections were chosen for the category, visibility, refresh rate, and region for the channel.

4.3.2.5 Glue Channel

The other type of channel built in Junaio was the visual-based Glue channel. A GUI was available for these channels through the Junaio developer website. This GUI was called the Glue Channel Manager.

The first step in making a Glue channel was to input descriptions into the available fields and add an associated icon. These descriptors included name, categories, and region. Next, components were added to the channel, such as name, file type, texture, reference image, scale, rotation, and location. The reference image is then used to test the channel and digitally displayed the associated object overtop the trigger location.

4.3.3 Models

The models used in Junaio came from both pre-built models available on various websites and models built in-house. SketchUp, an application produced by Google, and Blender, a freeware application, were both used in the development of 3D objects, as illustrated by Figure 4-4 and Figure 4-5, and 3D text, and in the conversion of KML files outputted from ArcGIS. Blender was also used to convert SketchUp objects from Collada, or .dae, format to MD2 format. This required a Python script and an outdated version of the Blender software. The conversion was necessary due to limitations of both SketchUp and SketchUp Pro, the paid version, which could only output one format for use in Junaio, the OBJ file format.

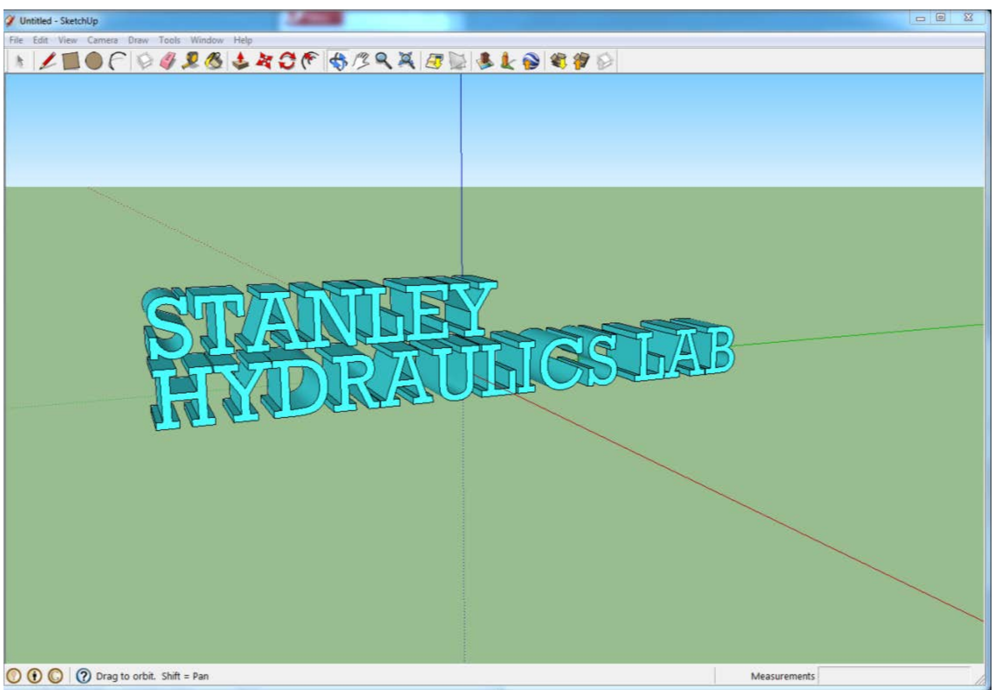

Figure 4-4. A 3D model of text displayed within the Google SketchUp environment.

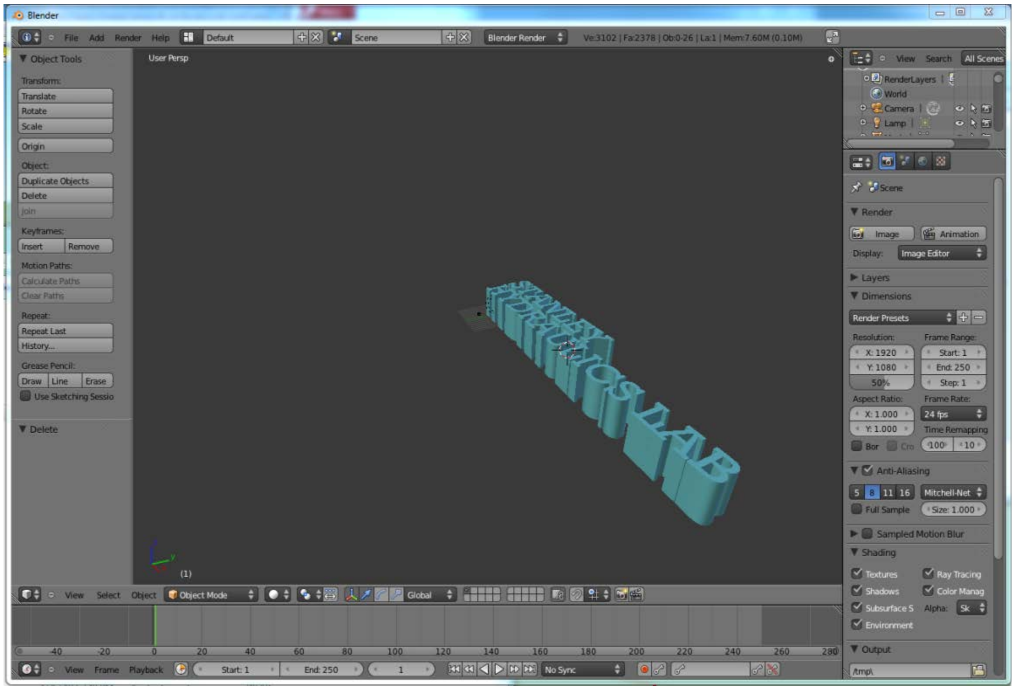

Figure 4-5. A 3D object model of text displayed within the Blender software.

CHAPTER 5 : RESULTS AND ANALYSIS

5.1 Questionnaires

Significant problems were initially encountered while attempting analysis of the survey results. The original intent was to use STATA, an available piece of statistical software. Survey results were therefore downloaded from SurveyMonkey in XML format to be imported into STATA. STATA failed to recognize the files and returned an error during the import process.

The second type of software tried was Microsoft Excel. Survey results were downloaded in Excel and CSV format for use in Excel. These results imported without any problems, but contained text-based answers to questions, which were unusable for variable-based statistical analysis.

The last option was data processing within the SurveyMonkey platform. SurveyMonkey provided *Filter Responses* and *Crosstab Responses*, two methods for data analysis. The filter feature reduced the total number of responses for every question to only respondents who had also provided a specific answer to the filter question. This provided a general idea of how the trends for each question changed once a specific demographic was removed or selected. The summary of each question is also contained for both surveys within Appendices C and F.

Crosstab Responses, the second analysis feature offered by SurveyMonkey, compiled the number of corresponding answers between a specific question and the rest of the questionnaire. Essentially, the Crosstab feature acted as a method to compare the correlation between different variables by comparing respondents who selected the same answers among multiple questions. This provided a method to establish response trends between various demographics and individual respondents.

Combining Crosstab and Filter was also possible, but generally resulted in two few responses to have an impact on analysis. In fact, the large number of questions with multiple choices or selections combined with the sparse number of respondents spread out individual responses significantly. Individual analysis of the most popular selections for most questions was required due to general lack of correlation between respondents fitting specific answer characteristics.

5.1.1 Emergency Managers

The response rate for the first survey was relatively high for communication via passive sampling. Given the assumption that only dues-paying counties were sent invitations by the IEMA; then approximately 36 percent of invitees, based on 30 respondents from 84 counties, participated in the survey. This grouping was also potentially skewed by access to the Internet and toward emergency managers in a full-time position. However, respondents represented a mix of various population sizes from less than 10,000 people to greater than 40,000 residents.

The total number of respondents, while a high response rate for a mail or website survey, represented a relatively small sample size. Therefore, the complexity of each question voided correlation comparisons between individual question responses within the survey. Instead, analysis of the total number of responses to each question provided the most useful feedback.

Approximately two thirds of respondents agreed that improvements could be made to flood response. This automatically reduced the total number of respondents down to 20 for the rest of the questionnaire. Also, given that one respondent chose to skip the question, a caveat should probably have been added to force respondents to answer the question before continuing. Unfortunately, skipping questions with incorporated logic was not anticipated during the design of the questionnaire.

Responses to the terrain and local condition questions elicited a mixture of responses. Most respondents indicated that the local terrain included hills and flat land, with few bluffs or valleys. Row crops, as expected, were also the dominant feature selected with some selection of forest and pastureland.

Flooding sources were reported as primarily small waterways and streams. Major waterways and seasonal ditches were the second highest sources of flooding. The type of flooding matched these sources with a slightly larger prevalence of long-term flooding than flash flooding.

5.1.1.1 Forecasting Services

Respondents indicated that NWS resources were used to procure forecasts during a flood event. The NWS website was the most popular choice, followed by the weather radio. Phone calls from the NWS were also typically received by 14 of the 20 respondents. TV Channels and commercial radio stations were the two other popular forecast sources.

Opinions related to forecast quality were generally positive. Respondents had favorable responses to forecasts being up-to-date, thorough, detailed and pin-pointed. Forecasts were also considered to not be confusing or vague.

Comments pertaining to these responses were submitted to describe possibilities for improvement in forecasts. For example, one respondent found that being on the border between two WFO service areas was problematic. Citizens can get confused by reports issued for a different service area. This is an important point for improving communication and efficacy for individuals.

Other comments included concerns for the amount of gage data available to the NWS. One respondent pointed to a lack of gages in Mills County and lead time for evacuations, but noted that three IFC bridge sensors had been installed, courtesy of the Iowa Department of Natural Resources (DNR). Emergency managers also noted a need for better flash flooding data, including how much and when, and a desire to know the confidence level for issued forecasts. This corresponded to surprisingly accurate responses to a question regarding the definition of uncertainty. Most respondents indicated that uncertainty implied a lack of adequate observations or potential error caused by assumptions.

Emergency managers were most interested in forecasts including both a probabilistic and advice component. Such forecasts, while expected to be popular for their ability to alleviate decision making by the emergency manager, would technically be impossible to practice due to limitations of the NWS. Instead, the second most popular forecast types, statements of forecaster expectations and probabilistic forecasts, have the highest potential for implementation. Purely advice-driven and deterministic forecasts were the least popular options.

Possible partnerships between emergency managers and other government agencies were greeted with varying levels of interest. Emergency managers were interested in partnering with businesses and government agencies to develop individualized and community action plans. There was also a desire for forecasters to assist emergency managers with instructing various demographics during flood events. Emergency managers were split on whether an agency already fulfilled these roles.

Potential consultation with a scientific group on hydrologic and hydraulic computations was met with a strongly positive response. Emergency managers were generally favorable toward building outside relationships. This included a willingness to fund forecasting services from sources at every level of government. The inclusion of county monies into the question spoke to the actual level of interest.

5.1.1.2 Mapping Services

Respondents showed a surprising predilection for using ArcGIS. Almost two thirds of respondents selected ArcGIS as a type of mapping software used during flood events. The next most popular mapping services included FEMA flood maps and Google Maps. Also, a few respondents indicated not using any mapping software or services.

The three primary uses of maps indicated were to map routes, identify at-risk structures and determine flooded zones. These applications related to the reportedly common usage of ArcGIS, FEMA maps, and Google Maps. There was also overwhelmingly positive response to potentially having access to high-resolution inundation maps during a flood event and forecasts illustrated as probable inundation maps. Similar to forecasting, emergency managers were willing to use county funds to pay for these services.

5.1.1.3 Communication Services

Emergency managers reported using a myriad of media to notify the public during flood events. The two most common methods were radio and television. Landlines, cell phones, and the official county website were slightly less popular with an even split regarding county access to a call center. Facebook was also a selected communication medium, along with Twitter and YouTube, the two least popular choices. The current usage of social media, while small, speaks to a growing trend and possible widespread adoption of social media for dissemination.

Almost every respondent reported access to an emergency broadcasting system. However, respondents were relatively neutral on the effect of access to call centers, and the existence of shared resources between fellow counties, the state government, and other organizations.

5.1.1.4 Technologies

The potential future technologies offered to emergency managers received a mixed reception. However, the majority of responses were positive with a desire for additional information. This included questions asking about interest in AR channels, dynamic routing, and spatial triggers. Ultimately, respondents were most interested simulation software for training responders and running simulations before real-world implementation.

5.1.2 City Officials

I extended an open invitation to city officials throughout Iowa for participation in the second flood response survey. Of the invitees, 89 respondents began the questionnaire and approximately 90 percent responded that they had direct involvement in emergency flood response. Most of the involvement included administrative, public works, and communication. The question was designed to only allow one selection, which did not include administrative duties and caused multiple respondents to use the *Other* selection to specify multiple roles. This may have skewed some results away from law enforcement, medical, and evacuation selections.

Approximately a third of all city officials selected a negative response to the question gauging interest in providing feedback on emergency response and resources. Therefore, 33 people were redirected to the demographics page without providing additional feedback. Another 15 skipped the question, which showed that future questionnaires should require respondents to answer important filtering questions before proceeding.

Responses to local geography included a mixture of topography. The most popular selections were flat, hilly and floodplains with almost half of respondents skipping the questions. Typical local land use was also mixed, with predominance toward urban, rural, and mixed urban and suburban municipality types, which were surrounded by mostly row crops and pastureland.

City officials, unlike county emergency managers, reported experiencing more flash flooding than long-term flooding. This flooding also typically originated in small streams and major waterways. Seasonal waterways and stationary water bodies were the least likely sources of flooding.

5.1.2.1 Forecasting Services

NWS services were the most popular forecast sources for city officials and generally received positive responses from users. The NWS website was the most popular choice with NWS weather radios and commercial television stations coming in second place. Other commercial resources, websites and radio stations, were also selected as commonly used forecasts sources.

Respondents indicated that NWS forecasts were up-to-date, thorough, detailed, and not confusing. City officials were also only mildly in agreement on the location precision of forecasts and felt that forecasts tended toward being vague. This indicated a mostly positive attitude toward NWS forecasts and related to a strong interest, indicated by the next question, for statements incorporating the forecaster expectations into either deterministic or probabilistic forecasts.

Probabilistic and deterministic forecast types were both selected by at least 50 percent of respondents, many of whom also selected the option to receive a statement outlining forecaster expectations. Advice-driven forecasts were the least popular selection, which, interestingly, corresponded with seemingly less confidence in forecaster capabilities than emergency managers.

City officials were less familiar with the term *uncertainty* than emergency managers, believing that it indicated the forecast was untrustworthy, lacked scientific understanding, and reflected fears of being wrong by the forecaster. However, some city officials had picked up on the concept of uncertainty, indicating that uncertainty related to a lack of adequate observations and potential error caused by assumptions.

Partnerships with outside agencies were mildly interesting to city officials. Developing business action plans and designing response for varying demographics were both balanced between negative and positive responses. Enthusiasm for government agency help planning for, responding to, and navigating through flood-related problems was minimal. Responses also indicated that these three partnerships already existed in up to a third of respondent cities. Partnership with a scientific group elicited the most positive response with over half of responses indicating interest and the smallest number pointing to existing relationships.

The forecast services funding question was virtually unusable for measuring willingness to pay. Unfortunately, a selection of municipal funding was left out of the answers. This reduced the usefulness of both the forecast and mapping services funding questions. Respondents pointed to a willingness to use funding from other levels of government, but also showed interest in matching funds.

5.1.2.2 Mapping Services

City officials showed a similar amount of map usage to emergency managers. This included a tendency to use Google Maps, FEMA flood maps, and ArcGIS. Respondents were allowed to select more than one mapping services, which explained the relatively large number of users reported for several mapping services.

Almost 41 percent of respondents indicated that they did not currently use any mapping software. Filtering all respondents by those not using mapping services, as shown below in Figure 5-1, also reduced the sample size to cities with populations less than 15,000. The lack of map use among small municipalities could be a reflection of staffing and resource availability. This assumption is based on the size of the communities and a majority of these respondents indicating a desire to have a scientific group available for hydrologic and hydraulic calculations.

The applications of mapping services paralleled uses among emergency managers. City officials indicated using maps for routing, identifying at-risk structures, determining flooded zones, checking specific elevations, and locating evacuation zones. Approximately three quarters of city officials responded positively to the concept of high-resolution inundation maps and forecast maps with associated probabilities.

Interestingly, no respondents used maps to compute discharge values, which spoke to the need to partner with a scientific group or agency.

Municipal Inputs on Flood Response SurveyMonkey

Approximately what population size does your municipality serve?		
	Do you use any mapping services or software during a flood event? (Please select all that apply)	
	I do not currently use any software	Response Totals
<2,001	25.0% (4)	25.0% (4)
2,001 to 5,000	**43.8% (7)**	**43.8% (7)**
5,001 to 15,000	31.3% (5)	31.3% (5)
15,001 to 40,000	0.0% (0)	0.0% (0)
40,000<	0.0% (0)	0.0% (0)
answered question	16	16
	skipped question	2

Figure 5-1. Responses to a question within the questionnaire with a filter applied regarding the use of maps during response.

5.1.2.3 Communication Services

There was an interesting variety of responses to who acts as the coordinator during flood emergency response. Some city officials indicated that FEMA or IHSEMD performed the role of coordination. Most respondents indicated county emergency managers or municipal leaders coordinated response, with significant overlap between the two groups. Unfortunately, this question was intended to allow only a single answer, but unfortunately ended up as a multiple selection question. Respondents may have inadvertently misread the question as an inquiry regarding all parties responsible for emergency response, instead of the primary coordinator.

Half of the cities surveyed were located near or on a county border. However, responses overwhelmingly indicated no problems during coordination between multiple county emergency managers. Furthermore, the majority of city officials were uninterested in regional or statewide emergency operations centers for coordination of multi-county flooding incidents.

Almost all respondents indicated a personal responsibility to notify the public of evacuations and other actions during a flood event. The most common media were radio stations, government websites, cell phone calls, landline phone calls, and local television stations. Some of these information sources were also used less during long-term flood events than in flash flooding.

5.1.2.4. Technology

Social media were the least popular information distribution resources, with few respondents reporting usage of Twitter or Facebook and zero selecting YouTube. This corresponded with the responses to future technology possibilities. Respondents selected a balance of positive and negative answers for every selection, which suggested a general miscomprehension regarding the technologies being described. The percentage of respondents indicating interest, but desiring further explanation exemplified the lack of understanding.

5.1.3 Summary

Both questionnaires produced a small total number of respondents. Limiting invitations to only IEMA and ILC members caused audience reduction and, subsequently, respondents. However, these groups provided a platform to contact potentially the most active and interested administrative officials in Iowa.

Most of the combined respondents showed interest in providing feedback to explore possible improvements in flood response. Unfortunately, some respondents skipped this question, which was an important gauge of enthusiasm. Future questionnaires would need to include question logic to force a response before continuing.

City officials and emergency managers differed by preferred forecasts types. City officials were generally split between selections for deterministic and probabilistic forecasts, and both groups included a desire for a statement of forecaster expectations. This selection likely correlated with the general misunderstanding of the term *uncertainty*. Emergency managers preferred probabilistic forecasts with actual advice, instead of an objective statement of forecast expectations. The second forecast type was likely popular for removing decision-making requirements from forecast interpretation, however, the NWS working parameters prohibit dispensing of advice.

Following the theme of forecast explanation, respondents were generally interested in consulting with a scientific group for various hydrologic and hydraulic computational needs. This corresponded with positive responses regarding using monies from any level of government, including counties, to fund research in forecasting and mapping.

Respondents were remarkably versed in 2D mapping software using ArcGIS, FEMA flood maps, and Google Maps to map routes, identify at-risk structures, and determine flooded zones. This matched desire to view forecasts as high-resolution inundation maps. Interest in future technologies included 3D digital visualization, 2D forecast maps, and flood simulation software.

Ultimately, the surveys did little to directly guide the other research. Some results did indicate an interest in some technologies and various agency partnerships. However, due to the low number of responses, future questionnaires should possibly consider a more traditional method. Phone surveys in particular may work nicely to engage the respondent.

5.2 Two Dimensional Mapping

As I noted in Chapter 4, technology and time constraints negated exploring applications of Spatial Triggers and Dynamic Routing. Regardless, these technologies represent very real possibilities for research. Table 5-1 and Table 5-2 summarize the potential uses and drawbacks, needs of a fully functional system, and readiness level for each technology.

5.3 Three Dimensional Mapping

5.2.1 Wikitude

I abandoned Wikitude after the development of two worlds. The first world, developed by Jerry Mount, a PhD candidate in the Department of Geography at the University of Iowa (UI), consisted of buildings on the UI campus. The building footprints were taken from existing records and points extracted from each building. This acted as a "Hello world"-type of first attempt at making a Wikitude world. Figure 5-2 and Figure 5-3 illustrate the 3D and 2D views created by the Wikitude world.

The second, and last, world built for Wikitude contained buildings and parks in the Des Moines, Iowa, area. These had an added level of complexity with indicators based on residence within the 100- or 500-year floodplains. This world was built to include floodplain demarcation for demonstration purposes.

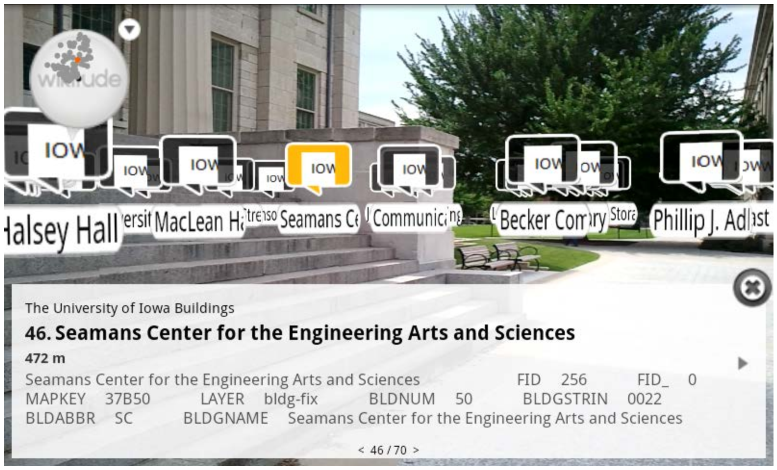

Figure 5-2. The first Wikitude world created with buildings from the University of Iowa campus.

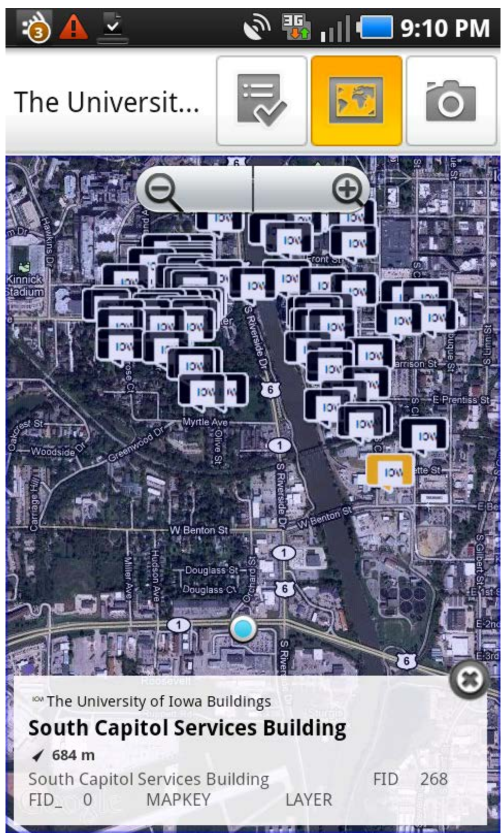

Figure 5-3. A 2D display of the first world created in Wikitude.

5.2.2 Junaio

During the development process, Jerry Mount and I created several channels within Junaio. These channels were intended to demonstrate the potential of Junaio and exercise the limitations. The channels successfully demonstrated both information distribution and visualization potential while encountering software problems.

5.2.2.1 Location-based Channels

Jerry Mount built the first channel in Junaio. The channel was of comprised UI buildings, similar to the first Wikitude world. Each building included details and a link to the UI facilities website. The channel acted as a demonstration of Junaio usability, especially in terms of creating a georeferenced channel with POI details and a link to webhosted information.

The next two channels created were both related to gage stations throughout Iowa. One contained USGS gages and the other included all gages hosted on the IFIS website. The USGS channel provided thumbnails of the USGS logo and a link to each gage website. The IFIS channel contained IFC issued logos with a link back to mobile versions of each IFIS hosted gage information.

Problems arose during the development and implementation of the USGS and IFIS channels in Junaio. In fact, the second method for creating Junaio channels was developed in response to a cap on the maximum results returned in any given query, which created a problem for the first attempted USGS channel. By default, every Junaio channel returns a maximum of 20 POIs for every query (POIs/search 2011). This cap can be raised by the developer, up to 200 POIs, and had not been manually set in the code for the first attempt of the USGS channel.

A lack of spatial query capabilities within Junaio led to the results cap problem. The query sent by a user loading the channel pulled data for every USGS gage within the state, without filtering for distance. Junaio then capped the displayed results at 20 sites, which were queried by numeral ranking, instead of location.

We developed the second channel methodology, based on Python scripting in response to spatial query limitations. This method limited potential results to a fixed radius, before queuing the locations of gages to display. The final product was a spatially queried set of up to 20 gages within a usable region.

One problem remained with both the USGS and IFIS channels after being written using PHP masked Python. The channels failed to work on both Android operating system (OS) devices list in Appendix G. Each channel would initially load, but, unlike the iOS devices, did not populate with POIs. The problem was associated with two different developer accounts: both working in iOS, but not Android OS. No solution was found to this problem, which was presumed to be a compatibility problem with the version of Junaio released for the Android OS.

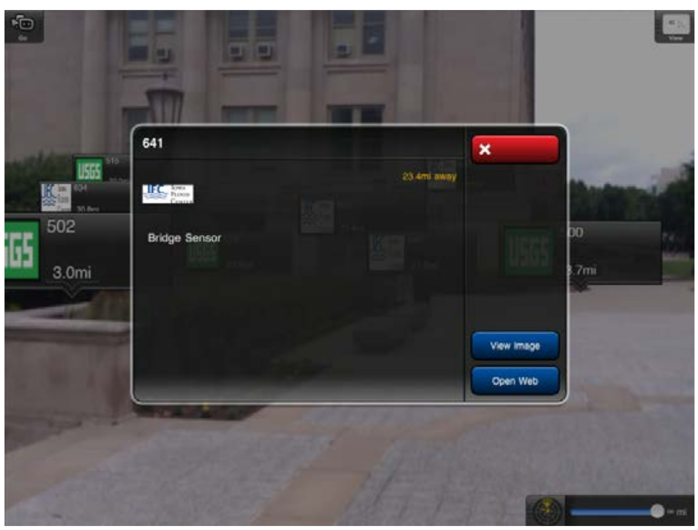

Figure 5-4.   A 3D view of the IFIS channel created for Junaio

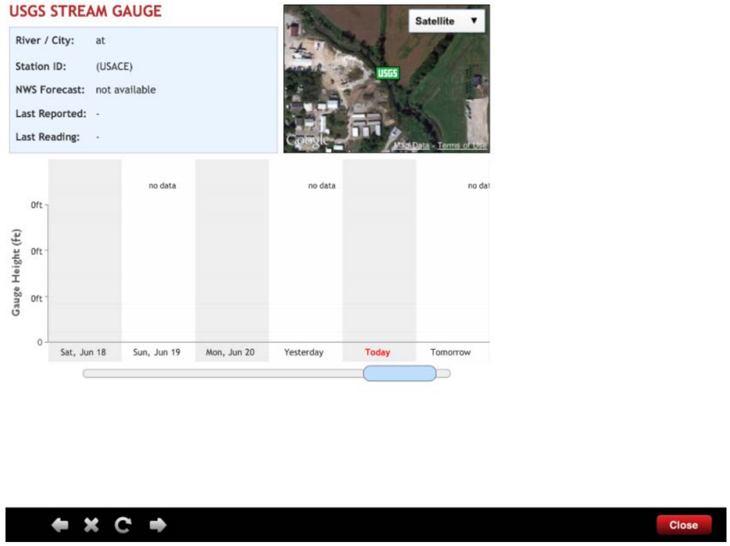

Figure 5-5. Selecting a point within the IFIS channel allowed users to link to the corresponding mobile website.

Figure 5-6. A 2D view of the USGS and IFC gages returned by a query originating in downtown Iowa City, Iowa.

The other channels built in Junaio included 3D objects and text. These were intended to demonstrate the possibility of overlaying text labels on buildings and visualizing 3D flood inundations. The labels were clickable and contained potential for future clickable access to audio, video, or text files containing explanations for either response workers or private citizens. Video overlay of 3D objects was also possible and explored with mixed results. Orienting the object and streaming video were both challenging due to the iterative process of changing code and refreshing the channel by emptying the local cache.

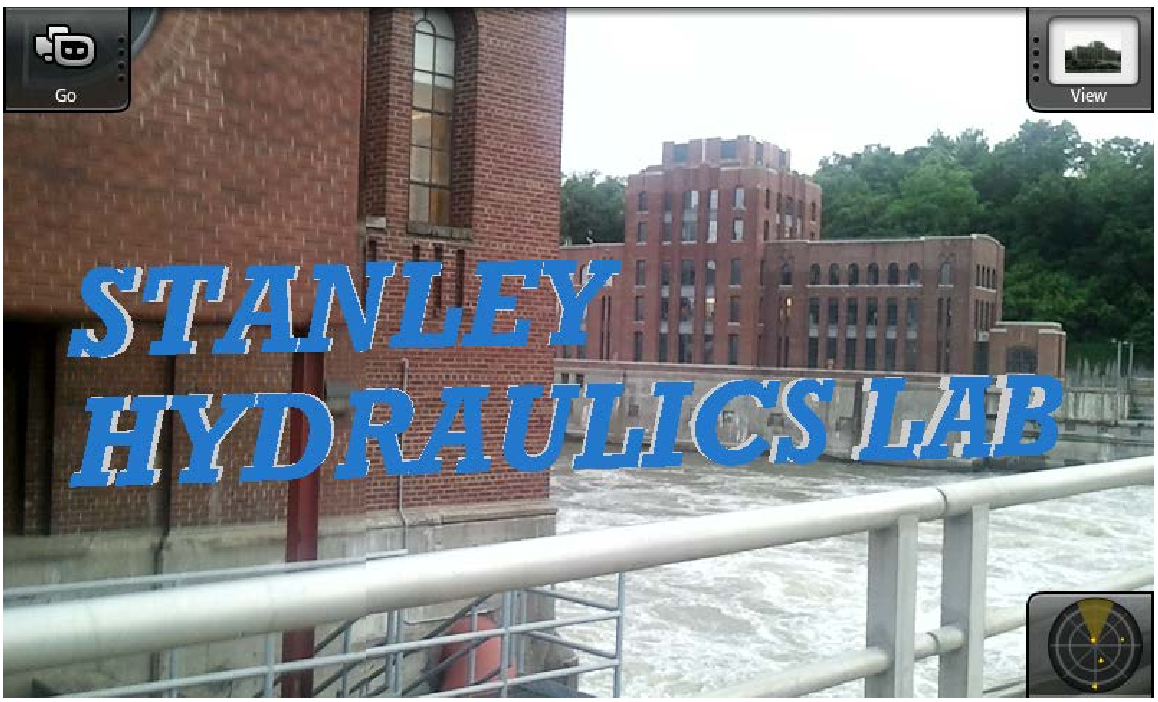

Figure 5-7. A label of the Stanley Hydraulics Lab, in Iowa City, Iowa, in the correct color and approximate location captured by an phone using the Android operating system.

Limitations on 3D object size and lack of support for GIS shapefiles presented a significant problem for displaying flood inundation in Junaio. These files began as shapefiles and were exported from ArcGIS as 3D KML files with an arbitrary depth. However, the new files were larger than the maximum file size allowed by Junaio, which was 500 kilobytes. Furthermore, Google SketchUp froze and crashed every time the files were loaded into the program to be processed and converted into OBJ files. The limitation of Junaio accepting only OBJ or MD2 files severely reduced options for 3D display in Junaio and ultimately eliminated the possibility of displaying digital inundations.

5.2.2.1 Glue Channels

Difficulties also arose with the image-based, Glue channels. Junaio only occasionally recognized images used as tags for 3D objects hosted by a channel. The channel building website had bugs. For example, several attempts resulted in an image and associated 3D object initially not working on an existing channel and then working in the same context on a newly created channel.

Fixing the bugs in Junaio could lead to the use of glue channels to host streaming audio, video, or text triggered by visual cues attached to building or other objects. These would operate more smoothly than QR codes redirecting a user to a website. Instead, users would see or hear information while pointed at the specified object and without having to exit the primary application.

5.2.3 Summary

In retrospect, Layar may have been the best option for development in AR. Wikitude was chosen because it was the first AR application discovered. Junaio was used because it was the first AR application found with support for 3D objects, video, audio, and animation. Layar, discovered last and after investing significant time into Junaio, should be the next step for research into applications of AR. Table 5-3 and Table 5-4 describe the two primary applications of future work in AR and the realistic potential of implementation. Notably, these descriptions are based on current AR technology, which will likely become increasingly robust and capable with time. As of now, I recommend considering Layar for any further experimentation. The popularity and apparent robustness of Layar provides a litany of new possibilities, and potential for an environment containing minimal glitches.

5.4 Information Distribution

The survey results showed minimal immersion of emergency managers and city officials into social networking. County emergency managers do use the coordination software, WebEOC, for resource and response coordination within official channels. However, the surveys indicated little use of social media for information dissemination, to coordinate with the public, and to provide a sounding board for public questions and discussion. Table 5-5, Table 5-6, and Table 5-7 contain a summary of technologies capable of dynamic, approachable information distribution. Each technology is ready for implementation and several are already being implemented by some government agencies.

Table 5-1. Spatial Triggers

Intention	Potential Problems	Projected Effort and Complexity		Assessment
		Least	Most	
Facilitates personal efficacy with direct, active warning communication to affected stakeholders	Privacy concerns with usage of GPS signal. No service in poor cell service areas and overburdened cell networks.	Incorporate into existing host server. Simplified system involves opt-in method with automatic spatial queries of cell signal and automated SMS message, email, or telephone call.	Needs mobile application for in-device message processing. Server would broadcast personally tailored data, including connections to services, such as an automated Dynamic Routing system	Can begin development

Table 5-2. Dynamic Routing

Intention	Potential Problems	Projected Effort and Complexity		Assessment
		Least	Most	
Asserts control over the flow of vehicle traffic during evacuations	Privacy concerns with having to track individual GPS signals. GPS signal resolution may incorrectly route individuals.	Anonymous movement data is processed to illustrate areas with highest traffic density, similar to Google Traffic. Users manually input location to receive the fastest route around traffic and hazardous areas.	Individual user movement is tracked. Users receive a continuously variable route, which automatically refreshes as the server processes incoming information. Both the server and mobile application would require significant computing power to render changes in real-time	Can begin development

Table 5-3. Augmented Reality: Digital Overly of Building Information

Intention	Potential Problems	Projected Effort and Complexity		Assessment
		Least	Most	
Provides detailed, localized information in a 3D environment	File size, rendering, refresh rate, and other hosting Limitations of current mobile Augmented Reality applications. Weak and inaccurate GPS signals.	Create a service within an existing AR application. Connect users to a dynamic source of building information. Use of a dedicated server may be required.	Embed a mobile AR service within a dedicated flood response application. Create a virtual landscape of buildings and other infrastructure; especially potentially invisible infrastructure. Add selectability to models to peel away digital layers, view specific details, activate instructional videos, etc.	Can begin minimal development

Table 5-4. Augmented Reality: Digital Overly of Predicted Inundation

Intention	Potential Problems	Projected Effort and Complexity		Assessment
		Least	Most	
Shows predicted flood extents in the real world landscape	File size, rendering, refresh rate, and other hosting Limitations of current mobile Augmented Reality applications. Incorrect object placement relative to landscape.	Create a service within an existing AR application. Connect users to a dynamic source of inundation maps hosted on a server. Selected inundation file changes with forecast and with each query.	Embed a mobile AR service within a dedicated flood response application. Create a high-resolution, virtual river with enough precision to clearly show predicted inundation regions.	Requires increased robustness of current mobile Augmented Reality applications

Table 5-5. Coordination via Social Networks

Intention	Potential Problems	Projected Effort and Complexity		Assessment
		Least	Most	
Utilizes existing communication networks with controllable access and relative ease of use	Reliance on external source for hosting and control structures. Lack of familiarity among users, especially with mobile versions.	Create a profile page.	Create a profile page that users turn to as a resource. Incorporate links to pertinent information and external resources. Include Facebook, LinkedIn, Twitter and other social network information in communication trees.	Currently used in limited applications; short and simple development process

Table 5-6. Information Distribution via Social Networks

Intention	Potential Problems	Projected Effort and Complexity		Assessment
		Least	Most	
Exists at rudimentary levels with significant self-policing within public forums	Devolution of an open forum into unconstructive discussions. Needs to be used in conjunction with other communication media.	Create a profile page.	Actively engage social media users as members of the public and information sources, even during periods without emergencies. Create a profile page, actively guide discussions, and glean pertinent information from public commentary.	Currently used by some organizations; short and simple development process

.

Table 5-7. QR Code Information Tagging

Intention	Potential Problems	Projected Effort and Complexity		Assessment
		Least	Most	
Allows static building signs to become a dynamic source of information	Requires a smartphone and a balance between visibility and obnoxiousness for the QR code.	A simple direct URL link to a server with information regarding building status and needs.	A link providing options to load mobile applications and open other information sources. The mobile applications could include Augmented Reality views of the building, unseen infrastructure, and predicted inundation. Information could include instructions complete with videos and georeferenced notes.	Can begin development

CHAPTER 6 : SUMMARY AND RECOMMENDATIONS

> When there's a disaster the first question people ask is 'what is the government doing? But as soon as the disaster fades from their memory...in many cases (regional) authorities and business people challenge us when we say land is unsuitable for building because of flood risk.
>
> Dominique Voynet, French Environment Minister 1997-2001

6.1 Summary

Flood response in the State of Iowa represents a complex set of relationships and hierarchy stretching from the individual citizen to State and Federal agencies. These relationships add surprising levels of complexity to a constantly evolving system. County emergency managers are ultimately the individuals in charge of flood response. However, coordination of resources is typically managed by the IHSEMD through a State EOC and supplemented by local NWS WFOs. Adding to the difficulties of flood response is the lack of water resources related education among emergency managers, many of whom are less than full time staff.

Regardless of the staffing challenges, county emergency managers and city officials responding to the questionnaires reported an encouragingly abundant application of current technologies and great interest in developing new opportunities. While there was minimal usage of social media, such as Facebook, YouTube and Twitter, some managers were already using these as a means for disseminating official messages. Furthermore, managers and city officials, through the survey, and other officials, anecdotally, expressed interest in the application of new technologies for forecast dissemination, alerts, and visualization.

The introduction of new communication technologies is quickly blurring the line between end-user and source. Traditionally, personal interaction with forecasters is relegated to emergency managers via phone calls with local WFOs. Recent interest in mobile weather services by the NWS has shifted this paradigm and illustrated a potential future of both crowdsourcing and social media enabling close relationships between stakeholders and forecasters. The future includes a multitude of methods for dissemination and data collection without single direction progression from producers to consumers.

Implementation of new mapping technologies holds promise for providing flood response efficacy to individual citizens. Unfortunately, prototype systems for Spatial Triggers and Dynamic Routing were beyond the current technologic capabilities available during this study. Future research could easily include design of rudimentary spatial triggers, provided a mobile application is available for hosting and processing related data. The conceptual parameters are also laid out for implementation of dynamic routing; given extensive design of a server-based routing program, dynamic inclusion of crowdsourced location and obstacle data, and a containing mobile application are required for implementation. Regardless of the current limitations, future development of Spatial Triggers and Dynamic Routing systems could minimize emergency event-related stress by directly supplying pertinent information and pre-packaged evacuation routes during emergency situations.

Augmented Reality transforms these 2D mapping technologies by turning smartphone and tablet viewfinders into information portals. For this work, Junaio was the primary application used in exploring the possibilities of AR. Spatial queries in Junaio were developed to display pertinent information sources in a radial distance around a user, which I would recommend replacing with watershed-based queries. Future development of AR services may also be done in Layar, which is very well reviewed by users. Problems with cross compatibility between the iOS and Android platforms, and with image-based Glue channels reduced the functionality of Junaio.

Advances in smartphone hardware technology; such as GPS, compass, camera, accelerometer, and Internet connectivity; provide users with important capabilities required to fully utilize these new technologies. Future users have the potential of knowing the exact forecast probability of floodwater, receiving spatially triggered notes, viewing instructional videos digitally overlaid on the real world, interacting with digital displays of building information and hidden infrastructure, and visualizing digital representation of predicted inundation in real-time.

6.2 Recommendations

I recommend conducting future work in two dimensional mapping, three dimensional mapping, and information distribution. Table 6-1 summarizes my recommendations and anticipation of required effort. Some of these technologies continue to reside at the horizon of development. For example, the primary applications of AR require substantial improvements in software capability. However, considering the amount of development mobile AR has gone through in the past two years, I would anticipate many of these features becoming available within the next 12 months to two years.

Other technologies, such as social networking are already in place and ready for implementation. The key issues with these technologies are reliance on external servers and having to work within the boundaries of an already built system. Conversely, two dimensional mapping technologies, such as Spatial Triggers and Dynamic Routing will require construction of information processing software, servers, and communication method for contacting mobile devices.

Ultimately, I intended to find ways to augment flood response. Therefore, all of these technologies have the potential for augmenting flood response and should be considered as additions to existing services, instead of wholesale replacements of existing systems. The final goal is a set of appropriate additions to the existing flood response systems in Iowa, which both facilitate coordination among emergency personnel and enable personal efficacy among individuals.

Table 6-1. Summary of Technologies

Technology	Effort	Potential Problems	Assessment
Spatial Triggers	Medium	Hardware, Software, and People	Can begin development
Dynamic Routing	Large	Hardware, Software and People	Can begin development
Augmented Reality: Digital Overly of Building Information	Large	Software	Can begin minimal development
Augmented Reality: Digital Overly of Predicted Inuncation	Large	Software	Requires major software improvements
Coordination via Social Networks	Small	External Reliance on networks	Currently available for implementation
Information Distribution via Social Networks	Small	External Reliance on networks	Currently available for implementation
QR Code Information Tagging	Small	Hardware and minimal software	Can begin development

BIBLIOGRAPHY

2009. http://www.pivotalconstruction.co.uk/ (accessed August 7, 2010).

2010. http://www.evenconstruction.com/#/our_homes/ (accessed August 7, 2010).

"Question Wording: A Problem of Communication." In *Marketing Research*, by David A. Aaker, V. Kumar, George S. Day and Robert P. Leone, 283-286. John Wiley & Sons Pte Ltd., 2011.

About the ROC. 2011. http://www.roc.noaa.gov/WSR88D/About.aspx (accessed 2011).

AHPS. March 11, 2011. http://www.floodsafety.noaa.gov/ahps.shtml.

Alabaster, Jay. "Tsunami-Hit Towns Forgot Warnings from Ancestors." *Associated Press*, April 8, 2011.

Anderson, Eric. *Snow Accumulation and Ablation Model--SNOW-17.* National Weather Service, 2006.

Associated Press. *Flood Evacuation Reinstated for Louisiana's Butte Larose Area.* May 23, 2011. http://www.foxnews.com/us/2011/05/23/flood-evacuation-reinstated-louisianas-butte-larose-area/.

Associated Programme on Flood Management. *Integrated Flood Management.* Concept, World Meteorological Organizaiton, The United Nations, 1956.

Augusta Canal. *The Canal Digitrail.* 2011. http://www.augustacanal.com/Default.aspx?PageId=55.

AWIPS. 2011. http://www.nws.noaa.gov/ops2/ops24/awips.htm.

Azuma, Ronald T. "A Survey of Augmented Reality." *Presence: Teleoperators and Virtual Environments* 6, no. 4 (August 1997): 355-385.

Barth, Dave. *The bright side of sitting in traffic: Crowdsourcing road congestion data.* August 25, 2009. http://googleblog.blogspot.com/2009/08/bright-side-of-sitting-in-traffic.html.

Bastin, G., B. Lorent, C. Duqué, and M. Gevers. "Optimal Estimation of the Average Areal Rainfall and Optimal Selection of Rain Gauge Locations." *Water Resources Research* 20, no. 4 (1984): 463-470.

Bell, Barbara. “The Oldest Record of the Nile Floods.” *The Geographical Journal* (Blackwell Publishing) 136, no. 4 (December 1970): 569-573.

Bennett, David, Marc Armstrong, and Jerry Mount. "MoGeo: A location-based educational service." In *Location Based Services and TeleCartography*, 493-509. Berlin Heidelberg: Springer , 2007.

Blankstein, Andrew. "LAPD asks celebrities to tweet out word on 405 Freeway closure." *Los Angeles Times*, June 30, 2011.

Bradley, A. Allen. "Precipitation Estimation And Hydrologic Forecasting Using Nexrad Data." The University of Iowa, Iowa City, 1997.

Brocca, L., F. Melone, T. Moramarco, and R. Morbidelli. "Spatial-temporal variability of soil moisture and its estimation across scales." *Water Resources Research*, 2010: 1-14.

Butler, Howard. "A Guide to the Python Universe for ESRI Users." *ESRI.* 2005. http://proceedings.esri.com/library/userconf/proc04/docs/pap1027.pdf.

Buyya, Rajkumar, Chee Shin Yeo, and Srikumar Venugopal. "Market-Oriented Cloud Computing: Vision, Hype, and Reality for Delivering IT Services as Computing Utilities." *Proceedings of the 10th IEEE International Conference on High Performance Computing and Communications.* Dalian, China: IEEE CS Press, 2008.

Byrne, Michael, and Colin Whitmore. *Crisis Informatics.* IAEM Bulletin, 2008.

Cameron, Chris. *Students Explore Their City with Expedition Deventer.* December 16, 2010. http://site.layar.com/company/blog/category/layers/games/.

Castle, John. "The Coralville Dam and Reservoir: Design and Operation." In *A Watershed Year: Anatomy of the Iowa Floods of 2008*, edited by Cornelia Mutel, 95-102. University Of Iowa Press, 2010.

CIA Factbook. *Geography:Netherlands.* Central Intelligence Agency. July 20, 2010. https://www.cia.gov/library/publications/the-world-factbook/geos/nl.html (accessed July 26, 2010).

CNN Wire Staff. "Levee breach lowers river, but record flooding still forecast." *CNN U.S.*, May 3, 2011.

—. *More than 700 dead in Chinese floods.* July 21, 2010. http://www.cnn.com/2010/WORLD/asiapcf/07/20/china.floods/index.html (accessed July 26, 2010).

Committee on Developing Mesoscale Meteorological Observational Capabilities to Meet Multiple National Needs. *Observing Weather and Climate from the Ground Up: A Nationwide Network of Networks.* Washington, D.C.: The National Academies Press, 2009.

Committee to Assess the NWS AHPS. *Toward a New Advanced Hydrologic Prediction Service.* Washington, D.C.: National Academies Press, 2006.

Contributor, Radio Iowa. *Council Bluffs starts flooding hotline to answer questions, rumors.* June 8, 2011. http://www.radioiowa.com/2011/06/08/council-bluffs-starts-flooding-hotline-to-answer-questions-rumors/.

Costa, John E. "The dilemma of flood control in the United States." *Environmental Management*, 1978: 313-322.

Couper, Mick P., Michael W. Traugott, and Mark J. Lamias. "Web Survey Design and Administration." *The Public Opinion Quarterly* 65, no. 2 (2001): 230-253.

Csiki, Shane, and Bruce L. Rhoads. "Hydraulic and geomorphological effects of run-of-river dams." *Progress in Physical Geography*, 2010: 755-780.

Curtis, Pat. *Heavy rains leads to flash flooding, evacuations in Oskaloosa.* August 10, 2010. http://www.radioiowa.com/2010/08/10/heavy-rains-leads-to-flash-flooding-evacuations-in-oskaloosa/ (accessed August 11, 2010).

de Groot, Mirjam, and Wouter T. de Groot. “"Room for river" measures and public visions in the Netherlands: A survey on river perceptions among riverside residents.” *Water Resources Research* 45 (July 2009).

Denso Wave. *About 2D Code.* 2011. http://www.denso-wave.com/qrcode/aboutqr-e.html.

DNR IOWATER Staff. *IOWATER Mission and Goals.* 2011. www.iowater.net.

Downstream Residents Dodge Bullet After Lake Delhi Dam Fails. July 24, 2010. http://www.kcrg.com/news/local/Lake-Delhi-Dam-Has-Been-Compromised-99164894.html (accessed July 26, 2010).

Duffy, P. "Engaging the YouTube Google-Eyed Generation: Strategies for Using Web 2.0 in Teaching and Learning." *The Electronic Journal of e-Learning* 6, no. 2 (2008): 199-130.

Duranton, Gilles. *Distance, Land, and Proximity, Economic analysis and the evolution of cities.* Department of Geography & Environment, London School of Economics, January 1999.

Education for disaster risk reduction, a growing priority for UNESCO. August 21, 2010. http://www.unesco.org/en/pcpd/post-conflict-post-disaster-education/dynamic-content-single-view/news/education_for_disaster_risk_reduction_a_growing_priority_for_unesco/back/23179/cHash/8487002644/.

Emergency Management Institute. *ICS Management Characteristics.* 2011. www.fema.gov/emergency/nims/ICSpopup.htm.

Espinosa-Villegas, Claudia O., and Jerald L. Schnoor. "Comparison of Long-Term Observed Sediment Trap Efficiency with Empirical Equations for Coralville Reservoir, Iowa." *Journal of Environmental Engineering* 135, no. 7 (July 2009): 518-525.

Facebook. *Create a Page.* 2011. www.facebook.com/pages/create.php.

—. *Help Center.* 2011. www.facebook.com/help/?page=812.

Feiner, Steven, Blair MacIntyre, Tobias Höllerer, and Anthony Webster. "A Touring Machine: Prototyping 3D Mobile Augmented Reality Systems for Exploring the Urban Environment." *Personal Technologies* (Springer-Verlag), no. 1 (1997): 208-217.

FFMP Frequently Asked Questions. 2011. http://www.nws.noaa.gov/mdl/scan/test2/ffmpFaq.html.

Flash Flood Guidance. 2011. http://www.srh.noaa.gov/rfcshare/ffg.php.

Flickr. *About.* 2011. http://www.flickr.com/about/.

Floating House Makes Debut in New Orleans. October 6, 2009. http://www.cbsnews.com/stories/2009/10/06/tech/main5367856.shtml (accessed August 8, 2010).

Flood defences go up in Bewdley. February 4, 2004. http://www.bbc.co.uk/herefordandworcester/features/2004/02/bewdley_floods.shtml (accessed August 7, 2010).

Fox, Richard J., Melvin R. Crask, and Jonghoon Kim. "Mail Survey Reponse Rate: A Meta-Analysis of Selected Techniques for Inducing Response." *Public Opinion Quarterly* 52, no. 4 (1988): 467-491.

Frozen Ground Modeling. September 10, 2001. http://www.nws.noaa.gov/oh/hrl/frzgrd/index.html.

Fuhrmann, Anton, Gerd Hesina Zsolt Szalavári, L. Miguel Encarnação, Michael Gervautz, and Werner Purgathofer. "The Studierstube Augmented Reality Project." *Presence* 11, no. 1 (February 2002): 33-54.

Gilberto, Vicente A., Roderick A. Scofield, and W. Paul Mentzel. “The Operational GOES Infrared Rainfall Estimation Technique.” *Bulletin of the American Meteorological Society* 79 (1998): 1883-1898.

Goecks, Jeremy, and Elizabeth D. Mynatt. "Leveraging Social Networks for Information Sharing." *CSCW'04.* Chicago: ACM Digital Library, 2004.

Green, Colin. *Best Practice Methods for Valuing Flood Control Benefits.* Middlesex, UK: World Commission on Dams, 2000.

Grimes, D. I. F., E. Pardo-Igúzquiza, and R. Bonifacio. "Optimal areal rainfall estimation using rain gauges and satellite data." *Journal of Hydrology* 222, no. 1-4 (September 1999): 93-108.

Gruntfest, Eve, and John Handmer, . *Coping With Flash Floods.* Vol. 77. Dordrecht: Kluwer Academic Publishers, 2001.

Harris, Gardiner. "Dangers of Leaving No Resident Behind." *The New York Times*, March 21, 2011.

Hart, Susan. "The Use of the Survey in Industrial Market Research." *Journal of Marketing Management* 3, no. 1 (1987): 25-38.

Hayes, John L. *Service Assessment: Central United States Flooding of June 2008.* Silver Spring, Maryland: National Weather Service, 2009.

Hedley, Nicholas R., Mark Billinghurst, Lori Postner, Richard May, and Hirokazu Kato. "Explorations in the Use of Augmented Reality for Geographic Visualization." *Presence* (Massachusetts Institute of Technology) 11, no. 2 (April 2002): 119-133.

Huang, Jin, Huug M. van den Dool, and Konstantine P. Georgakakos. "Analysis of Model-Calculated Soil Moisture over the United States (1931-1993) and Applications to Long-Range Temperature Forecasts." *Journal of Climate*, 1995: 1350-1362.

IFC. *Inundation Maps.* 2011. http://ut.iihr.uiowa.edu/ifc/detailed_inundation_maps.html.

—. *Iowa Flood Information Service.* 2011. http://ut.iihr.uiowa.edu/ifis/main/.

IHSEMD Home. June 10, 2011. http://www.iowahomelandsecurity.org/index.html.

Interactive NWS. 2011. http://inws.wrh.noaa.gov/.

Iowa Disaster History. June 17, 2011. http://www.fema.gov/news/disasters_state.fema?id=19.

Iowa State University of Science and Technology. *Iowa Environmental Mesonet.* 2011. http://mesonet.agron.iastate.edu/current/.

Johnson, Dennis, Michael Smith, Victor Koren, and Bryce Finnerty. "Comparing Mean Areal Precipitation Estimates From NEXRAD And Rain Gauge Networks." *Journal of Hydrologic Engineering*, 1999: 117-134.

Kanuk, Leslie, and Conrad Berenson. "Mail Surveys and Response Rates: A Literature Review." *Journal of Marketing Research* 12, no. 4 (1975): 440-453.

Kaplowitz, Michael D., Timothy D. Hadlock, and Ralph Levine. "A Comparison of Web and Mail Survey Response Rates." *The Public Opinion Quarterly* 68, no. 1 (2004): 94-101.

Klijn, Frans, Paul Samuels, and Ad Van Os. “Towards Flood Risk Management in the EU: State of affairs with example from various European countries.” *International Journal of River Basin Management* 6, no. 4 (2008): 307-321.

Layar. May 4, 2011. https://market.android.com/details?id=com.layar.

Layar Reality Browser - Augmented Reality software. May 16, 2011. http://itunes.apple.com/us/app/layar-reality-browser-augmented/id334404207?mt=8.

Layer to KML. November 2008. https://market.android.com/details?id=com.layar.

Lenhart, Amanda, Kristen Purcell, Aaron Smith, and Kathryn Zickuhr. *Social Media & Mobile Internet Use Among Teens and Young Adults.* Pew Internet & American Life Project, Pew Research Center, Washington, D.C.: pewinternet.org, 2010.

Lima, Carlos H. R., and Upmanu Lall. "Spatial scaling in a changing climate: A hierarchical bayesian model for non-stationarity multi-site annual maximum and monthly streamflow." *Journal of Hydrology,* 2010: 307-318.

Ludlow, Benjamin M. *The Grand Canal and the Three Gorges Dam: A Historical Comparison.* Washington, D.C.: American University, 1998.

Markus, Francis. *China's history of floods.* August 21, 2002. http://news.bbc.co.uk/2/hi/asia-pacific/2207324.stm.

Marshall, Claire. *'Invisible' flood barrier on show.* July 14, 2009. http://news.bbc.co.uk/2/hi/uk_news/england/hereford/worcs/8147542.stm (accessed August 6, 2010).

Mayerowitz, Scott. *At Least 16 Campers Killed in Arkansas Flash Flood.* June 11, 2010. http://abcnews.go.com/WN/Media/campers-killed-arkansas-flash-flood-albert-pike-campground/story?id=10889327&page=1 (accessed July 27, 2010).

Milly, P. C. D., et al. "Stationarity Is Dead: Whither Water Management?" *Science*, 2008: 573-574.

Multimedia Weather Briefing Product Description Document. 2011. http://products.weather.gov/PDD/MultimediaWeatherBriefing.pdf.

Multimedia Weather Briefing. October 1, 2009. http://www.crh.noaa.gov/dmx/briefing/.

National Research Council's Board on Atmospheric Sciences and Climate. *Flash Flood Forecasting Over Complex Terrain With An Assessment Of The Sulphur Mountain NEXRAD In Southern California.* Washington, DC: National Academies Press, 2005.

National Weather Service. *Storm Reports via Twitter.* April 15, 2010. http://www.weather.gov/stormreports/ (accessed May 2011).

NIMS. 2010. http://www.fema.gov/emergency/nims/ (accessed July 15, 2010).

NOAA's National Weather Service. 2011. http://www.youtube.com/user/usweathergov.

Ntelekos, Alexandros A., Konstantine P. Georgakakas, and Witold F. Krajewski. "On the Uncertainties of Flash Flood Guidance: Toward Probabilistic Forecasting of Flash Floods." *Journal of Hydrometeorology*, 2006: 896-915.

NWS. "WS Form E-19." *National Weather Service.* 2008. http://www.nws.noaa.gov/os/hod/E-19/E19_008.pdf.

"NWSRFS Overview." *National Weather Service River Forecast System.* 2011. http://www.weather.gov/iao/pdf/Manual.pdf.

OHD. *Office of Hydrologic Development.* May 20, 2011. http://www.weather.gov/oh/.

Oswald, Tom, interview by Timothy J. Middlemis-Brown. *IHSEMD* (March 15, 2011).

Ozel, F. "Time pressure and stress as a factor during emergency egress." *Safety Science*, 2001: 95-107.

Palca, Joe. *Spurred by Rising Seas, Dubai's Floating Ambition.* April 21, 2008. http://www.npr.org/templates/story/story.php?storyId=89767297 (accessed August 8, 2010).

Peel, Murray C., and Günter Blöschl. "Hydrological modelling in a changing world." *Progress in Physical Geography*, 2011.

Perry, Ronald W. "What Is a Disaster?" In *Handbook of Disaster Research*, 1-15. Handbooks of Sociology and Social Research, 2007.

Perumal, Muthiah, Kunjan Bhakta Shrestha, and U. C. Chaube. "Reproduction of Hysteresis in Rating Curves." *Journal of Hydraulic Engineering*, 2004: 870-878.

Plate, Erich J. "Flood risk and flood management." *Journal of Hydrology* 267 (2002): 2-11.

POIs/search. 2011. http://www.junaio.com/publisher/poissearch.

Rees, Phil, Paul Waley, and Li Heming. "Reservoir resettlement in China: past experience and the Three Gorges Dam." *The Geographical Journal* 167, no. 3 (September 2001): 195-212.

Refsgaard, Jens Christian, Jeroen P. van der Sluijs, James Brown, and Peter van der Keur. "A framework for dealing with uncertainty due to model structure error." *Advances in Water Resources*, 2006: 1586-1597.

Rein, Lisa. "A new batch of younger employees finding their place in federal workforce." *The Washington Post*, August 7, 2010: A01.

Rekimoto, Jun, Yuji Ayatsuka, and Kazuteru Hayashi. "Augment-able Reality: Situated Communication through Physical and Digital Spaces." *Proceedings International Symposium on Wearable Computers.* ISWC'98, 1998. 68-75.

Reminders. 2011. http://www.apple.com/ios/ios5/features.html#reminders.

Rieber, Lloyd P. "Seriously considering play: Designing interactive learning environments based on the blending of microworlds, simulations, and games." *Educational Technology Research and Development* 44, no. 2 (1996): 43-58.

Rogers, George O. "The Dynamics of Risk Perception: How Does Perceived Risk Respond to Risk Events?" *Risk Analysis*, 1997: 745-757.

Rosenburg, Matt. *China Population.* June 14, 2010. http://geography.about.com/od/populationgeography/a/chinapopulation.htm (accessed July 27, 2010).

—. *Polders and Dikes of the Netherlands.* About.com. 2011. http://geography.about.com/od/specificplacesofinterest/a/dykes.htm (accessed July 25, 2010).

Roxin, A., J. Gaber, M. Wack, and A. Nait-Sidi-Moh. *Survey of Wireless Geolocation Techniques.* Washington, DC: IEEE Globecom Workshops, 2007.

Sainz, Adrian. "Historic flood begins to abate, but far from over." *Associated Press*, June 4, 2011.

Sanglap, Ranina. *More Google Map users on the mobile than the PC.* May 30, 2011. http://au.ibtimes.com/articles/154058/20110530/google-maps.htm.

Sayre, Robert F. "The Dam and the Flood: Cause or Cure?" In *A Watershed Year: Anatomy of the Iowa Floods of 2008*, edited by Cornelia Mutel, 103-110. Iowa City: University of Iowa Press, 2010.

Schmit, Timothy J., et al. "Validation and Use of GOES Sounder Moisture Information." *Weather and Forecasting*, 2002: 139-154.

Seo, Bong-Chul, Witold F. Krajewski, Anton Kruger, Piotr Domaszcynski, James A. Smith, and Matthias Steiner. "Radar-rainfall estimation algorithms of Hydro-NEXRAD." *Journal of Hydroinformatics*, 2011: 277-291.

Shaman, Diana. "Builder Offers a Floating House." *The New York Times*, August 2, 1981.

Sheehan, Kim. "E-mail Survey Response Rates: A Review." *Journal of Computer-Mediated Communication* 6, no. 2 (2001).

Shu, Li, and Brian Finlayson. "Flood management on the lower Yellow River: hydrological and geomorphological perspectives." *Sedimentary Geology* 85 (1993): 285-296.

Smith, Parker. *Demolition of flood-damaged Iowa City homes begins.* September 16, 2009. http://www.dailyiowan.com/2009/09/16/Metro/12912.html (accessed July 24, 2010).

Stop Disasters! 2011. http://www.stopdisastersgame.org/en/home.html.

"Strategic Science Plan." *Office of Hydrologic Development.* April 2010. http://www.nws.noaa.gov/oh/src/docs/Strategic_Sience_Plan2010.pdf.

Sutton, Jeannette, Leysia Palen, and Irina Shklovski. "Backchannels on the Front Lines: Emergent Uses of Social Media in the 2007 Southern California Wildfires." Edited by F. Fiedrich and B. Van de Walle. *Proceeding of the 5th International ISCRAM Conference.* Washington, D.C., May 2008.

Takeuchi, Kuniyoshi. *Floods and society: a never-ending evolutional relation.* Keynote Lecture, Yamanashi University, New York: Science Press, New York Ltd., 2002.

The Delta Works. 2004. http://www.deltawerken.com/Deltaworks/23.html (accessed 2010 йил 25-July).

The first floods. 2004. http://www.deltawerken.com/The-first-floods/302.html (accessed 2010 йил 25-July).

The Layar Platform. March 2011. http://www.layar.com/development/.

The Tagwhat Team. *About Tagwhat.* 2011. http://www.tagwhat.com/about.php.

"Total River and Hydrologic Forecasting System." *National Weather Service River Forecast System.* 2011. http://www.nws.noaa.gov/iao/pdf/Manual.pdf.

Twitter: About. *Twitter is the best way to discover what's new in your world.* 2011. http://twitter.com/about.

Urbina, Elba, and Brian Wolshon. "National review of hurricane evacuation plans and policies: a comparison and contrast of state practices." *Transportation Research Part A: Policy and Practice* 37, no. 3 (2003): 257-275.

USGS. *Current Streamflow.* May 18, 2011. http://waterwatch.usgs.gov/.

Van Baars, Dr. S., and I. M. Van Kempen. *The Causes and Mechanisms of Historical Dike Failures in the Netherlands.* Official Publication, Delft University of Technology, Delft: European Water Association (EWA), 2009.

van Dantzig, D. “Economic Decision Problems for Flood Prevention.” *Econometrica* (The Econometric Society) 24, no. 3 (July 1956): 276-287.

van Stokkom, H. T.C., and A. J.M. Smits. *Flood defense in The Netherlands: a new era, a new approach.* Keynote Lecture, New York: Science Press, New York Ltd., 2002.

Vicente, Gilberto A., Roderick A. Scofield, and Paul Menzel W. “The Operational GOES Infrared Rainfall Estimation Technique.” *Bulletin of the American Meteorological Society* 79, no. 9 (September 1998): 1883-1898.

Villarini, Gabriele, Witold F. Krajewski, Alexandros A. Ntelekos, Konstantine P. Georgakakos, and James A. Smith. "Towards probabilistic forecasting of flash floods: The combined effects of uncertainty in radar-rainfall and flash flood guidance." *Journal of Hydrology*, 2010: 275-284.

Wagner, Daniel, Thomas Pintaric, Florian Ledermann, and Dieter Schmalstieg. "Towards Massively Multi-user Augmented Reality on Handheld Devices." *PERVASIVE 2005.* Springer-Verlag Berlin Heidelberg, 2005. 208-219.

Water: River Observations. May 2, 2011. htttp://www.weather.gov/.

Weather Terms and Warning/Advisory Criteria. 2011. http://www.crh.noaa.gov/lot/severe/wxterms.php.

WebEOC. 2011. http://esi911.com/esi/index.php?option=com_content&task=view&id=14&Itemid=30 .

WFO Hydrologic Forecast System. 2011. http://www.weather.gov/os/hod/SHManual/SHman056_whfs.htm.

White, Connie, Linda Plotnick, Jane Kushma, Starr Roxanne Hiltz, and Murray Turoff. "An Online Social Network for Emergency Management." Edited by J. Landgren and S. Jul. *Proceedings of the 6th International ISCRAM Conference.* Gothenburg, Sweden, 2009.

Wolf, Ray, interview by Timothy J. Middlemis-Brown. *Interview with Science and Operations Officer for NWS in Davenport, Iowa* (December 15, 2010).

Wong, Edward. "Water Levels Near Record at Three Gorges Dam in China." *The New York Times*, July 19, 2010.

Yancy, Katherine-Marie. *Families Reunite at Albert Pike Campground.* July 25, 2010. http://www.todaysthv.com/news/local/story.aspx?storyid=110418&catid=2 (accessed July 27, 2010).

Yi, Mun Y., and Yujong Hwang. "Predicting the use of web-based information systems: self-efficacy, enjoyment, learning goal orientation, and the technology acceptance model." *International Journal of Human-Computer Studies* 59, no. 4 (October 2003): 431-449.

Young, C. Bryan, A. Allen Bradley, Witold F. Krajewski, and Anton Kruger. "Evaluating NEXRAD Multisensor Precipitation Estimates for Operational Hydrologic Forecasting." *Journal of Hydrometeorology*, 2000: 241-254.

APPENDIX A: COVER LETTER FOR EMERGENCY MANAGERS

The University of Iowa
IIHR—Hydroscience & Engineering

March 2011
Iowa County Emergency Manager

Dear Respondent:

I am a graduate student researcher with the new Iowa Flood Center based out of IIHR—Hydroscience & Engineering at The University of Iowa. My research involves bridging the gap between scientific data and information that public officials can use. I hope to bridge that gap by finding ways to improve communication between flood forecasters and emergency managers, and, and the tools available to emergency managers when responding to water-related emergencies.

As an emergency manager, I need your expertise to guide me in improving communication. I developed a questionnaire to determine how emergency managers use weather forecast information, mapping software, and other tools during storm and flood events in Iowa. As a county-level coordinator, you can provide me with vital data on information sources you typically use, the problems associated with those information sources, and other typical issues that you encounter during local flood events. I am also interested in whether you need a change in emergency response resources, and how the Iowa Flood Center and government agencies can help improve your ability to respond. We want to know if there is anything broken on our end of science communication and what is needed to fix it.

I have made the survey available on the Internet at SurveyMonkey for you to complete before (date). Please click here to be redirected or type https://www.surveymonkey.com/s/FloodIowa into your web browser. I anticipate that the survey will take approximately ten to 15 minutes. Please let me know if you would prefer either a paper copy or an emailed electronic document version to complete. I would be happy to receive replies by mail (207-6 SHL), fax (319 335 5238), or email (tmiddlem@engineering.uiowa.edu).

I can only offer you a heartfelt thank you in exchange for your time and participation in this survey. However, in time, your answers may help to improve the quality of information that you receive during flood events. Ultimately, this questionnaire is a first step in determining what the scientific community needs to do to provide emergency managers the correct tools to protect lives and property. Please take time to participate in this survey, even if you think no improvements are needed. Your input is vital and greatly appreciated.

Thank you very much for your assistance and I hope that we are able to provide you with some in return.

Sincerely,

Timothy J Middlemis-Brown
Graduate Student Researcher

ADDRESS	PHONE	EMAIL	WEB
SHL, Iowa City, Iowa 52246	(319) 325-5124	tmiddlem@iowa.uiowa.edu	www.iihr.uiowa.edu

APPENDIX B: QUESTIONNAIRE FOR EMERGENCY MANAGERS

Flood Response

1. Justification

1. Do you feel that any improvements could be made to the resources currently available to you before, during, and after a flood event?

- ◯ Yes (Please select if you would like to provide feedback to change response tools)
- ◯ No (Please select if you would not like to change currently available response tools)

Flood Response

2. Forecasting

1. What is the typical geography in your county? (Please select all that apply)

- [ ] Hilly
- [ ] Flat
- [ ] Bluffs
- [ ] Smooth valleys
- [ ] Other (please specify)

2. What is the typical land use in your county? (Please select all that apply)

- [ ] Forested
- [ ] Row Crops
- [ ] Pastureland
- [ ] Urban
- [ ] Suburban
- [ ] Other (please specify)

3. Which type of flood event do you typically encounter?

- ◯ Flash Flooding (typically less than six hours in length)
- ◯ Long-term Flooding (typically days to weeks in length)

4. Where does your flooding typically come from? (Please select all that apply)

- [ ] Major waterways
- [ ] Small waterways/streams
- [ ] Seasonal waterways/ditches
- [ ] Ponds and lakes
- [ ] Other

Flood Response

5. Where does your forecast come from during a rainstorm and/or flood event? (Please select all sources)

- [ ] National Weather Service (Phone call)
- [ ] National Weather Service (Website)
- [ ] National Weather Service (Weather Radio)
- [ ] Commercial weather website (Please specify below)
- [ ] TV Channel
- [ ] Radio Station
- [ ] Other (Please specify below

Additional Comments

6. The forecasts that you receive from the National Weather Service are:

	Definitely Agree	Somewhat Agree	No opinion	Somewhat Disagree	Definitely Disagree
Up-to-date	○	○	○	○	○
Thorough	○	○	○	○	○
Detailed	○	○	○	○	○
Confusing	○	○	○	○	○
Pin-pointed	○	○	○	○	○
Vague	○	○	○	○	○

7. Please share any thoughts on how forecasts could be improved:

8. Which would you prefer?

- [ ] A statement of the forecaster's expectations (For example: Flash flooding seems very likely given the current and forecast conditions)
- [ ] Advice on what action to take (For example: preparation for flash flooding is recommended at the following locations...)
- [ ] Forecasts with a likelihood value (probability) attached (For example: a 70% chance of heavy rain showers)
- [ ] Multiple forecasts and their corresponding likelihood (probabilities) (For example: a 30% chance of 2 inches of rain, 60% chance of 1 inch of rain, and a 90% chance of 0.5 inches of rain)
- [ ] A combination of likelihood (probability) and advice (For example: There is a 90% chance of 0.5 inches of rain and preparation for flooding is recommended...)

Flood Response

9. What does the term "uncertainty," used in a forecast, suggest to you? (Please select all that apply)

- [ ] The forecast can't be trusted
- [ ] Lack of scientific understanding of nature
- [ ] Forecaster is worried about being wrong
- [ ] Potential error caused by assumptions
- [ ] Lack of forecaster skill
- [ ] Lack of adequate observations

10. How can we help?

	Agree	No Opinion	Disagree
Would you be interested in partnering with businesses and a government agency, such as the National Weather Service, to develop action plans for the businesses and to tailor responses?	○	○	○
Should forecasters, such as the National Weather Service, help county emergency managers determine how to instruct various demographics to respond during floods?	○	○	○
Is there an adequate government agency who helps you with pre-planning for, responding to, and navigating through flood-related issues?	○	○	○
Would you appreciate having a scientific group that you could consult with to compute hydrologic and hydraulic values? (For example: estimating the amount of discharge traveling through a storm drain during a flood event)	○	○	○

11. If you had to pay directly for forecasting services, then what funding sources would you be willing to use? (Please select all that apply)

- [ ] Federal
- [ ] State
- [ ] County
- [ ] Matched funds with another level of government

Flood Response

5. What funding sources would you be willing to use to upgrade mapping services? (Please select all that apply)

- [ ] Federal
- [ ] State
- [ ] County
- [ ] Matched funds with another level of government

Flood Response

4. Communication

1. How do you notify the public during flood events?

	Flash Flooding (less than six hours)	Long-term Flooding (many hours to weeks)
Radio	☐	☐
Landline Telephone	☐	☐
Cell Phone	☐	☐
Television	☐	☐
County website	☐	☐
Facebook	☐	☐
Twitter	☐	☐
Youtube	☐	☐
Other	☐	☐

(please specify)

2. Does your county have access to a call center for public interface?

◯ Yes

◯ No

Flood Response

5. Call Center

1. Where is the call center located? Please select all that apply)

- [ ] County
- [ ] State
- [ ] Other (please specify)

Flood Response

6. Communication

1. Please elaborate on any of the following questions as needed.

	Yes	No
Do you have access to an emergency broadcasting system?	◯	◯
Does your access, or lack of access, to either an emergency broadcasting network or a call center affect your response?	◯	◯
Are there currently any shared resources, shared responses, communication networks, etc. between counties?	◯	◯
Are there currently any shared resources, shared responses, communication networks, etc. provided by the State Government?	◯	◯
Are there any OTHER shared resources, shared responses, communication networks, etc.?	◯	◯

Please list any sources from above

Flood Response

7. Technology

1. Please consider the following possible future technologies. If made available, would you use...

	I'm interested	I'm interested, but would like further explanation	I'm not sure what this means	I'm not interested, but may be interested in something similar	I'm not interested
simulation software designed both as a training device and to simulate flood response before applying it to an actual event?	○	○	○	○	○
Augmented Reality software to visualize predicted floodwaters on the actual landscape through the viewfinder of your smart-phone camera?	○	○	○	○	○
navigation software using forecasts to continuously provide the shortest route as floodwaters make roadways and bridges impassable?	○	○	○	○	○
software alerting responders with their plan-of-action during a flash flood based on their phone's GPS coordinates?	○	○	○	○	○
software sending alerts to individual private citizens when their cell phone GPS signal indicates that they are in a dangerous area?	○	○	○	○	○
Augmented Reality software allowing users to view a city-scape through their phone and see lists of response-related tasks overlaying each building?	○	○	○	○	○

Flood Response

8. Demographics

1. How many people staff your emergency management team?

Full-time

Part-time

Temporary (for a typical response)

2. Please indicate which agency performs the roles listed below?

Law Enforcement

Medical

Evacuation

Communication

3. Approximately what population size does your county serve?

- ◯ <10,001
- ◯ 10,001 to 15,000
- ◯ 15,001 to 20,000
- ◯ 20,001 to 40,000
- ◯ 40,000<

Flood Response

9. Thank You!

Thank you very much for your participation!

Building:
Stanley Hydraulics Laboratory
IIHR-Hydroscience & Engineering
The University of Iowa

APPENDIX C: QUESTIONNAIRE RESULTS FOR EMERGENCY MANAGERS

Flood Response

SurveyMonkey

1. Do you feel that any improvements could be made to the resources currently available to you before, during, and after a flood event?

	Response Percent	Response Count
Yes (Please select if you would like to provide feedback to change response tools)	**69.0%**	**20**
No (Please select if you would not like to change currently available response tools)	31.0%	9
answered question		**29**
skipped question		**1**

2. What is the typical geography in your county? (Please select all that apply)

	Response Percent	Response Count
Hilly	**65.0%**	**13**
Flat	50.0%	10
Bluffs	40.0%	8
Smooth valleys	30.0%	6
Other (please specify)	0.0%	0
answered question		**20**
skipped question		**10**

3. What is the typical land use in your county? (Please select all that apply)

	Response Percent	Response Count
Forested	35.0%	7
Row Crops	**100.0%**	**20**
Pastureland	55.0%	11
Urban	20.0%	4
Suburban	30.0%	6
Other (please specify)	5.0%	1
	answered question	**20**
	skipped question	**10**

4. Which type of flood event do you typically encounter?

	Response Percent	Response Count
Flash Flooding (typically less than six hours in length)	40.0%	8
Long-term Flooding (typically days to weeks in length)	**60.0%**	**12**
	answered question	**20**
	skipped question	**10**

5. Where does your flooding typically come from? (Please select all that apply)

	Response Percent	Response Count
Major waterways	60.0%	12
Small waterways/streams	**85.0%**	**17**
Seasonal waterways/ditches	45.0%	9
Ponds and lakes	10.0%	2
Other	0.0%	0
	answered question	**20**
	skipped question	**10**

6. Where does your forecast come from during a rainstorm and/or flood event? (Please select all sources)

	Response Percent	Response Count
National Weather Service (Phone call)	70.0%	14
National Weather Service (Website)	**90.0%**	**18**
National Weather Service (Weather Radio)	75.0%	15
Commercial weather website (Please specify below)	25.0%	5
TV Channel	65.0%	13
Radio Station	45.0%	9
Other (Please specify below	20.0%	4
	Additional Comments	4
	answered question	**20**
	skipped question	**10**

7. The forecasts that you receive from the National Weather Service are:

	Definitely Agree	Somewhat Agree	No opinion	Somewhat Disagree	Definitely Disagree	Response Count
Up-to-date	**65.0% (13)**	35.0% (7)	0.0% (0)	0.0% (0)	0.0% (0)	20
Thorough	**55.0% (11)**	40.0% (8)	5.0% (1)	0.0% (0)	0.0% (0)	20
Detailed	47.4% (9)	**52.6% (10)**	0.0% (0)	0.0% (0)	0.0% (0)	19
Confusing	0.0% (0)	5.3% (1)	21.1% (4)	**47.4% (9)**	26.3% (5)	19
Pin-pointed	21.1% (4)	**42.1% (8)**	26.3% (5)	10.5% (2)	0.0% (0)	19
Vague	0.0% (0)	5.3% (1)	26.3% (5)	**36.8% (7)**	31.6% (6)	19
					answered question	**20**
					skipped question	**10**

8. Please share any thoughts on how forecasts could be improved:

	Response Count
	5
answered question	**5**
skipped question	**25**

9. Which would you prefer?

	Response Percent	Response Count
A statement of the forecaster's expectations (For example: Flash flooding seems very likely given the current and forecast conditions)	35.0%	7
Advice on what action to take (For example: preparation for flash flooding is recommended at the following locations...)	20.0%	4
Forecasts with a likelihood value (probability) attached (For example: a 70% chance of heavy rain showers)	25.0%	5
Multiple forecasts and their corresponding likelihood (probabilities) (For example: a 30% chance of 2 inches of rain, 60% chance of 1 inch of rain, and a 90% chance of 0.5 inches of rain)	30.0%	6
A combination of likelihood (probability) and advice (For example: There is a 90% chance of 0.5 inches of rain and preparation for flooding is recommended...)	**65.0%**	**13**
	answered question	**20**
	skipped question	**10**

10. What does the term "uncertainty," used in a forecast, suggest to you? (Please select all that apply)

	Response Percent	Response Count
The forecast can't be trusted	21.1%	4
Lack of scientific understanding of nature	15.8%	3
Lack of adequate observations	**57.9%**	**11**
Potential error caused by assumptions	52.6%	10
Forecaster is worried about being wrong	5.3%	1
Lack of forecaster skill	0.0%	0
	answered question	**19**
	skipped question	**11**

11. How can we help?

	Agree	No Opinion	Disagree	Response Count
Would you be interested in partnering with businesses and a government agency, such as the National Weather Service, to develop action plans for the businesses and to tailor responses?	**65.0% (13)**	35.0% (7)	0.0% (0)	20
Should forecasters, such as the National Weather Service, help county emergency managers determine how to instruct various demographics to respond during floods?	**55.0% (11)**	30.0% (6)	15.0% (3)	20
Is there an adequate government agency who helps you with pre-planning for, responding to, and navigating through flood-related issues?	40.0% (8)	15.0% (3)	**45.0% (9)**	20
Would you appreciate having a scientific group that you could consult with to compute hydrologic and hydraulic values? (For example: estimating the amount of discharge traveling through a storm drain during a flood event)	**65.0% (13)**	30.0% (6)	5.0% (1)	20
			answered question	**20**
			skipped question	**10**

12. If you had to pay directly for forecasting services, then what funding sources would you be willing to use? (Please select all that apply)

	Response Percent	Response Count
Federal	**57.9%**	**11**
State	42.1%	8
County	36.8%	7
Matched funds with another level of government	31.6%	6
	answered question	**19**
	skipped question	**11**

13. Do you use any mapping services or software during a flood event? (Please select all that apply)

	Response Percent	Response Count
Google Maps	30.0%	6
Yahoo Maps	5.0%	1
Bing Maps	0.0%	0
FEMA Flood Maps	40.0%	8
Geographical Information Systems (ArcGIS)	**65.0%**	**13**
I do not currently use any software	25.0%	5
Other (please specify)	10.0%	2
	answered question	**20**
	skipped question	**10**

14. How do you use the maps? (Please select all that apply)

	Response Percent	Response Count
Map safe and efficient routes	75.0%	12
Identify at-risk structures	75.0%	12
Determine flooded zones	**87.5%**	**14**
Check individual elevations	18.8%	3
Compute discharge values	0.0%	0
Other (please specify)	0.0%	0
	answered question	**16**
	skipped question	**14**

15. Would high-resolution inundation maps be useful to you during a response?

	Response Percent	Response Count
Yes	**90.0%**	**18**
No	10.0%	2
	answered question	**20**
	skipped question	**10**

16. Would you like forecasts illustrated as probable inundation maps?

	Response Percent	Response Count
Yes	**95.0%**	**19**
No	5.0%	1
	answered question	**20**
	skipped question	**10**

17. What funding sources would you be willing to use to upgrade mapping services? (Please select all that apply)

	Response Percent	Response Count
Federal	**70.0%**	**14**
State	60.0%	12
County	45.0%	9
Matched funds with another level of government	45.0%	9
	answered question	**20**
	skipped question	**10**

18. How do you notify the public during flood events?

	Flash Flooding (less than six hours)	Long-term Flooding (many hours to weeks)	Response Count
Radio	100.0% (19)	68.4% (13)	19
Landline Telephone	90.9% (10)	63.6% (7)	11
Cell Phone	83.3% (10)	58.3% (7)	12
Television	87.5% (14)	68.8% (11)	16
County website	81.8% (9)	63.6% (7)	11
Facebook	100.0% (7)	71.4% (5)	7
Twitter	100.0% (3)	66.7% (2)	3
Youtube	100.0% (1)	100.0% (1)	1
Other	66.7% (2)	66.7% (2)	3
		(please specify)	5
		answered question	20
		skipped question	10

19. Does your county have access to a call center for public interface?

	Response Percent	Response Count
Yes	50.0%	10
No	50.0%	10
answered question		20
skipped question		10

20. Where is the call center located? Please select all that apply)

	Response Percent	Response Count
County	60.0%	6
State	0.0%	0
Other (please specify)	40.0%	4
answered question		10
skipped question		20

21. Please elaborate on any of the following questions as needed.

	Yes	No	Response Count
Do you have access to an emergency broadcasting system?	**95.0% (19)**	5.0% (1)	20
Does your access, or lack of access, to either an emergency broadcasting network or a call center affect your response?	**57.9% (11)**	42.1% (8)	19
Are there currently any shared resources, shared responses, communication networks, etc. between counties?	**52.6% (10)**	47.4% (9)	19
Are there currently any shared resources, shared responses, communication networks, etc. provided by the State Government?	42.1% (8)	**57.9% (11)**	19
Are there any OTHER shared resources, shared responses, communication networks, etc.?	33.3% (5)	**66.7% (10)**	15
		Please list any sources from above	2
		answered question	**20**
		skipped question	**10**

22. Please consider the following possible future technologies. If made available, would you use...

	I'm interested	I'm interested, but would like further explanation	I'm not sure what this means	I'm not interested, but may be interested in something similar	I'm not interested	Response Count
simulation software designed both as a training device and to simulate flood response before applying it to an actual event?	**55.0% (11)**	40.0% (8)	5.0% (1)	0.0% (0)	0.0% (0)	20
Augmented Reality software to visualize predicted floodwaters on the actual landscape through the viewfinder of your smart-phone camera?	**40.0% (8)**	**40.0% (8)**	15.0% (3)	5.0% (1)	0.0% (0)	20
navigation software using forecasts to continuously provide the shortest route as floodwaters make roadways and bridges impassable?	35.0% (7)	**40.0% (8)**	5.0% (1)	20.0% (4)	0.0% (0)	20
software alerting responders with their plan-of-action during a flash flood based on their phone's GPS coordinates?	**36.8% (7)**	**36.8% (7)**	21.1% (4)	5.3% (1)	0.0% (0)	19
software sending alerts to individual private citizens when their cell phone GPS signal indicates that they are in a dangerous area?	**40.0% (8)**	35.0% (7)	15.0% (3)	5.0% (1)	5.0% (1)	20
Augmented Reality software allowing users to view a city-scape through their phone and see lists of response-related tasks overlaying each building?	30.0% (6)	25.0% (5)	**40.0% (8)**	5.0% (1)	0.0% (0)	20
					answered question	**20**
					skipped question	**10**

23. How many people staff your emergency management team?

	Response Average	Response Total	Response Count
Full-time	1.11	31	28
Part-time	2.20	33	15
Temporary (for a typical response)	**5.00**	**65**	13
		answered question	**29**
		skipped question	**1**

24. Please indicate which agency performs the roles listed below?

	Response Percent	Response Count
Law Enforcement	95.7%	22
Medical	95.7%	22
Evacuation	95.7%	22
Communication	**100.0%**	**23**
	answered question	**23**
	skipped question	**7**

25. Approximately what population size does your county serve?

	Response Percent	Response Count
<10,001	10.3%	3
10,001 to 15,000	**31.0%**	**9**
15,001 to 20,000	20.7%	6
20,001 to 40,000	10.3%	3
40,000<	27.6%	8
	answered question	**29**
	skipped question	**1**

APPENDIX D: COVER LETTER FOR CITY OFFICIALS

IIHR Hydroscience & Engineering

IFC Iowa Flood Center

April 2011
City Official

Dear Respondent:

I am a graduate student researcher with the new Iowa Flood Center based out of IIHR—Hydroscience & Engineering at The University of Iowa. My research involves bridging the gap between scientific data and information that public officials can use. I hope to bridge that gap by finding ways to improve communication between flood forecasters and those directly interfacing with the public, and determine the necessary tools to facilitate improvements. To guide my work, I am gathering information on current procedures; including forecast dissemination, mapping tools, and communication methods.

As a part of the hierarchy of response, I need your expertise to guide me in improving communication. I developed a questionnaire to determine how city officials, while interacting with a local county emergency manager, use weather forecast information, mapping software, and other tools during storm and flood events in Iowa. As a city official, you can provide me with vital data on information sources you typically use, the problems associated with those information sources, and other typical issues that you encounter during local flood events. I am also interested in whether you need a change in emergency response resources, and how the Iowa Flood Center and government agencies can help improve your ability to respond. We want to know if there is anything broken on our end of science communication and what is needed to fix it.

I have made the survey available on the Internet at SurveyMonkey for you to complete before 20 April 2011. Please click here to be redirected or type https://www.surveymonkey.com/s/CityFloodResponse into your web browser. I anticipate that the survey will take approximately ten to 15 minutes. Please let me know if you are unable to participate in the survey via the SurveyMonkey website or are not available until after the 20th of April. Hopefully, I can make any necessary accommodations.

In exchange for your time and participation in this survey, you will be entered into a prize contest hosted by SurveyMonkey. However, your answers are also greatly appreciated because they may help to improve the quality of information that everyone related to emergency flood response receives during flood events. Ultimately, this questionnaire is a first step in determining what the scientific community needs to do to provide everyone with the correct tools to protect lives and property. Please take time to participate in this survey, even if you think no improvements are needed. Your input is vital and greatly appreciated.

Thank you very much for your assistance and I hope that we are able to provide you with some in return.

Sincerely,

Timothy J Middlemis-Brown
Graduate Student Researcher

ADDRESS	PHONE	EMAIL	WEB
SHL, Iowa City, Iowa 52246	(319) 325-5124	tmiddlem@iowa.uiowa.edu	www.iihr.uiowa.edu

APPENDIX E: QUESTIONNAIRE FOR CITY OFFICIALS

Municipal Inputs on Flood Response

1. Placement

*** 1. Are you directly involved in emergency response during local flood events?**

- ◯ Yes
- ◯ No

Municipal Inputs on Flood Response

2. Justification

1. How would you categorize your flood responsibilities?

- ◯ Law Enforcement
- ◯ Medical
- ◯ Evacuation
- ◯ Communication
- ◯ Forecast
- ◯ Other (please specify)

*** 2. For your response, are you interested in providing feedback on current and potential emergency response and resources available during flood events?**

- ◯ Yes (Please select to provide feedback)
- ◯ No (Please select to skip to demographics)

Municipal Inputs on Flood Response

3. Justification

*** 1. Are you interested in providing feedback on current and potential emergency response and resources available during flood events?**

- ◯ Yes (Please select to provide feedback)
- ◯ No (Please select to skip to demographics)

Municipal Inputs on Flood Response

4. Forecasting

1. What is the typical geography around your municipality? (Please select all that apply)

- [ ] Hilly
- [ ] Flat
- [ ] Bluffs
- [ ] Floodplains
- [ ] Valleys
- [ ] Other (please specify)

2. What is the typical land use surrounding your municipality? (Please select all that apply)

- [ ] Forested
- [ ] Row Crops
- [ ] Pastureland
- [ ] Other (please specify)

3. Which terms best describes your municipality...

- ○ Urban (Concrete and developed stormwater sewers)
- ○ Suburban (New development with catchment ponds)
- ○ Rural (Small town with drainage ditches)
- ○ Mixed urban and suburban

4. Which type of flood event do you typically encounter?

- ○ Flash Flooding (typically less than six hours in length)
- ○ Long-term Flooding (typically days to weeks in length)

Municipal Inputs on Flood Response

5. Where does your flooding typically come from? (Please rank each answer from one for highest to four for lowest)

	Ranking
Major waterways	
Small waterways/streams	
Seasonal waterways/ditches	
Ponds and lakes	

6. Where does your forecast come from during a rainstorm and/or flood event? (Please select all sources)

- ☐ National Weather Service (Phone call)
- ☐ National Weather Service (Website)
- ☐ National Weather Service (Weather Radio)
- ☐ Commercial weather website (Please specify below)
- ☐ TV Channel (Please specify below)
- ☐ Radio Station (Please specify below)

Please specify commercial source

7. The forecasts that you receive from the National Weather Service are:

	Agree	No opinion	Disagree
Up-to-date	○	○	○
Thorough	○	○	○
Detailed	○	○	○
Confusing	○	○	○
Pin-pointed	○	○	○
Vague	○	○	○

Municipal Inputs on Flood Response

8. Which type or combination of types would you prefer? (Please only select more than one if you would like a combination of forecast types)

- ☐ A statement of the forecaster's expectations (For example: Flash flooding seems very likely given the current and forecast conditions)
- ☐ Advice on what action to take (For example: preparation for flash flooding is recommended at the following locations...)
- ☐ Forecasts with a likelihood value (probability) attached (For example: a 70% chance of heavy rain showers)
- ☐ Multiple forecasts and their corresponding likelihood (probabilities) (For example: a 30% chance of 2 inches of rain, 60% chance of 1 inch of rain, and a 90% chance of 0.5 inches of rain)

9. What does the term "uncertainty," used in a forecast, suggest to you? (Please select all that apply)

- ☐ Lack of scientific understanding of nature
- ☐ The forecast can't be trusted
- ☐ Lack of adequate observations
- ☐ Potential error caused by assumptions
- ☐ Lack of forecaster skill
- ☐ Forecaster is worried about being wrong

10. How can we help?

	Yes	No	Already Exists
Would you be interested in partnering with businesses and a government agency, such as the National Weather Service or Federal Emergency Management Agency, to develop action plans for the businesses and to tailor responses?	○	○	○
Would you like help from a government agency when determining the best flood response for various demographics?	○	○	○
Would you like a government agency to help you with pre-planning for, responding to, and navigating through flood-related issues?	○	○	○
Would you appreciate having a scientific group that you could consult with to compute hydrologic and hydraulic values? (For example: estimating the amount of discharge traveling through a storm drain during a flood event)	○	○	○

Please elaborate on any existing relationships

Municipal Inputs on Flood Response

11. If you had to pay directly for forecasting services, then what funding sources would you be willing to use? (Please select all that apply)

- [ ] Federal
- [ ] State
- [ ] County
- [ ] Matched funds with another level of government

Municipal Inputs on Flood Response

5. Mapping

1. Do you use any mapping services or software during a flood event? (Please select all that apply)

- ☐ Google Maps
- ☐ Yahoo Maps
- ☐ Bing Maps
- ☐ FEMA Flood Maps
- ☐ Geographical Information Systems (ArcGIS)
- ☐ I do not currently use any software
- ☐ Other (please specify)

2. How do you use the maps? (Please select all that apply)

- ☐ Map safe and efficient routes
- ☐ Identify at-risk structures
- ☐ Determine flooded zones
- ☐ Check individual elevations
- ☐ Compute discharge values
- ☐ Determine evacuation zones
- ☐ Other (please specify)

3. Would high-resolution inundation maps be useful to you during a response?

- ◯ Yes
- ◯ No

4. Would you like forecasts illustrated as probable inundation maps?

- ◯ Yes
- ◯ No

Municipal Inputs on Flood Response

5. What funding sources would you be willing to use to upgrade mapping services? (Please select all that apply)

- [ ] Federal
- [ ] State
- [ ] County
- [ ] Matched funds with another level of government

Municipal Inputs on Flood Response

6. Communication

1. Who coordinates emergency response to local flood events?

- [ ] Federal Emergency Management Agency
- [ ] Iowa Homeland Security and Emergency Management
- [ ] The County Emergency Manager
- [ ] Municipal Leaders

2. Which best describes the location of your municipality?

- ◯ Straddles the county borderline (in two or more counties)
- ◯ Within two miles of a county borderline (in one county)
- ◯ Not within two miles of a county borderline (in one county)

3. Are there any issues with coordination between county emergency managers during multi-county floods?

- ◯ Yes
- ◯ No

4. Would you be interested in regional or statewide emergency operations centers controlling response to multi-county flooding?

- ◯ Yes
- ◯ No

5. Do your duties include notifying the public of evacuations and other required actions during flood events?

- ◯ Yes
- ◯ No

Municipal Inputs on Flood Response

7. Communication

1. How do you notify the public during flood events?

	Flash Flooding (less than six hours)	Long-term Flooding (multiple hours to weeks)
Local radio station	☐	☐
Local government website	☐	☐
Cell phone calls	☐	☐
Local government twitter account	☐	☐
Landline phone calls	☐	☐
Local government Youtube channel	☐	☐
Local television station	☐	☐
Local government Facebook page	☐	☐
Other	☐	☐

(please specify)

Municipal Inputs on Flood Response

8. Technology

1. Please consider the following possible future technologies. If made available, would you use...

	I'm interested	I'm interested, but would like further explanation	I'm not sure what this means	I'm not interested, but may be interested in something similar	I'm not interested
simulation software designed both as a training device and to simulate flood response before applying it to an actual event?	◯	◯	◯	◯	◯
Augmented Reality software to visualize predicted floodwaters on the actual landscape through the viewfinder of your smart-phone camera?	◯	◯	◯	◯	◯
navigation software using forecasts to continuously provide the shortest route as floodwaters make roadways and bridges impassable?	◯	◯	◯	◯	◯
software alerting responders with their plan-of-action during a flash flood based on their phone's GPS coordinates?	◯	◯	◯	◯	◯
software sending alerts to individual private citizens when their cell phone GPS signal indicates that they are in a dangerous area?	◯	◯	◯	◯	◯
Augmented Reality software allowing users to view a city-scape through their phone and see lists of response-related tasks overlaying each building?	◯	◯	◯	◯	◯

Municipal Inputs on Flood Response

9. Demographics

1. How many people staff your emergency management team?

Full-time [ ]

Part-time [ ]

Temporary (for a typical response) [ ]

2. Please indicate which agency performs the roles listed below?

Law Enforcement [ ]

Medical [ ]

Evacuation [ ]

Communication [ ]

3. Approximately what population size does your municipality serve?

- ◯ <2,001
- ◯ 2,001 to 5,000
- ◯ 5,001 to 15,000
- ◯ 15,001 to 40,000
- ◯ 40,000<

Municipal Inputs on Flood Response

10. Thank You!

Thank you very much for your participation!

Building:
Stanley Hydraulics Laboratory
IIHR-Hydroscience & Engineering
The University of Iowa

APPENDIX F: QUESTIONNAIRE RESULTS FOR CITY OFFICIALS

Municipal Inputs on Flood Response

SurveyMonkey

1. Are you directly involved in emergency response during local flood events?

	Response Percent	Response Count
Yes	**86.5%**	**77**
No	13.5%	12
answered question		**89**
skipped question		**0**

2. How would you categorize your flood responsibilities?

	Response Percent	Response Count
Law Enforcement	4.1%	3
Medical	0.0%	0
Evacuation	1.4%	1
Communication	41.9%	31
Forecast	0.0%	0
Other (please specify)	**52.7%**	**39**
answered question		**74**
skipped question		**15**

3. For your response, are you interested in providing feedback on current and potential emergency response and resources available during flood events?

	Response Percent	Response Count
Yes (Please select to provide feedback)	63.5%	47
No (Please select to skip to demographics)	36.5%	27
answered question		74
skipped question		15

4. Are you interested in providing feedback on current and potential emergency response and resources available during flood events?

	Response Percent	Response Count
Yes (Please select to provide feedback)	50.0%	6
No (Please select to skip to demographics)	50.0%	6
answered question		12
skipped question		77

5. What is the typical geography around your municipality? (Please select all that apply)

	Response Percent	Response Count
Hilly	36.2%	17
Flat	**48.9%**	**23**
Bluffs	10.6%	5
Floodplains	40.4%	19
Valleys	21.3%	10
Other (please specify)	8.5%	4
	answered question	47
	skipped question	42

6. What is the typical land use surrounding your municipality? (Please select all that apply)

	Response Percent	Response Count
Forested	21.3%	10
Row Crops	**76.6%**	**36**
Pastureland	34.0%	16
Other (please specify)	10.6%	5
	answered question	47
	skipped question	42

7. Which terms best describes your municipality...

	Response Percent	Response Count
Urban (Concrete and developed stormwater sewers)	**42.6%**	**20**
Suburban (New development with catchment ponds)	4.3%	2
Rural (Small town with drainage ditches)	27.7%	13
Mixed urban and suburban	25.5%	12
	answered question	**47**
	skipped question	**42**

8. Which type of flood event do you typically encounter?

	Response Percent	Response Count
Flash Flooding (typically less than six hours in length)	**57.4%**	**27**
Long-term Flooding (typically days to weeks in length)	42.6%	20
	answered question	**47**
	skipped question	**42**

**9. Where does your flooding typically come from? (Please rank each answer from one for high
four for lowest)**

Ranking

	1	2	3	4
Major waterways	**42.5% (17)**	7.5% (3)	25.0% (10)	25.0% (10)
Small waterways/streams	**39.5% (17)**	32.6% (14)	7.0% (3)	20.9% (9)
Seasonal waterways/ditches	20.5% (8)	**41.0% (16)**	25.6% (10)	12.8% (5)
Ponds and lakes	3.1% (1)	6.3% (2)	18.8% (6)	**71.9% (23)**
				answered question
				skipped question

10. Where does your forecast come from during a rainstorm and/or flood event? (Please select all sources)

	Response Percent	Response Count
National Weather Service (Phone call)	19.1%	9
National Weather Service (Website)	**70.2%**	**33**
National Weather Service (Weather Radio)	46.8%	22
Commercial weather website (Please specify below)	25.5%	12
TV Channel (Please specify below)	44.7%	21
Radio Station (Please specify below)	31.9%	15
	Please specify commercial source	19
	answered question	**47**
	skipped question	**42**

11. The forecasts that you receive from the National Weather Service are:

	Agree	No opinion	Disagree	Response Count
Up-to-date	**89.4% (42)**	8.5% (4)	2.1% (1)	47
Thorough	**80.9% (38)**	14.9% (7)	4.3% (2)	47
Detailed	**68.9% (31)**	22.2% (10)	8.9% (4)	45
Confusing	11.1% (5)	40.0% (18)	**48.9% (22)**	45
Pin-pointed	32.6% (15)	**47.8% (22)**	19.6% (9)	46
Vague	17.8% (8)	**42.2% (19)**	40.0% (18)	45
			answered question	**47**
			skipped question	**42**

12. Which type or combination of types would you prefer? (Please only select more than one if you would like a combination of forecast types)

	Response Percent	Response Count
A statement of the forecaster's expectations (For example: Flash flooding seems very likely given the current and forecast conditions)	42.6%	20
Advice on what action to take (For example: preparation for flash flooding is recommended at the following locations...)	21.3%	10
Forecasts with a likelihood value (probability) attached (For example: a 70% chance of heavy rain showers)	51.1%	24
Multiple forecasts and their corresponding likelihood (probabilities) (For example: a 30% chance of 2 inches of rain, 60% chance of 1 inch of rain, and a 90% chance of 0.5 inches of rain)	**53.2%**	**25**
	answered question	47
	skipped question	42

13. What does the term "uncertainty," used in a forecast, suggest to you? (Please select all that apply)

	Response Percent	Response Count
The forecast can't be trusted	30.4%	14
Lack of scientific understanding of nature	23.9%	11
Lack of adequate observations	28.3%	13
Potential error caused by assumptions	**45.7%**	**21**
Forecaster is worried about being wrong	17.4%	8
Lack of forecaster skill	6.5%	3
	answered question	**46**
	skipped question	**43**

14. How can we help?

	Yes	No	Already Exists	Response Count
Would you be interested in partnering with businesses and a government agency, such as the National Weather Service or Federal Emergency Management Agency, to develop action plans for the businesses and to tailor responses?	37.8% (17)	**40.0% (18)**	22.2% (10)	45
Would you like help from a government agency when determining the best flood response for various demographics?	31.1% (14)	**35.6% (16)**	33.3% (15)	45
Would you like a government agency to help you with pre-planning for, responding to, and navigating through flood-related issues?	**37.8% (17)**	28.9% (13)	33.3% (15)	45
Would you appreciate having a scientific group that you could consult with to compute hydrologic and hydraulic values? (For example: estimating the amount of discharge traveling through a storm drain during a flood event)	**52.3% (23)**	29.5% (13)	18.2% (8)	44
		Please elaborate on any existing relationships		10
			answered question	**46**
			skipped question	**43**

15. If you had to pay directly for forecasting services, then what funding sources would you be willing to use? (Please select all that apply)

	Response Percent	Response Count
Federal	47.5%	19
State	42.5%	17
County	42.5%	17
Matched funds with another level of government	**52.5%**	**21**
	answered question	**40**
	skipped question	**49**

16. Do you use any mapping services or software during a flood event? (Please select all that apply)

	Response Percent	Response Count
Google Maps	22.7%	10
Yahoo Maps	2.3%	1
Bing Maps	0.0%	0
FEMA Flood Maps	**40.9%**	**18**
Geographical Information Systems (ArcGIS)	31.8%	14
I do not currently use any software	**40.9%**	**18**
Other (please specify)	6.8%	3
	answered question	**44**
	skipped question	**45**

17. How do you use the maps? (Please select all that apply)

	Response Percent	Response Count
Map safe and efficient routes	32.1%	9
Identify at-risk structures	60.7%	17
Determine flooded zones	**64.3%**	**18**
Check individual elevations	50.0%	14
Compute discharge values	0.0%	0
Determine evacuation zones	39.3%	11
Other (please specify)	3.6%	1
	answered question	**28**
	skipped question	**61**

18. Would high-resolution inundation maps be useful to you during a response?

	Response Percent	Response Count
Yes	**75.6%**	**31**
No	24.4%	10
	answered question	**41**
	skipped question	**48**

19. Would you like forecasts illustrated as probable inundation maps?

	Response Percent	Response Count
Yes	69.0%	29
No	31.0%	13
	answered question	42
	skipped question	47

20. What funding sources would you be willing to use to upgrade mapping services? (Please select all that apply)

	Response Percent	Response Count
Federal	63.2%	24
State	55.3%	21
County	44.7%	17
Matched funds with another level of government	60.5%	23
	answered question	38
	skipped question	51

21. Who coordinates emergency response to local flood events?

	Response Percent	Response Count
Federal Emergency Management Agency	6.8%	3
Iowa Homeland Security and Emergency Management	11.4%	5
The County Emergency Manager	75.0%	33
Municipal Leaders	**77.3%**	**34**
	answered question	44
	skipped question	45

22. Which best describes the location of your municipality?

	Response Percent	Response Count
Straddles the county borderline (in two or more counties)	18.6%	8
Within two miles of a county borderline (in one county)	27.9%	12
Not within two miles of a county borderline (in one county)	**53.5%**	**23**
	answered question	43
	skipped question	46

23. Are there any issues with coordination between county emergency managers during multi-county floods?

	Response Percent	Response Count
Yes	11.9%	5
No	88.1%	37
answered question		42
skipped question		47

24. Would you be interested in regional or statewide emergency operations centers controlling response to multi-county flooding?

	Response Percent	Response Count
Yes	43.2%	19
No	56.8%	25
answered question		44
skipped question		45

25. Do your duties include notifying the public of evacuations and other required actions during flood events?

	Response Percent	Response Count
Yes	86.0%	37
No	14.0%	6
answered question		43
skipped question		46

26. How do you notify the public during flood events?

	Flash Flooding (less than six hours)	Long-term Flooding (multiple hours to weeks)	Response Count
Local radio station	**90.6% (29)**	65.6% (21)	32
Local government website	69.6% (16)	**73.9% (17)**	23
Cell phone calls	**100.0% (18)**	55.6% (10)	18
Local government twitter account	**66.7% (2)**	**66.7% (2)**	3
Landline phone calls	**95.7% (22)**	47.8% (11)	23
Local government Youtube channel	0.0% (0)	0.0% (0)	0
Local television station	**80.0% (16)**	65.0% (13)	20
Local government Facebook page	**100.0% (5)**	80.0% (4)	5
Other	**70.0% (7)**	**70.0% (7)**	10
		(please specify)	13
		answered question	**37**
		skipped question	**52**

27. Please consider the following possible future technologies. If made available, would you use...

	I'm interested	I'm interested, but would like further explanation	I'm not sure what this means	I'm not interested, but may be interested in something similar	I'm not interested	Response Count
simulation software designed both as a training device and to simulate flood response before applying it to an actual event?	**40.0% (16)**	27.5% (11)	2.5% (1)	2.5% (1)	27.5% (11)	40
Augmented Reality software to visualize predicted floodwaters on the actual landscape through the viewfinder of your smart-phone camera?	28.9% (11)	15.8% (6)	13.2% (5)	7.9% (3)	**34.2% (13)**	38
navigation software using forecasts to continuously provide the shortest route as floodwaters make roadways and bridges impassable?	23.7% (9)	23.7% (9)	0.0% (0)	21.1% (8)	**31.6% (12)**	38
software alerting responders with their plan-of-action during a flash flood based on their phone's GPS coordinates?	**36.8% (14)**	13.2% (5)	5.3% (2)	15.8% (6)	28.9% (11)	38
software sending alerts to individual private citizens when their cell phone GPS signal indicates that they are in a dangerous area?	**35.9% (14)**	23.1% (9)	0.0% (0)	10.3% (4)	30.8% (12)	39
Augmented Reality software allowing users to view a city-scape through their phone and see lists of response-related tasks overlaying each building?	26.3% (10)	21.1% (8)	5.3% (2)	10.5% (4)	**36.8% (14)**	38
					answered question	41
					skipped question	48

28. How many people staff your emergency management team?

	Response Average	Response Total	Response Count
Full-time	8.49	416	49
Part-time	4.36	144	33
Temporary (for a typical response)	**21.91**	**723**	33
		answered question	**60**
		skipped question	**29**

29. Please indicate which agency performs the roles listed below?

	Response Percent	Response Count
Law Enforcement	**98.4%**	**60**
Medical	88.5%	54
Evacuation	91.8%	56
Communication	93.4%	57
	answered question	**61**
	skipped question	**28**

30. Approximately what population size does your municipality serve?

	Response Percent	Response Count
<2,001	29.2%	19
2,001 to 5,000	**35.4%**	**23**
5,001 to 15,000	23.1%	15
15,001 to 40,000	6.2%	4
40,000<	6.2%	4
	answered question	**65**
	skipped question	**24**

APPENDIX G: PHONE SPECIFICATIONS

Apple iPad 2

Operating System	iOS 4
Display	9.7" touchscreen with 1024x4768 pixels
Processor	1 GHz dual-core Apple A5
Memory	512 MB RAM
Data Connection	CDMA and GSM

Apple iPhone 3GS

Operating System	iOS 4
Display	3.5" touchscreen with 320x480 pixels
Processor	600 MHz
Memory	256 MB RAM
Data Connection	GSM

Apple iPhone 4

Operating System	iOS 4
Display	3.5" touchscreen with 640x960 pixels
Processor	1GHz Apple A4
Memory	512 MB RAM
Data Connection	CDMA and GSM

HTC Thunderbolt

Operating System	Android 2.2
Display	4.3" touchscreen with 480x800 pixels
Processor	1GHz Snapdragon

Memory	768 MB RAM
Data Connection	CDMA and LTE

Samsung Fascinate

Operating System	Android 2.2
Display	4.0" touchscreen with 480x800 pixels
Processor	1GHz Cortex A8 Hummingbird
Memory	384 MB RAM / 512 MB ROM
Data Connection	CDMA