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Hazus-MH flood loss estimation on a web-based system

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HAZUS-MH FLOOD LOSS ESTIMATION ON A WEB-BASED SYSTEM

by

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

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To my family

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ABSTRACT

In last decades, the importance of flood damage and loss estimation systems has increased significantly because of its social and economic outcomes. Flood damage and loss estimation systems are useful to understand possible impacts of flooding and prepare better resilience plans to manage and allocate resources for emergency decision makers. Recent web-based technologies can be utilized to create a system that can help to analyze flood impact both on the urban and rural area. With taking advantage of web-based systems, decision makers can observe effects of flooding considering many different scenarios with requiring less effort. Most of the emergency management plans have been created using paper-based maps or GIS (Geographical Information System) software. Paper-based materials generally illustrate floodplain maps and give basic instructions about what to do during flooding event and show main roads to evacuate people from their neighborhood. After the development of GIS (Geographic Information System) software, these plans have been prepared with giving more detail information about demographics, building, critical infrastructure etc.

With taking advantage of GIS, there are several software have been developed for the understanding of disaster impacts on the community. One of the widely-used GIS-based software called Hazus-MH (Multi-Hazard) which is created by FEMA (Federal Emergency Management Agency) can analyze disaster effects on both urban and rural area. Basically, it allows users to run a disaster simulation (earthquake, hurricane, and flood) to observe disaster effects. However, its capabilities are not broad as web-based technologies. Hazus-MH has some limitations in terms of working with specific software requirements, the ability to show a limited number of flood scenarios and lack of

representing real time situation. For instance, the software is only compatible with Windows operated computers and specific version of ArcMap rather than other GIS software. Users must have GIS expertise to operate the software. In contrast, web-based system allows use to reduce all these limitations. Users can operate the system using the internet browser and do not require to have GIS knowledge. Thus, hundreds of people can connect to the system, observe flood impact in real time and explore their neighborhood to prepare for flooding.

In this study, Iowa Flood Damage Estimation Platform (IFDEP) is introduced. This platform is created using various data sources such as floodplain maps and rasters which are created by IFC (Iowa Flood Center), default Hazus-MH data, census data, National Structure Inventory, real-time USGS (United States Geological Survey) Stream gage data, real time IFC bridge sensor data, and flood forecast model which created by IFC. To estimate damage and loss, damage curves which are created by Army Corps of Engineers are implemented. All of these data are stored in PostgreSQL. Therefore, hundreds of different flood analyses can be queried with making cross-sectional analyses between floodplain data and census data. Regarding to level analyses which are defined by FEMA as three level, Level 3 type analysis can be done on the fly with using web-based technology. Furthermore, better and more accurate results are presented to the users. Using real-time stream gauge data and flood forecast data allow to demonstrate current and upcoming flood damage and loss which cannot be provided by current GIS-based desktop software. Furthermore, analyses are visualized using JavaScript and HTML5 for better illustration and communication rather than using limited visualization selection of GIS software.

To give the vision of this study, IFDEP can be widened using other data sources such as National Resources Inventory, National Agricultural Statistics Service, U.S. census data, Tax Assessor building data, land use data and more. This can be easily done on the database side. Need to address that augmented reality (AR) and virtual reality (VR) technologies can enhance to broad capabilities of this platform. For this purpose, Microsoft HoloLens can be utilized to connect IFDEP, real-time information can be visualized through the device. Therefore, IFDEP can be recruited both on headquarters for emergency managers and on the field for emergency management crew.

PUBLIC ABSTRACT

The purpose of this study is creating a web-based system that allows its users to understand and observe flooding impact in community namely, demographics, building damage, content damage, utility conditions, critical infrastructure and emergency centers. There are some software available to do similar analysis, however, there are some limitations such as software requirements, a limited number of scenario and having expertise on GIS-based software. One of the examples for software is called Hazus-MH. It developed by FEMA (Federal Emergency Management Agency) in order to understand natural disaster effects on a community. This study focuses on its flood component.

To reduce these limitations, this study presents IFDEP (Iowa Flood Damage Estimation Platform). In IFDEP, flood damage analysis can be done on the web browser without requiring Windows operator computer, the specific type of ArcMap software and additional licenses to run analyses. Besides users can operate IFDEP and analyze many numbers of scenarios without having GIS knowledge. Therefore, thousands of people can reach the system.

For the future application, IFDEP can extend with additional data resources such as National Resources Inventory, National Agricultural Statistics Service, U.S census data, Tax Assessor building data, land use and more. Also, Augmented Reality technology can be utilized for this system for stronger visualizations.

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CHAPTER 1 INTRODUCTION

1.1 Motivation of the Study

Flooding is one of the most common natural disasters which causes many deaths and billions of dollars of damage across the world every year. Based on this fact, many researchers and flood emergency managers try to develop disaster plans, tools, and maps to take action against flooding. In the United States of America, having a flood insurance is obligatory for places where high-risk flood area (Special Flood Areas or SFHAs) (FEMA, 2014). The U.S government created the National Flood Insurance Program (NFIP) in 1968 because of impacts of flooding in terms of human life and financial loss. Many insurance companies hire hydrologists and invest millions of dollars in flood insurance business sector. Using floodplain maps, hydrological data, and building values, companies arrange their insurance rates for their customers. Besides scientific foundations and federal organizations fund academics to create a useful tool to overcome flooding problems. One of the most influential examples can be investment by Federal Emergency Management Agency (FEMA) on disaster management software HAZUS-MH (Hazards U.S Multi Hazards). FEMA spent $63 million dollars to create disaster management software called HAZUS (Moffatt & Laefer, 2009). Considering all these efforts, the importance of flood damage and loss estimation systems can be understood obviously.

In this study, developing a web-based flood damage and loss estimation system is aimed to analyze multiple data resources for flood emergency decision makers and the public. Recent developments on the web-based technologies allow researchers to compute and visualize many analyses on the web browser in real time. With taking advantage of web-based systems, flood emergency decision makers and the public can access flood damage and loss estimation system. Currently flood related analyses are not conveniently available even for flood emergency managers. From the point of business sector, companies are not willing to share their information and their flood damage estimation system is not publicly available because of financial interest. Regarding academic and federal organization, there are few flood damage estimation systems that are available for the public. However, there are some limitations in these systems. In the section 1.4, these limitations will be explained in detail.

1.2 Overview of Flood Loss Estimation Systems

There are several flood damage estimation software that are created by federal organizations, academic institutions and army corps available for flood emergency managers. The majority of them rely on GIS-based software and some of them have independent frameworks. Currently, MIKE FLOOD, HEC-FDA (Flood Damage Reduction Analysis), HEC-FIA (Flood Impact Analysis), SOBEK 1D2D, and HAZUS are commonly used by flood emergency managers. Many of them requires additional independent software to run. For instance, MIKE FLOOD is able to work by linking with MIKE 11 (1D) and MIKE 21 (2D) (Vanderkrimpen, Melger, & Peeters, 2009).

In order to run a flood damage estimation simulation on these software, users must be familiar with hydrological estimations, river hydraulics basics, statistics, and GIS. Users also must keep their data that has exactly same format as this software accepted. A number of scenarios are limited based on probability of occurrence. Most of the results are shown considering 10, 25, 50, 100, 200, and 500-year return period flood. Depending on data quality, each scenario takes a considerable amount of time to simulate. If users want to evaluate detailed and trustworthy analyses, they must spend serious amounts of time to get results.

1.3 Brief Information about Hazus

Hazus is GIS-based software which was developed by FEMA as a planning tool to investigate social, economic and physical impacts of disaster such as earthquake, hurricane and floods. Flood component was released in 2004. Hazus is publicly available and can be downloaded through FEMA's website. Even though it is created as U.S nationally applicable software, several countries adjust software for themselves for instance Australia, Canada, Mexico. Hazus requires Windows operating system, ArcMap, ArcGIS spatial analyst tool, Microsoft SQL. In order to run the software, users must have license to satisfy these requirements. Most of analyses are done in census block level as depicted in Figure 1.1.

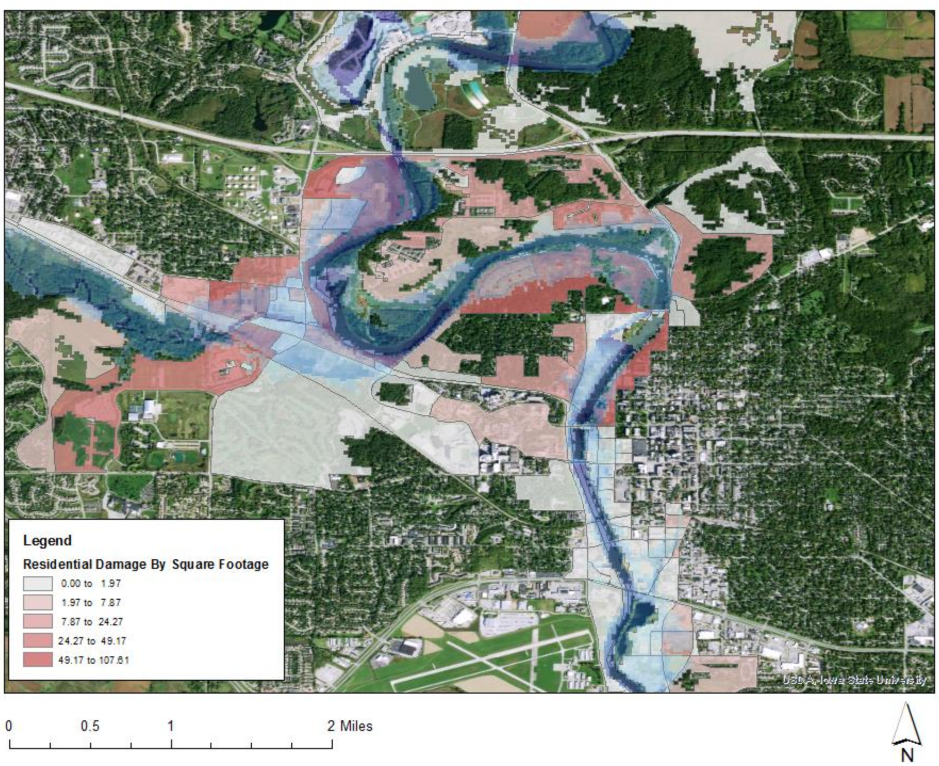

Figure 1.1 Residential Buildings within 100-year Return Period Flood / Iowa City

The flood component is able to estimate damage and loss both riverine flooding and coastal flooding. In this study, riverine flooding case is examined. In Figure 1.2, order of each step is illustrated for running a simulation on Hazus.

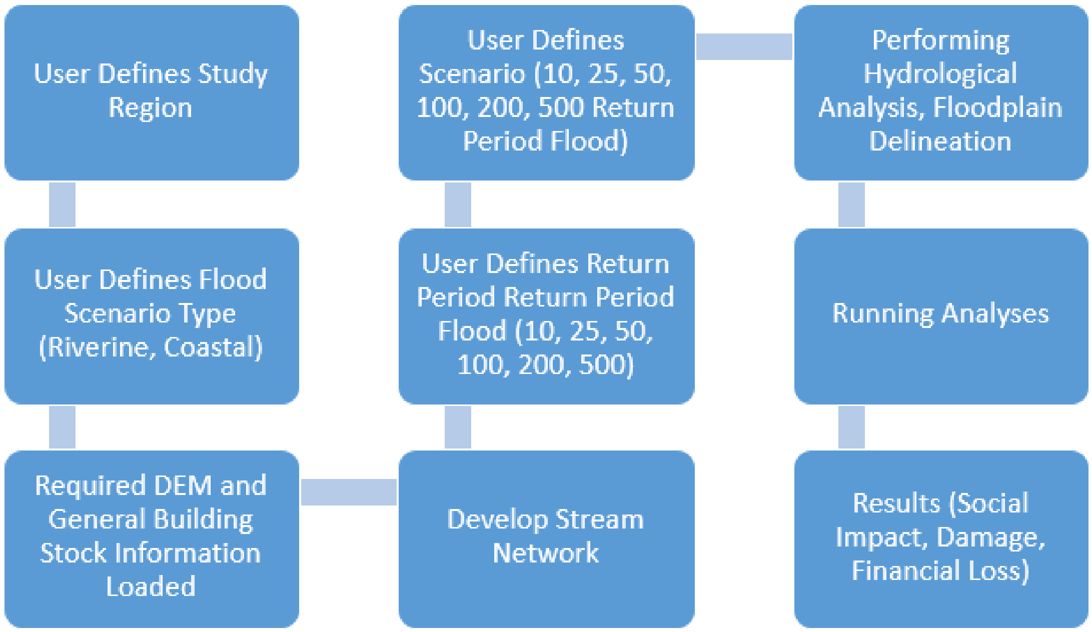

Figure 1.2 Steps for Flood Damage & Loss Estimation Analyses

Hazus allows flood emergency managers to evaluate various types of buildings such as fire station, police station, care facilities, schools, potable water facilities, waste water facilities, electric power plants, communication facilities, emergency centers. Also, damage percentage, dollar amount damage, functionality, structural and content damage, structural and content loss are estimated to understand flooding impacts. All this information has spatial locations on the map and other important information about facility name, address, number of beds, and estimated days to hundred percent functionality for buildings can be illustrated on Hazus. Figure 1.3 and Figure 1.4 demonstrate essential facilities and utility systems on the Hazus interface.

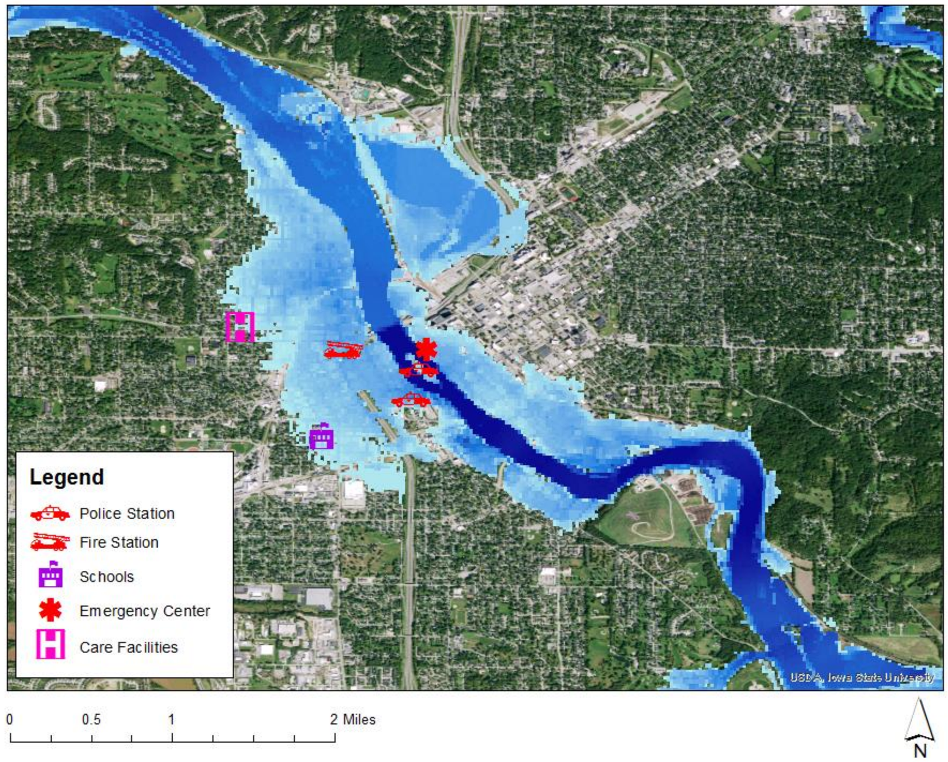

Figure 1.3 Essential Facilities within 500-year Return Period Flood / Cedar Rapids

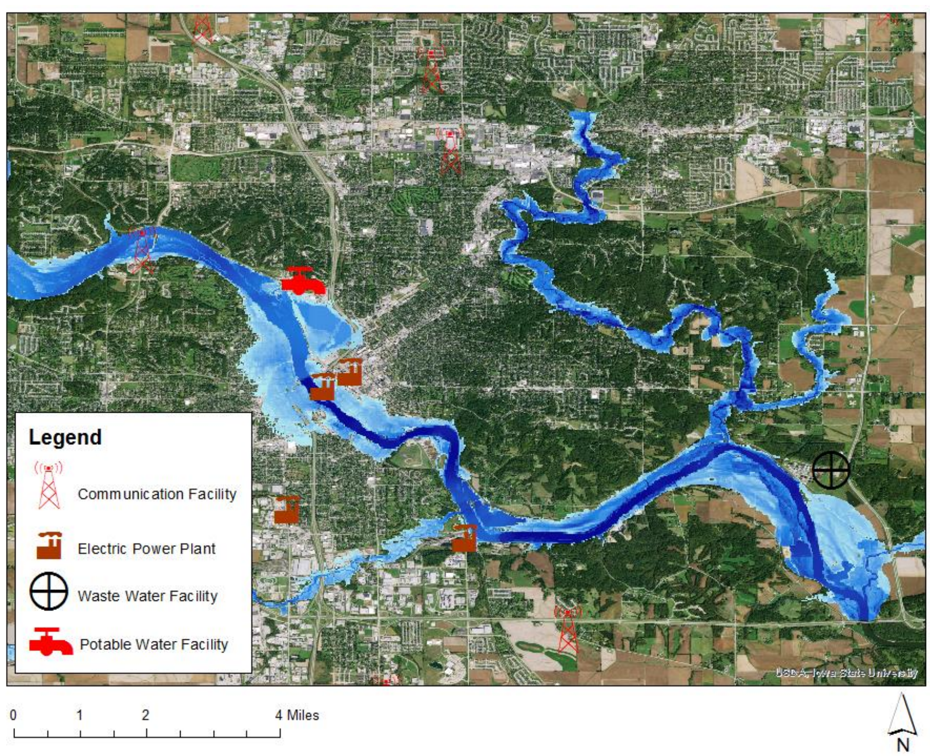

Figure 1.4 Safe Utility Systems near 500-year Return Period Flood / Cedar Rapids

Analysis about buildings under flood effect are visualized in census block level. Users can query general occupancy type in terms of residential, commercial, industrial, agriculture, religion, government, and education. Also specific occupancy type can be queried. For instance, users can query RES1 (Single Family Dwelling House) under flooding effect and see structural and content loss, damage percentage for structural and content. Figure 1.5 depicts number of residential buildings in each census block under 500-year return period flood effect.

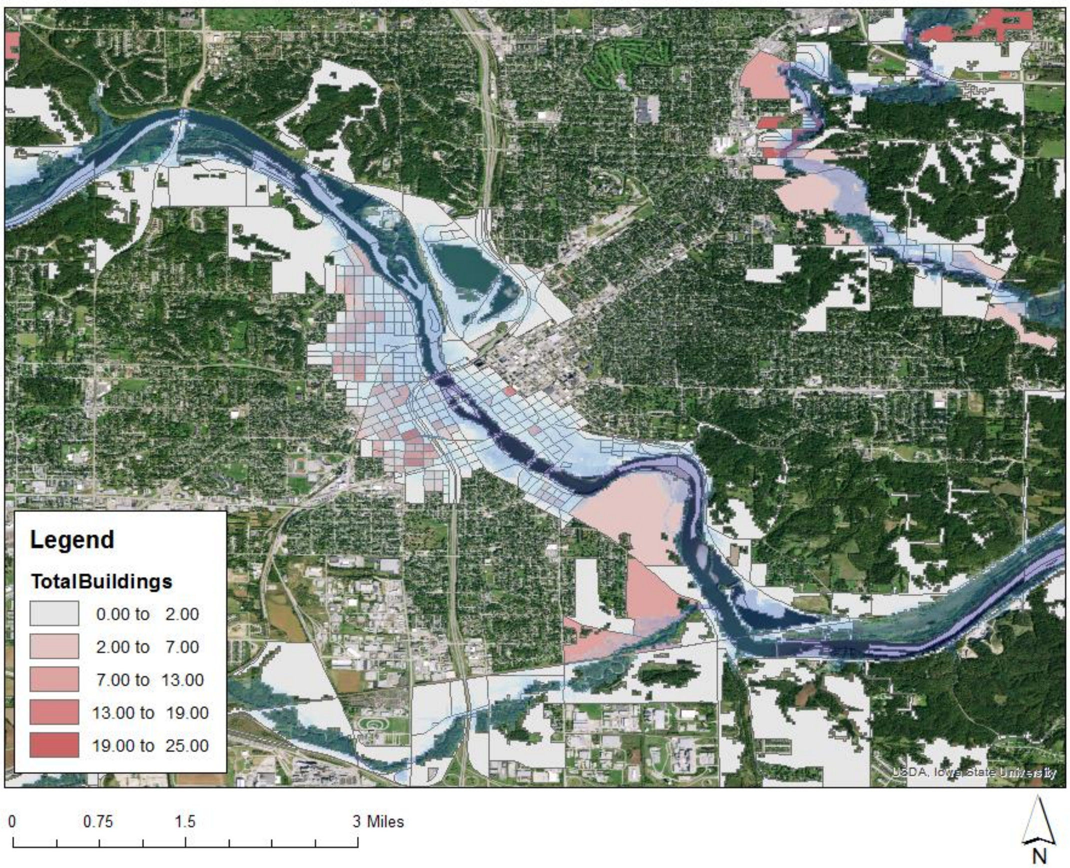

Figure 1.5 Total Buildings within 500-year Return Period Flood / Cedar Rapids

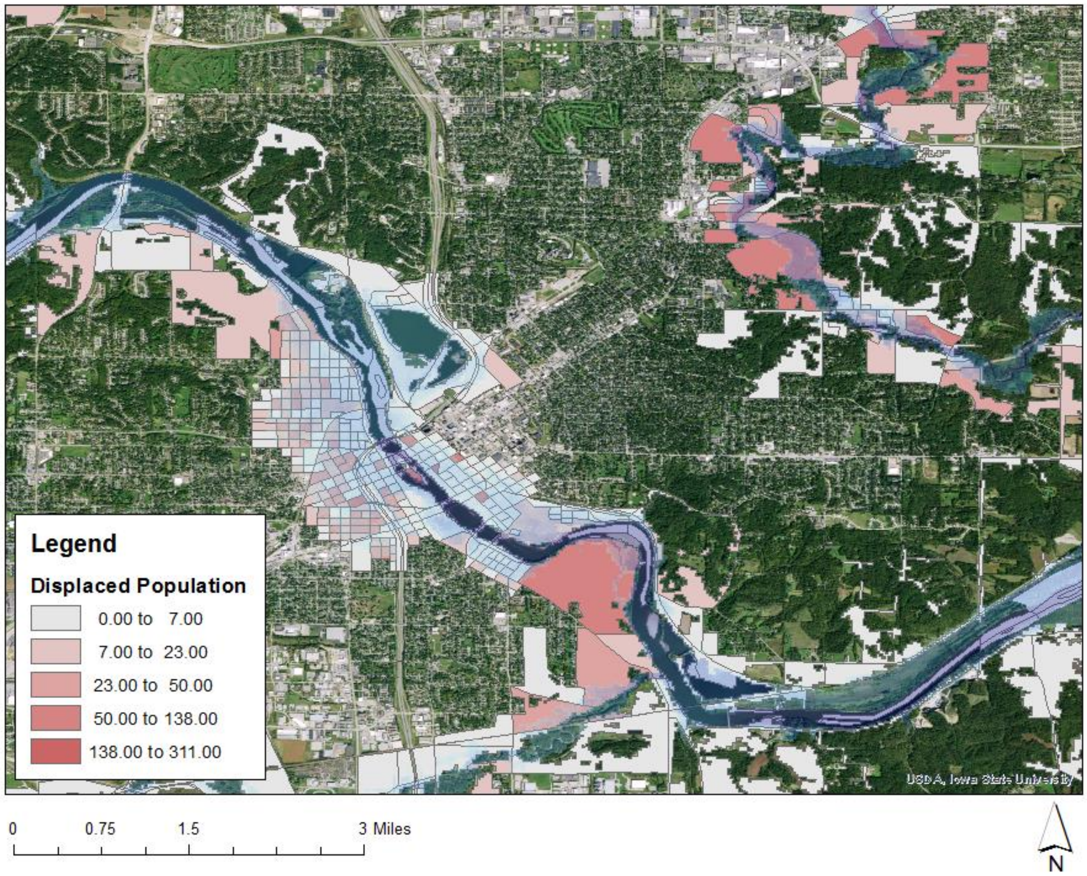

Figure 1.6 Displaced People within 500-year Return Period Flood / Cedar Rapids

Hazus can generate summary reports for each parameter in terms of buildings, emergency centers, utility systems, functionality of facilities, vehicles, shelter requirements, and agricultural losses. Both content loss and structural loss are represented in summary report. Table 1.1 expresses the shortest quick assessment report for Cedar Rapids under 500-year return period flood condition. Information about disaster area such as number of blocks, number of buildings, number of people, building exposure, economic loss, and shelter requirement are represented in quick assessment report.

Table 1.1 Cedar Rapids Quick Assessment Report for 500-year Return Period Flood

Study Region :	CedarRapids
Scenario :	cedar
Return Period:	500
Analysis Option:	0

Regional Statistics

Area (Square Miles)	725
Number of Census Blocks	6,241
Number of Buildings	
Residential	73,410
Total	80,757
Number of People in the Region (x 1000)	211
Building Exposure ($ Millions)	
Residential	19,759
Total	26,131

Scenario Results

Shelter Requirements	
Displaced Population (# Households)	1,553
Short Term Shelter (# People)	3,030
Economic Loss	
Residential Property (Capital Stock) Losses ($ Millions)	125
Total Property (Capital Stock) Losses ($ Millions)	612
Business Interruption (Income) Losses ($ Millions)	6

1.4 Limitations of Hazus

Even though Hazus offers very useful analyses as a planning tool, there are several limitations are exist. Limitations for Hazus can be classified into four main considerations namely, software knowledge and requirements, demonstrating few number of scenario, long time for processing simulation, being accessible by less people. These limitations are significant obstacle for users.

Regarding software requirements, ArcMap and ArcGIS spatial analyst tool are necessary to operate Hazus. Both of them require specific license and users must pay for them. Besides they require some expertise both on GIS science and GIS software. Also, Hazus cannot be used without Windows operated computer. Especially in the United States, Apple personal computers are widely used. Therefore, the number of prospective users may decrease dramatically. Hazus requires specific format on Microsoft SQL server to plug other data resources.

Time for processing simulation is considerably high in Hazus. In table 1.1, time for each step is represented for a fair desktop computer which has 8 GB Ram, and 2.40 GHz CPU. Evaluation of multiple scenarios may not be convenient for flood emergency decision makers.

Table 1.2 Processing Times for Cedar Rapids

Job Definition	**Time**
Define Study Region	5 min
Create Study Region	11 min
Develop Stream Network	61 min
Hydrological Analysis	26 min
Hydraulic Analysis	65 min
Damage Analysis	11 min
Total	179 min

Population of Cedar Rapids and Des Moines are roughly about 100,000 and 200,000 respectively. Based on this, Cedar Rapids scale may be accepted as average scale for State of Iowa. Therefore, flood analysis for average scale city takes three hours long simulation time for one scenario. To make instant decisions, three hours may not be convenient.

Hazus runs simulations based on return period flood. User can observe flooding effects on community regarding to 10, 25, 50, 100, 200, and 500-year return period flood.

In reality, flooding may not occur under same condition as a case of return period flood. Assuming a user has simulation results for 100 and 200-year return period flooding and real flooding is between these scenarios. Event that the case, user may not make a good approximation or interpolation between these scenarios to understand what exactly happens in real situation.

Since Hazus requires licensed version of specific software and GIS knowledge, this may be an obstacle for users. Also, user experience decreases because of long time analysis. Regarding these, number of Hazus user would be less than expected.

1.5 Thesis Contributions

In this study, a web-based system called IFDEP (Iowa Flood Damage Estimation Platform) is developed to reduce limitations that are explained in the previous section. IFDEP provides a comprehensive flood damage and loss estimation system for help flood emergency decision makers. Contributions of the platform can be classified into five group namely, creating generic queries, providing various scenarios, high-speed analysis, removing software requirement and GIS knowledge, and reaching thousands of people.

Generic SQL queries that are applicable for other data sources are created in this research. Using over 4000 floodplain maps and rasters that are provided by Iowa Flood Information System, same queries can be used to estimate flood damage for other structural data sources. Generic SQL queries can be used for other data resources with making few changes in their fields.

Depending on the study area, IFDEP can provide between 35 to 60 different flood scenarios for each city. Rather than observing six different flood scenarios which are based on 10, 25, 50, 100, 200, and 500-year return period flood, emergency decision makers can evaluate flooding effect in every half feet in their community.

By taking advantage of new development in web-based systems, average simulation time is able to be a couple of seconds instead of three hours long for one scenario. Therefore, instant decisions can be easily made using IFDEP. With moving flood slider, users can evaluate various type of flood scenarios in a very short time.

To run an analysis conveniently, software requirement obstacles are removed for flood emergency managers. In IFDEP, users can access every analysis by opening a web-browser. Thus, they do not have to pay license both for ArcMap and ArcGIS spatial analyst tool. Also, they can utilize the system using Mac OS, Windows, or Linux operating systems. Besides reducing GIS knowledge can create opportunity for cities where cannot afford GIS expertise to operate flood damage estimation systems. Local administrators can access flood damage analysis without GIS knowledge. Therefore, small communities may benefit from IFDEP.

With making IFDEP easy to access, thousands of people can reach to web site using web browser to experience flood analysis. For floodplain management process, public interest must be addressed (Correia, Fordham, Saraiva, & Bernardo, 1998). Information Systems can contribute public awareness of environmental issues with offering high quality environmental information considering time and cost effective way (Demir et al., 2009). Thus, a web-based system which covers flood damage and loss estimation analysis will definitely answer needs of flood emergency decision makers and public.

CHAPTER 2 HAZUS-MH METHODOLOGY

2.1. Flood Damage Curves

In order to estimate flood damage, flood depth-damage curves or functions are created mainly by the Federal Insurance Administration (FIA) considering 20 years of flood loss (Scawthorn, et al., 2006). Some of the depth-damage functions are developed by U.S Army Corps of Engineers (USACE). Primarily, flood depth damage curves are generated from flooded area and used as reference point for future floods (Smith, 1994). A flood depth damage curve represents mathematical relationship between the depth of the flood regarding the first floor of a structure and its damage percentage to the building. Depth-damage relationships are mostly stated structural damage as a percentage of structure value and content damage as a percentage of content value for every feet flood depth (Davis & Skaggs, 1992). The consensual definition of a structure is a lasting building and including every component that is attached to it. (Davis & Skaggs, 1992) Definition of content is every household that is not constant within the house (Davis & Skaggs, 1992). Therefore, building type and its structural and content loss are main considerations to create depth-damage functions. Hence, each type of building must have a unique damage curve for structural and content loss estimation. Otherwise, estimations may not be accurate to represent the real situation.

The main sources of the data are interviews with homeowner and business owner, data collected on the field measurements, and insurance claims adjustments. A video record of interviews and statement of landlords about inventory are used by the expert for developing damage estimates (USACE, 2006). These estimates are also grouped based on freshwater flooding and saltwater flooding. Buildings are classified and damage curves are uniquely created for a specific type of building. Square footage, a number of the story, the purpose of usage, the existence of basement and material of construction are considerations for classifying building classes and types. The significant reason to classify buildings is to group them into similar criterion in terms of valuation, and damage and loss characteristics (NIBS, 2003). Therefore, more accurate flood damage estimation is possible for every unique type of building.

Table 2.1 Current Damage Curve Types Used in Hazus

Damage Curve Name	**Coverage for Unique Type of the Building**
ABS Default	Vehicle damage
FIA	RES1, RES2
FIA (MOD.)	RES1
Hazus Default	Utility Classes
USACE-Chicago	RES1, RES2, RES3
USACE- Galveston	AGR1, COM1, COM2, COM3, COM4, COM5 COM6, COM7, COM8, COM9, COM10, EDU1, EDU2, GOV1, GOV2, IND1, IND2, IND3, IND4, IND5, IND6, REL1, RES1, RES2, RES3, RES4, RES5, RES6
USACE- IWR	RES1
USACE- New Orleans	AGR1, COM1, COM2, COM3, COM4, COM5 COM6, COM7, COM8, COM9, EDU1, EDU2, GOV1, IND6, REL1, RES1, RES2
USACE- St. Paul	COM2, COM4, COM8, RES1
USACE- Wilmington	COM1, COM2, COM3, COM4, COM5 COM6, COM7, COM8, COM9, COM10, EDU1, GOV1, IND2, REL1, RES1, RES2, RES3, RES4, RES5, RES6

In Table 2.1 types of flood depth-damage curves and their coverage for unique building type is illustrated. Most of the flood depth-damage curves are named based on disaster location name.

In general, buildings are classified into five main classes such as residential, commercial, industrial, educational, governmental, agricultural and religious. Some of the classes are also subclassified and named as type. As illustrated in Table 2.3, there are 33 main type of building defined in Hazus. Each one of the building types has specific damage curves for both structural damage and content damage. Using these damage curves both content and structural flood damage and loss are estimated. Damage curves for essential facilities such as fire stations, hospitals, and schools are taken from Hazus default damage curves. Regarding the type of the vehicle such as a light truck, heavy truck, and regular car, default damage curves are utilized to estimate vehicle damage (Scawthorn, et al., 2006). Thus, hundreds of damage curves are used to estimate damage and financial loss. Table 2.2 shows an example of damage curve for a building type.

Table 2.2 Flood Depth Damage Function (Curve) for RES1 Type Building

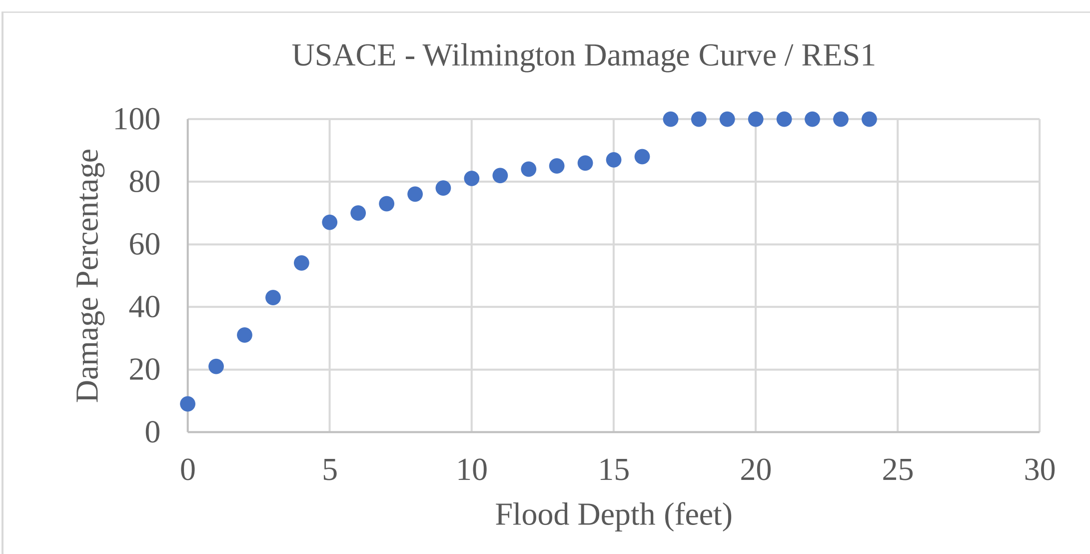

Table 2.3 List of Building Types in Hazus

RES1	Single Family Dwelling House	**Residential**
RES2	Mobile Home Mobile Home	
RES3	Multi Family Dwelling	
	RES3A Duplex	
	RES3B 3-4 Units	
	RES3C 5-9 Units	
	RES3D 10-19 Units	
	RES3E 20-49 Units	
	RES3F 50+ Units	
	Apartment/Condominium	
RES4	Temporary Lodging Hotel/Motel	
RES5	Institutional Dormitory Group housing (mil. college), Jails	
RES6	Nursing Home	
COM1	Retail Trade Store	**Commercial**
COM2	Wholesale Trade Warehouse	
COM3	Personal and Repair Services, Service Station/Shop	
COM4	Professional/Technical Services, Offices	
COM5	Banks	
COM6	Hospital	
COM7	Medical Office/Clinic	
COM8	Entertainment & Recreation, Restaurants/Bars	
COM9	Theaters	
COM10	Parking Garages	
IND1	Heavy Factory	**Industrial**
IND2	Light Factory	
IND1	Heavy Factory	
IND1	Light Factory	
IND3	Food/Drugs/Chemicals Factory	
IND4	Metals/Minerals Processing Factory	
IND5	High Technology Factory	
IND6	Construction Office	
AGR1	Agriculture	**Agriculture**
REL1	Church/Non-Profit	**Religion**
GOV1	General Services / Office	**Government**
GOV2	Emergency Response / Police/Fire Station/EOC	
EDU1	Grade Schools	**Education**
EDU2	Colleges/Universities /Group housing not included	

2.2 Flood Damage and Loss Estimation

Extracting floodplain grid is the first major step to estimate flood damage and loss by making hydrological analysis and hydraulic analysis. Hydrological analysis for the riverine flood is done using regression equations created by the USGS. Each region has been classified regarding hydrological region and following a form of regression equations have been built considering this by the USGS (Scawthorn & et al., 2006).

$$Q_T = Cf_i(P_1)f_2(P_2)\ldots f_n(P_n) \qquad (1.1)$$

Where Q_T=discharge value with an annual probability of exceedance of $1/T$; C=constant; and $f_i(P_i)$ characterize a function of the ith element of the equation.

Hydrological regions in the United States are stored in Hazus as shapefile. In the case of absence of regression equation for a specific region, historic stream gage data that can represent the watershed used to get discharge value (Scawthorn & et al., 2006).

Rating curves, especially for floodplain not for a channel, are used by hydraulic analysis to represent the ground shape and calculate depth grid. Therefore, depth is derived as a function of distance from channel to the floodplain edge. (Scawthorn & et al., 2006).

Actual flood depth is the main consideration to estimate flood damage and loss. Foundation height or the first floor height must be subtracted from calculated depth. Otherwise, damage percentage and financial loss are overestimated. Figure 2.1 depicts actual flood depth.

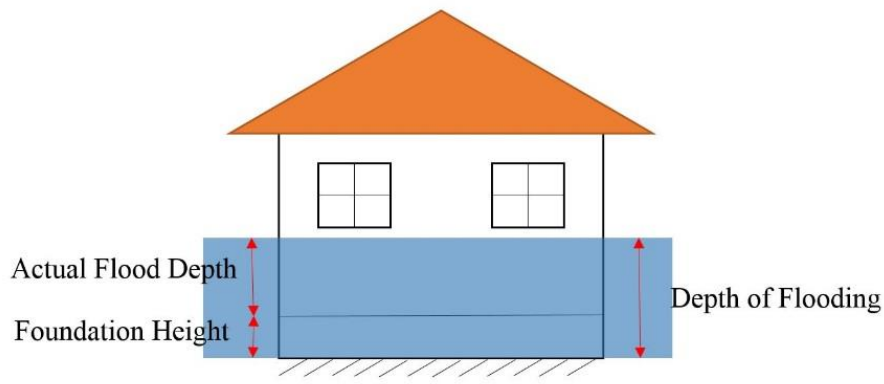

Figure 2.1 Actual Flood Depth for an Individual Building

In census block level, location for individual buildings is unknown. To calculate the depth of flooding area-weighted depth estimation is used. In other words, the number of grid cells within flood raster are counted and divided by total number of cells in the census block. Obtained result is called weighted damage for each census block, therefore, each type of building. For an individual building, depth of flooding is calculated and actual flood depth is extracted by subtracting foundation height.

2.3 Usage of Flood Depth-Damage Functions in IFDEP

Hazus library covers 900 flood depth damage curves for building types (Scawthorn, et al., 2006). In order to estimate damage for a specific building type, corresponding flood damage function is matched with its unique id and flooding depth is calculated for a point or census block. To calculate flood depth, PostGIS intersection tool is used. From the flood depth, actual flood depth is calculated and matched with correspondent damage percentage. Then, the damage is multiplied by the value of structure or value of content to estimate damage percentage and financial loss.

In IFDEP, four distinct flood depth-damage functions are used namely FIA, USACE – Chicago, USACE – Galveston, and USACE – Wilmington. In National Structure Inventory, there are 36 specific types of buildings for the State of Iowa. For this reason, the majority of functions in IFDEP are USACE – Galveston and USACE – Wilmington because of their coverage for specific types of building. These damage functions were derived from Galveston, TX and Wilmington, NC where encountered both riverine and coastal flooding. Therefore, damage functions for salt water and fresh water are available. In IFDEP, fresh water flood depth-damage functions are implemented because the State of Iowa is chosen as a study area.

In figure 2.2, flood damage and loss estimation processes is demonstrated for IFDEP. Briefly, point geometry of a building is intersected with raster to calculate depth and actual depth. Regarding the type of building appropriate damage function is chosen and damage and loss estimation are done in SQL side.

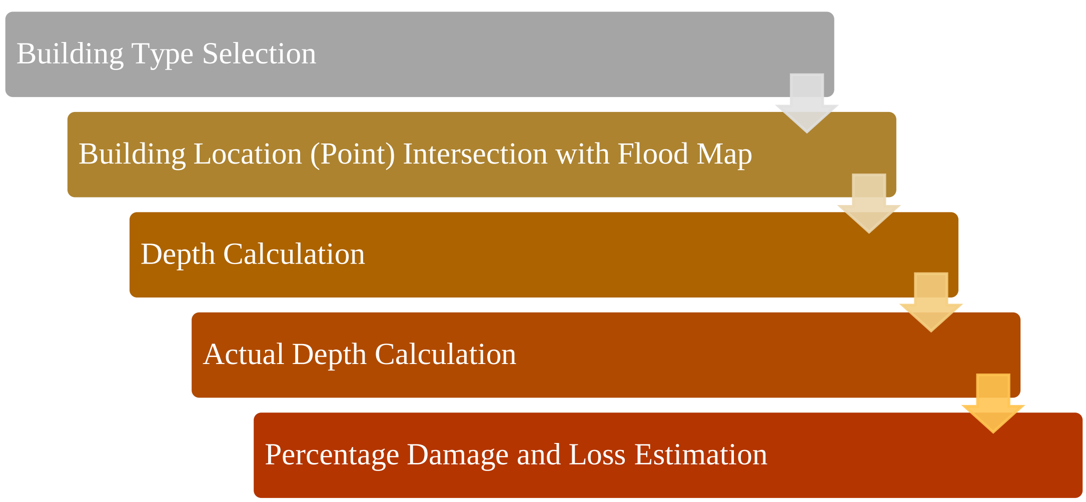

Figure 2.2 Flood Damage Percentage and Loss Estimation Process in IFDEP

CHAPTER 3 PORTING HAZUS TO A WEB-BASED SYSTEM

3.1 Capabilities of Web-based Platform for Flood Related Analyses

Web-based Hydroinformatics applications are powerful to manage and analyze water-related data, and visualize it in a meaningful way. New improvements in web-based technologies allow to share flood-related data and information and to improve visualization, management, and modeling and to advance timing for flood warnings and readiness for flood events (Demir & Krajewski 2013). Unlike GIS-based desktop software, web technology has many strong libraries that can be utilized to create a powerful visualization for a specific task. Desktop-like programs and visualizations and improved user experience are made possible with the developments of client and server-side scripting languages (e.g. AJAX JavaScript) (Demir, 2010). Web services are a broad architecture for connecting other devices and transferring all types of data. They are not limited to spatial data exchange (Kumar et al., 2005). Therefore, web-based applications will be useful to reduce software installation and software knowledge for users in the future.

Web technology also allows making a live analysis that can be made using real-time data acquisition tools on the web. Sufficient readiness, effective warning systems, and public response in a timing manner are most important aspects in order to decrease flooding losses (Hayden, et al., 2007). In order to provide good enough flood emergency management system, web-based technologies can achieve to satisfy these aspects.

To respond these needs, IFDEP (Iowa Flood Damage Estimation Platform) is created with making Hazus analysis and more on the web-based system. As mentioned in Chapter 1, Hazus has several limitations in terms of software knowledge and requirements, demonstrating few number of scenario, long time for processing simulation, being accessible by fewer people. The web application is capable of managing these limitations and brings more flexibility for future applications.

On the web, early flood warnings can be conveyed to public by acquiring real-time stream gage data from flood forecast models. With making intersection between census data and predicted flood stage height flooding, general sense of disaster impact on community can be evaluated.

3.2. Data Sources

IFDEP consists of a various type of data from different sources such as default Hazus data, National Structure Inventory, floodplain maps and rasters, flood depth-damage functions, real-time stream sensor data. These data are created by several different organizations and institutions such as U.S. Census Bureau, Iowa Flood Center, the U.S Army Corps of Engineers, USGS, Federal Insurance Administration, and National Weather Service. Most of the data sources have a spatial location and can be illustrated on Google Maps API utilizing PostgreSQL and PostGIS.

Flood inundation maps and rasters were created using high-resolution LIDAR elevation data by Iowa Flood Center (IFC). IFC and Iowa Department of Natural Resources have received $10 M funding from the State of Iowa for statewide floodplain mapping. The objective of the project is providing web-based flood inundation maps which can be helpful for flood emergency managers, public, local administrators in terms of planning and understanding of the flooding impact in their community (Gilles et al., 2012). Floodplain maps were created considering year return period flow and 0.5-foot river stage increment near USGS stream gage. Structural information such as bridges, levees, and weirs were considered for creating detailed urban flood inundation maps (Gilles et al. 2012). These data are publicly available for community in Iowa Flood Information System (IFIS) website. One of the biggest advantages of IFDEP is having an opportunity to benefit from over 4200 floodplain maps including depth and extend which are created in statewide floodplain mapping project. In IFDEP, there are 216 floodplain maps and rasters are stored in PostgreSQL for the first phase of the project.

Default Hazus data is the main source of the IFDEP. Overall, it covers demographics, structural, building content, emergency center, essential facilities, transportation segments, care facilities, and schools data. Detailed coverage of default Hazus data for the State of Iowa can be seen in Appendix B. Table B.1. In Appendix B. Table B.2 also shows demographics information fields in default Hazus data. Most records have polygon and point geometry fields. Therefore, it is easy to intersect with raster to get flood depth Rest of the tables have census id, facility id, and building id to connect the table which has geometric fields. The cost of the utilities, emergency centers, essential facilities, care facilities, and schools are stored as an integer.

In order to evaluate current flood condition, real-time USGS stream gages data are acquired. Gage data allows choosing accurate flood inundation map to analyze real time flood condition in the community. Real-time stream gage data updates itself every 15 minutes. Data acquisition is done using jQuery library on JavaScript programming language. Flood forecast data which is created by National Weather Service is also available. It creates an opportunity to observe upcoming river stage height for upcoming days and select appropriate flood inundation map to evaluate possible flooding damage and loss in the community. Flood forecast data which is created by IFC is also available for communities where NWS does not provide forecast model. Large-scale atmospheric data, hydrological real-time data, and river stage forecast data are available on IFIS (Krajewski, et al., 2017).

National Structure Inventory data which created by Army Corps of Engineers allows analyzing flood damage in point location level. It covers structural value, content value, schools, the number of students, the number of teachers, building material type, foundation type, and foundation height, within the building data. There are four main building classes defined in NSI data such as residential, commercial, industrial, and public. 36 main building types are classified from four main building classes. All information within National Structure Inventory has point feature as geometry. Compare to census level analysis, National Structure Inventory allows to estimate flood damage and loss more accurately.

3.3 Study Area

The State of Iowa is located in Midwest region of the United States and surrounded by Mississippi River on the east and Missouri River on the west. During last 20 years, State of Iowa had experienced with flooding in many cities. Due to 2008 flooding across the State of Iowa, approximately $10 billion damage was confirmed by Iowa Governor Chet Culver (NOAA, 2009). 85 of 99 counties were officially declared as the disaster area due to the floods of 2008 (Gilles et al., 2012) There are five different cities have been selected for the IFDEP. Main selection of the study area is analyzing different type of cities in terms of size, the prosperity of the settlement, the importance of political center, the importance of educational, and frequency of flooding. IFDEP covers five cities namely, Cedar Rapids, Des Moines, Iowa City, Rock Rapids, and Rock Valley.

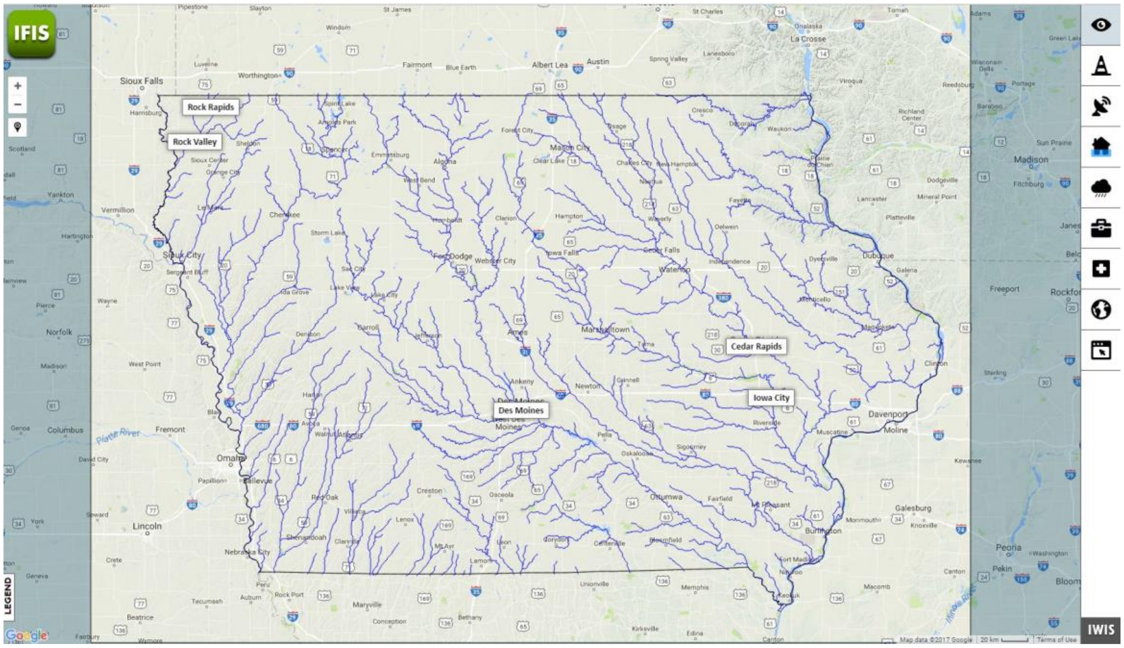

Figure 3.1 Study Sites in State of Iowa

Cedar Rapids is located on east side of the state of Iowa and the second largest city in the state. Also, one of the biggest river called Cedar River is passing through in the middle of the city. During the last couple decades, the city had severe flooding which caused billions of dollars financial loss. Nearly, 1300 blocks and most of the downtown area were affected by flooding in 2008 (NOAA, n.d.). Cedar Rapids is one of the most industrialized city in Iowa, therefore, the city is the main income source for thousands of people.

Des Moines is the Capital of the State of Iowa and it has a significant role in Iowa politics and trade. Similar to Cedar Rapids, Des Moines also frequently encounters with floods. Since the city is the metro district, many services can be stopped due to the flooding. As a result of the great flood of 1993, %80 of the businesses encountered lacking water in Des Moines (Tierney & Nigg, 1995). Estimated flood loss for the 1993 flood in Des Moines was $152 M (USACE, 2005).

Iowa City has the biggest university called the University of Iowa in the State of Iowa. The campus of the university is settled in two sides of the Iowa River. 2008 flooding caused millions of dollars loss to the university. Twenty university buildings, also Hancher Auditorium, were affected by flood in the University of Iowa Campus (NOAA, n.d.). In order to reduce future flooding damage, Iowa City is added into IFDEP.

Rock Valley and Rock Rapids are small towns in North West of State of Iowa. To help small communities, two cities have been added to IFDEP study area. Some of the small settlements cannot hire GIS analyst. Therefore, IFDEP can provide flood emergency planning tool for cities where do not have GIS expert.

CHAPTER 4 IOWA FLOOD DAMAGE ESTIMATION PLATFORM (IFDEP)

4.1 Overview of IFDEP

Hydroinformatics gathers all the developments in information related to water covering technologies that developed by current society, communication and giving it name on it (Abbott, 1999). Well-designed cyberinfrastructure is required for collecting data from different sources such as multiple weather radar, rain gauges, soil moisture sensors, and stream gages (Demir, et al., 2015). Because of the fact that collecting all water related information systematically in a web-based environment will give an opportunity of better accessibility of information for scientist, researchers, and public compared to desktop applications. With creating new possibilities like online modeling, mapping, and better visualization, web technologies start to take the place of desktop applications (Demir & Beck, 2009). Every group has their own perspective to process the data and analyze it to show the different result. Therefore, gathering information in an accessible environment is vital for future contributions. The web-based application is one of the most accessible systems by the public to achieve this goal.

The objective of the IFDEP is developing a web-based system that can cover multiple datasets from different resources and visualize and analyze them using flood inundation maps and rasters that were created by Iowa Flood Center. Also, IFDEP can be enlarged using other data sources to provide different analyses such as agricultural loss estimation. Currently, the system covers default Hazus data, National Structure Inventory, flood depth damage curves, real-time stream gage data and flood forecast data.

Generic queries, created for IFDEP will allow implementing same analyses for different cities and different data sources by making a small change in queries. Therefore, many flood emergency managers can benefit from IFDEP to make a decision and plan their community for flooding. IFDEP is aimed to update same analyses for same communities to support more accurate flood damage and loss analyses.

4.2 Data Management

Datasets that are explained in the previous chapter are stored in PostgreSQL server which runs on IIHR server. PostgreSQL is a powerful database to query, manipulate, and analyze spatial data using the extensive library of PostGIS. PostgreSQL has high performance to run queries using indexes. Definition of high performance is completing tasks within an acceptable amount of time for users (Douglas & Douglas, 2003). PostGIS supports geographic objects in PostgreSQL and makes possible to use as a spatial database for GIS, similar to ESRI's SDE (Spatial Database Engine) or Oracle's spatial extension (Postgresql, 2015). It allows to intersect, union, buffer, and other important spatial queries using geometric features such as points, linestrings, polygon, multipoints, multilinestrings, multipolygon, and geometry collection. Moreover, PostGIS is better to compare to commercial software such as IBM DB2 Spatial Extender and Oracle Spatial in terms of data management at Megabytes level (Zhou, et al., 2009).

Since IFDEP covers multiple different data sources, good data management plan require running queries effectively. For all datasets, one database is created and for each dataset, multiple schemas are created. Thus, data can be accessed and queried using one database privilege and information. In figure 4.1 data schema is illustrated for a community. All census and building related information are stored in community schema. In community schema, unique community tables were created for each a unique city. For each city, the unique schema for flood maps are created to record flood inundation maps and rasters named as community depth. Community depth consists five tables for each study area and covers both flood inundation shapefiles and raster. To make more convenient, all shapefile for a community were combined in one table. However, the same task was not efficient to do for raster. Therefore, each flood map rasters are stored one by one as a different table. Flood depth-damage functions are also recorded in a different schema called damage curves in the database as one table. In damage curves tables, there are 35511 attributes for damage functions.

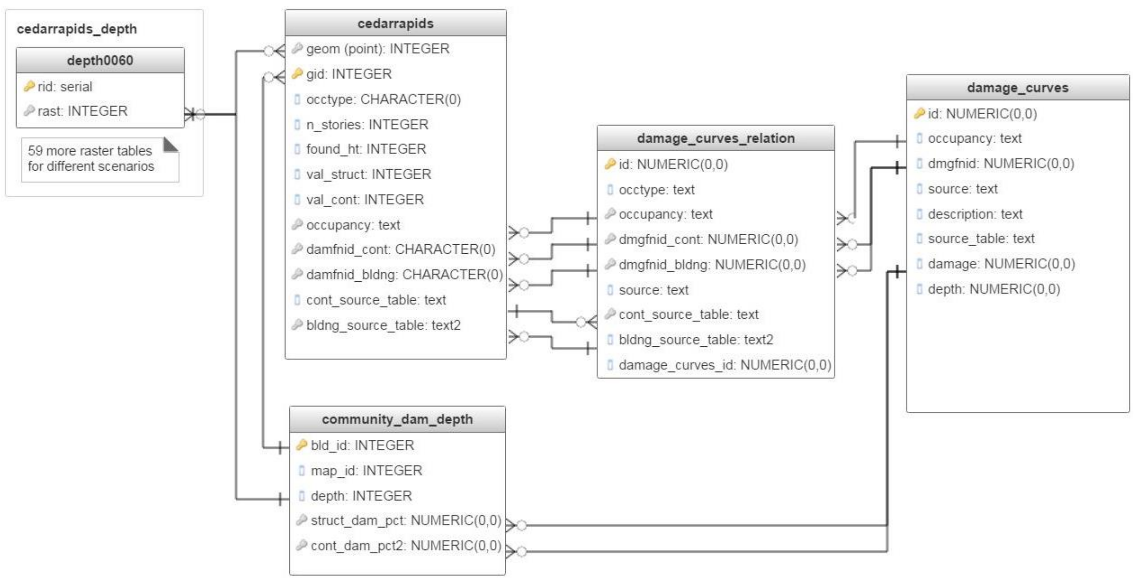

Figure 4.1 Data Schema of IFDEP for Cedar Rapids

As illustrated in figure 4.1, point geometry is taken from Cedar Rapids community map and intersected with Cedar Rapids community depth rasters to calculate flood depth. Considering specific occupancy, damage functions for structural loss and content loss were taken from damage curves table using damage curves relation table as a translator between community and damage curve. At the end, community damage and depth table for a city were created using flood depth, structural damage function, content damage function, specific occupancy, and damage. Community damage and depth table were created considering every unique scenario. As demonstrated in figure 4.1, 60 unique flood raster is intersected with buildings and required information as mentioned above to create community damage and depth table is stored in the table. This process is repeated for 4 cities.

4.2.1 Data Acquisition

IFDEP acquired data from various sources such as FEMA, IFC, USGS, USACE, and NWS. In order to store them into IFDEP database, there are several methods have been used to transfer data and check for their accuracy. QGIS import tool used to transfer Hazus data which has a geometric feature from MS SQL to PostgreSQL. Some of the data migration tools are available to transfer non-geometric data. However, their free versions are limited to transfer all fields properly. For this reason, non-geometric data was imported through MS SQL using Microsoft Excel. PostGIS import tool is used to upload flood inundation maps into IFDEP. ArcGIS and QGIS were used for validation of data which were taken from FEMA, USACE, and IFC. To acquire real-time data, USGS web site and jQuery library on JavaScript programming language have been used.

Default Hazus data which is publicly available on FEMA’s website is stored in Microsoft SQL Server. To move data from MS SQL to PostgreSQL, there are several data migration tools are became existing. However, most of them require the specific license and free versions migrate data incorrectly. Prices of these data migration tools are ranging $100 to $200 depending on their capabilities. For these reasons, PostGIS and QGIS are decided to use for data migration. QGIS is used to connect MS SQL Server to acquire data and transferred into PostgreSQL through QGIS. Therefore, migration of

Hazus data which has geometry fields has been completed. For non-geometric data, it exported from MS SQL Server as Excel file and transferred into PostgreSQL with creating every fields and table on PostgreSQL.

Migrating polygon and point geometry process can be easily done using QGIS, ArcMap, and PostGIS importer tools. However, migrating rasters cannot be transferred into PostgreSQL using same methods. To move floodplain rasters, shell scripts have been written on the command line. In the code, file directory, projection, the directory in database and schema, and server must be stated. In figure 4.2, uploading a raster flood map is illustrated. Floodplain raster data is stored as GeoTIFF file. More than 160 different survey related companies that work on GIS, cartographic, remote sensing utilize TIFF-based format for raster datasets imagery (OSGeo, 2014). Furthermore, IFDEP can analyze other raster data sources easily because of GeoTIFF query based analysis.

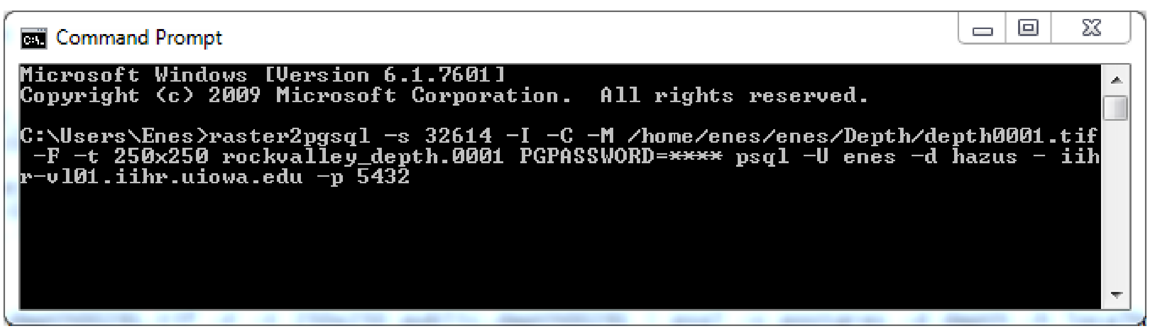

Figure 4.2 Shell Code to Transfer Data into PostgreSQL Server

Where letters state -d database name, -U user name, -M raster file directory, t- directory in database and schema

In order to check the accuracy of the data, ArcMap and QGIS are used. With making spatial queries in GIS software, results have been compared with results of SQL queries to understand whether there is a missing or distorted data. Assumed that observing same results shows that Hazus data has been migrated successfully. Then, geometric data and non-geometric data for same facilities have been compound into the same table to do further queries faster and more accurate. For National Structure Inventory (NSI), PostGIS importer tool is used to move NSI to PostgreSQL.

USGS stream gages create an opportunity for IFDEP to evaluate current flood condition in the community. The stream gage data is publicly available and can be acquired either historic or real-time using the specific link for a gage. JQuery is useful to get the stream gage data. JQuery API is a JavaScript library that can be utilized for HTML document traversal and manipulation, event handling, animation (jQuery, 2017). In client side, JavaScript code allows accessing real-time river stage information from USGS. In figure 4.3, river stage information from stream gauge that is located in the middle of Cedar Rapids is visualized using HTML and Ajax as a capability of JQuery.

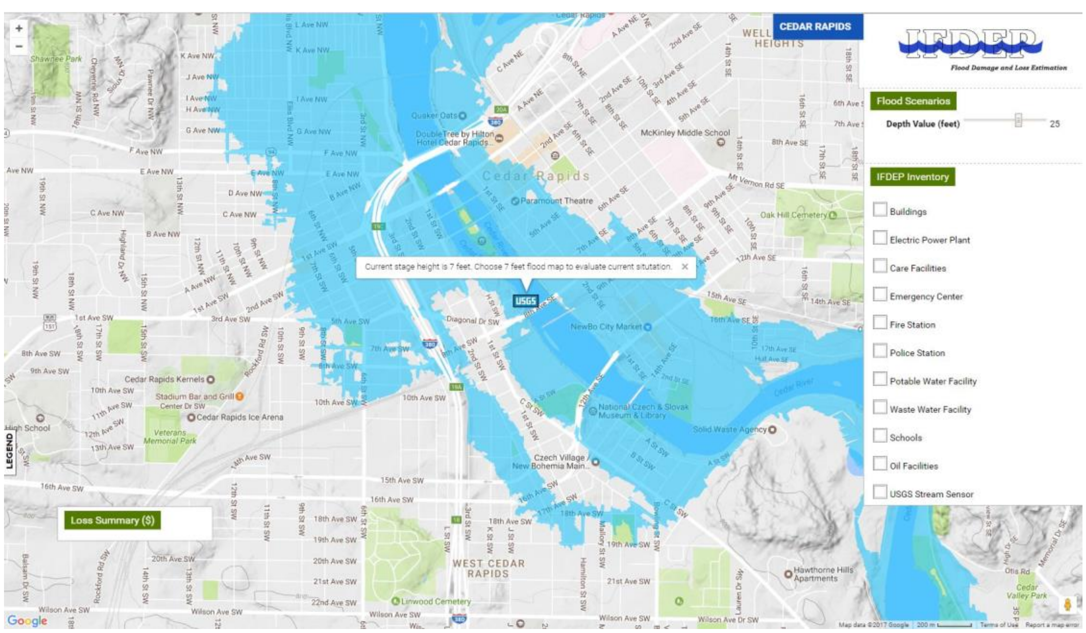

Figure 4.3 Real Time USGS Gage River Stage Acquisition for Cedar Rapids

In figure 4.4, how JQuery was used and how the data was parsed illustrated. As demonstrated in first 4 lines in the figure, source link, site no, period and format must be specified to access real-time stream gage data. Normally, the link provides where the data come from, description about the file, contact information, gage description, gage location, units, discharge, and stage height for the last 24 hour in every 15 minutes. Since IFDEP aims to provide current condition, last stage height value must be acquired. Therefore, the whole text must be parsed to get the latest value. Between lines 6 to 19 of figure 4.4, text which is taken from USGS link is parsed and the latest read from gage readings is written into res variable. At last, the message is pushed to Google maps marker layer to visualize for users.

```
1.     var contentString = $.ajax({
2.     method: "get",
3.     url: "https://waterdata.usgs.gov/nwis/uv",
4.     data: { site_no: "05464500", period: "1", format: "rdb" }
5.     })
6.    .done(function(msg) {
7.         var initialOffset = 1662;
8.         var newMsg = msg.substring(initialOffset-46);
9.         var resArr = newMsg.split("\t");
10.         var finalReadIndex = 0;
11.       for (var i=0,arrOffset=7;i<(resArr.length/7)-2;
12.             i++,arrOffset=arrOffset+7) {
13.             console.log(resArr[6+arrOffset]);
14.            finalReadIndex = 6+arrOffset;
15.       }
16.         var res = "Current stage height is "
17.         +Math.round(resArr[finalReadIndex])
18.         +" feet. Choose "+Math.round (resArr[finalReadIndex]) +
19.        " feet flood map to evaluate current situtation."
20.        infowindow = new google.maps.InfoWindow ({
21.        content: res
22.       });
23.   });
```

Figure 4.4 Data Acquisition Using Ajax from USGS Stream Gage

4.2.2 Data Processing

Since National Structure Inventory is independent of default Hazus data, it is not connected to damage curve tables. To assign damage curve ids, unique building types are considered and appropriate damage curves are matched for each building. To do this, a relational table which consists unique building name from National Structure Inventory and damage curve ids from damage curve database is created. With the SQL query that is shown in figure 4.5, National Structure Inventory tables for each study area is updated for further damage and loss estimation analyses.

Type	Input	Output	Variable
Structural, Content	damage_curves.hecfia community.rockrapids	community.rockrapids	flBldgStructDmgFn, flBldgContDmgFn

```
UPDATE community.rockrapids
SET dmgfnid_cont = hecfia2.dmgfnid_cont,
  dmgfnid_bldng = hecfia2.dmgfnid_bldng,
  occupancy = hecfia2.occupancy,
  source = hecfia2.source,
  cont_source_table = hecfia2.cont_source_table
  bldng_source_table = hecfia2.bldng_source_table
FROM damage_curves.hecfia2
WHERE damage_curves.hecfia.occtype = community.rockrapids.occtype
```

Figure 4.5 Assignment of Damage Function Id for National Structure Inventory Data

All queries in IFDEP were made using SQL query language. Since IFDEP is running on the web, these queries must be embedded into PHP scripting language. At this point, Google Maps JavaScript API requirements must be satisfied. In order to push spatial query into Google Maps JavaScript API, Google supports several formats such as GeoJSON (Geographic JavaScript Object Notation), XML (Extensible Mar), KML (Key Markup Language) (Google, 2017). In IFDEP, GeoJSON file format is preferred because of its capabilities. Geometry types such as Point, LineString, Polygon, MultiPolygon, MultiLineString, and MultiPolygon are supported by GeoJSON (GEOJSON, n.d.). Therefore, PHP link is encoded and formatted according to the GeoJSON format.

```
1.<?php
2.   //Dataset Connection//
3. $con1 = pg_connect("host=iihr****** port=****
4.    dbname=hazus user=*******  password=*******");
5.       if (!$con1) {
6.         echo "An error occurred.\n";
7.         exit;}
8.   $query = "
9.  SELECT row_to_json(fc) FROM
10.(SELECT 'FeatureCollection' As type,array_to_json(array_agg(f))
11.    As features
12. FROM( SELECT 'Feature' As type, ST_AsGeoJSON(query.geom)::json
13.    As geometry,        row_to_json
14.        ( (SELECT l FROM (SELECT bld_id, map_id, depth, damcat,
15.          val_struct, struct_dam_pct, structural_loss,
16.           val_cont, cont_dam_pct, content_loss) As l)
17.       ) As properties
18.      FROM ( SELECT b.bld_id, b.map_id, b.depth, geom, damcat,
19.           val_struct, struct_dam_pct, round(struct_dam_pct
20.           * val_struct/100.0::numeric, 2) as structural_loss,
21.           val_cont, cont_dam_pct, round(cont_dam_pct *
22.           val_cont/100.0::numeric, 2) as content_loss
23.       from(SELECT gid, geom, val_struct, val_cont, damcat
24.           FROM community.cedarrapids
25.       ) as a
26.       inner join community_dam_depth.cedarrapids_dam_depth b
27.        on a.gid = b.bld_id
28.        and b.map_id = " . $_GET["depth"] . "
29.         ) AS query) As f)  As fc;";
30.        $result = pg_query($con1, $query);
31.         if (!$result) {
32.             echo "An error occurred.\n";
33.                 exit; }
34.             else {
35.             $data = pg_fetch_all($result);
36.             foreach($data as $value) {
37.             foreach($value as $v) {
38.             echo  $v; }  }  }?>
```

Figure 4.6 PHP file to Get Point Building Flood Damage Analysis Results on the Web

As illustrated by line 1 to 7 figure 4.6, PHP file must be connected to the database with a database name, host name, a user name, password, and port id. Between line 8 to

30, the query is encoded in GeoJSON format and printing results follows in the rest of the PHP file. To open query for different flood inundation maps, `$_GET` function which is used from JQuery Library is utilized. Thus, different flood scenarios are easily done on the PHP side. PHP files are individually created for buildings, emergency centers, police station, care facilities, fire station, electric power facilities, potable water facilities, wastewater facilities, schools, and oil facilities.

4.3 Flood Damage and Loss Estimation and Optimization

IFDEP aims to create a web-based platform that can be easily updated with new data and expanded with additional data. For this purpose, generic queries that are applicable for additional data resources and different cities were created. GIS-based precalculated analyses might have been used however flexibility of updating IFDEP may shrink dramatically. In the case of having updated new floodplain maps or new community information, processing new data in GIS and visualizing on Google Maps API can take a serious amount of time. However, generic queries can reduce this limitation and make possible to update IFDEP easily. By making few changes in queries, many new flood-related analyses can be done. In figure 4.7, flood damage and loss estimation query which runs on the fly through precomputed tables is shown.

```
SELECT
b.bld_id, b.map_id, b.depth, ST_X(geom) , ST_Y(geom),
val_struct, struct_dam_pct, struct_dam_pct * val_struct/100.0 as structural_loss,
val_cont, cont_dam_pct, cont_dam_pct * val_cont/100.0 as content_loss
FROM community.cedarrapids as a
inner join community_dam_depth . cedarrapids_dam_depth b
on a.gid = b.bld_id
and b.map_id =150
***Blue shows Output, Red shows Input
```

Figure 4.7 Precalculated Flood Damage and Loss Estimation Query for Buildings

In figure 4.8, the query shows how damage and depth were precalculated for a community regarding content damage and structural damage.

Type	Input (red)	Output (blue)	Variable
Structural Content	Depth map, Community Table, Damage Curve	Gid, Value of Structure, damage percentage, damage cost	flBldgStructDmgFn, flBldgContDmgFn

```
WITH table1 as (
SELECT gid, a.depth, damage as struct_dam_pct FROM (SELECT gid, val_struct,
occupancy, dmgfnid_bldng, bldng_source_table,
(round(ST_Value(rast,(ST_Transform(ST_SetSRID(geom,4326), 32615))::numeric,
0)-found_ht) AS depth
FROM cedarrapids_depth."depth0001" CROSS JOIN community.cedarrapids
WHERE ST_INTERSECTS(rast,(ST_Transform(ST_SetSRID(geom,4326), 32615))) )
as a
inner join damage_curves.damage_curves b on CAST(a.dmgfnid_bldng AS
INTEGER) = b.dmgfnid and a.occupancy = b.occupancy
and a.depth = b.depth and b.source_table = 'flBldgStructDmgFn' ORDER BY gid
)

SELECT table1.gid as bld_id, 050 as map_id, table1.depth, table1.struct_dam_pct,
table2.cont_dam_pct FROM table1 LEFT JOIN

(SELECT gid, a.depth, damage as cont_dam_pct FROM (SELECT gid, val_cont,
occupancy, dmgfnid_cont, cont_source_table,
(round(ST_Value(rast,(ST_Transform(ST_SetSRID(geom,4326), 32615))::numeric,
0)-found_ht) AS depth
FROM cedarrapids_depth."depth0001" CROSS JOIN community.cedarrapids
WHERE ST_INTERSECTS(rast,(ST_Transform(ST_SetSRID(geom,4326), 32615))) )
as a
inner join damage_curves.damage_curves b on CAST(a.dmgfnid_cont AS INTEGER)
= b.dmgfnid and a.occupancy = b.occupancy
and a.depth = b.depth and b.source_table = 'flBldgContDmgFn' ORDER BY gid )
table2
ON table1.gid = table2.gid
```

Figure 4.8 On the Fly Flood Damage and Depth Estimation Query for Buildings

At the beginning of the study, all queries are planned to run on the fly to reduce database work. However, these queries were not time efficient. For instance, using the query in figure 4.8 to estimate damage and loss on the fly took 12 seconds to get results for the biggest floodplain in Cedar Rapids. In contrast, precomputed query which was demonstrated in figure 4.7 took 40 milliseconds to execute the query. Since IFDEP is a web-based system, time efficiency is important for better user experience. After deciding to use precomputed queries, precalculated tables for each study location were created.

For utilities, emergency centers, care facilities and schools similar plan is followed except estimation of depth and damage. In default Hazus data, these tables were divided into hazard tables which give generic information about the building and flood-related tables which give depth-damage function id, foundation height. Since the number of records are not high enough to run the query on the fly, view tables were created to run flood damage and loss queries. The highest query time took 20 milliseconds to execute. Thus, planned time efficiency is achieved for these layers.

Data scale is one of the most important considerations for query speed. Hence, census data which are not in the border of floodplain can be excluded. Because points of interests are floodplains on the communities, point buildings locations intersected with the biggest floodplain and this intersection is considered to make flood damage and loss estimation analyses. Considering Linn County of National Structure Inventory data, there are over 80000 buildings are recorded in the county. With making the intersection, the number of points are reduced to 4339 data point. In QGIS, data redundancy is solved, thus, the speed of damage and loss query is increased for better user experience.

4.4 Visualization and Communication of Flood Analyses

One of the biggest advantages of web-based technology is the existence of thousands of different visualization libraries for the specific point of interest. IFDEP is built on Google Maps API, therefore, Google Maps JavaScript API allows to create effective visualization and communication with the audience. Google Maps JavaScript API consists large libraries that reinforce many properties for visualization to process raw data to nice visualizations (GoogleDevelopers, Maps JavaScript API, 2017). All geometric queries within IFDEP return as JSON (JavaScript Object Notation) format because Google Maps API supports the format. Comparing XML (Extensive Markup Language), JSON has clearly more advantageous than XML in terms of parsing the data (GoogleDevelopers, Google Maps API Web Services, 2017). Furthermore, geometric features can powerfully be visualized on Google Maps API for users. In figure 4.9, using Google Maps markers flooded care facilities, emergency centers, police station and fire station were visualized.

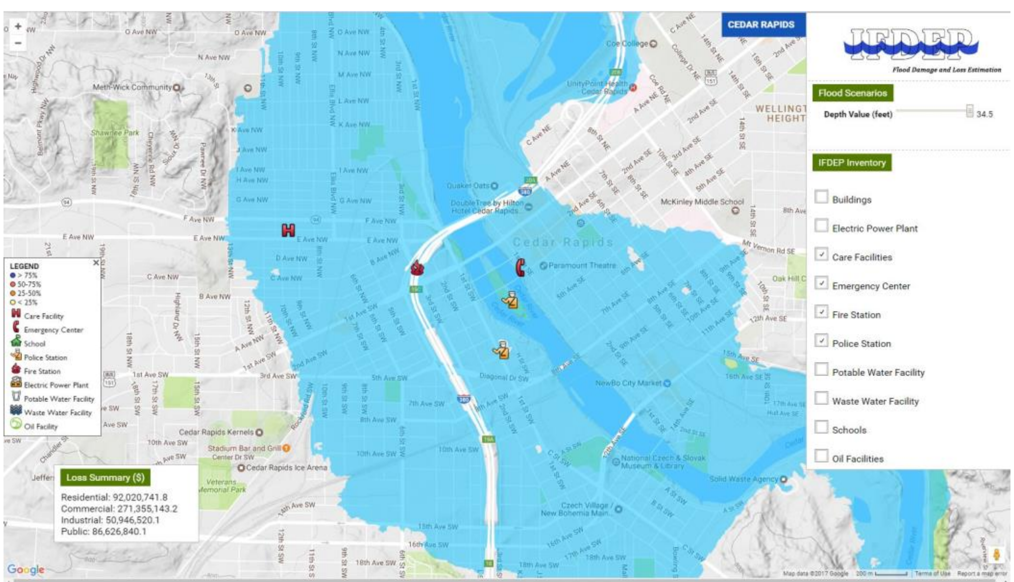

Figure 4.9 Essential Facilities under 40 feet Stage Height Flood in Cedar Rapids

In figure 4.10 and 4.11, different scenarios are visualized in IFDEP using flood slider. Every move in slider takes less than 1 second to visualize and execute the query.

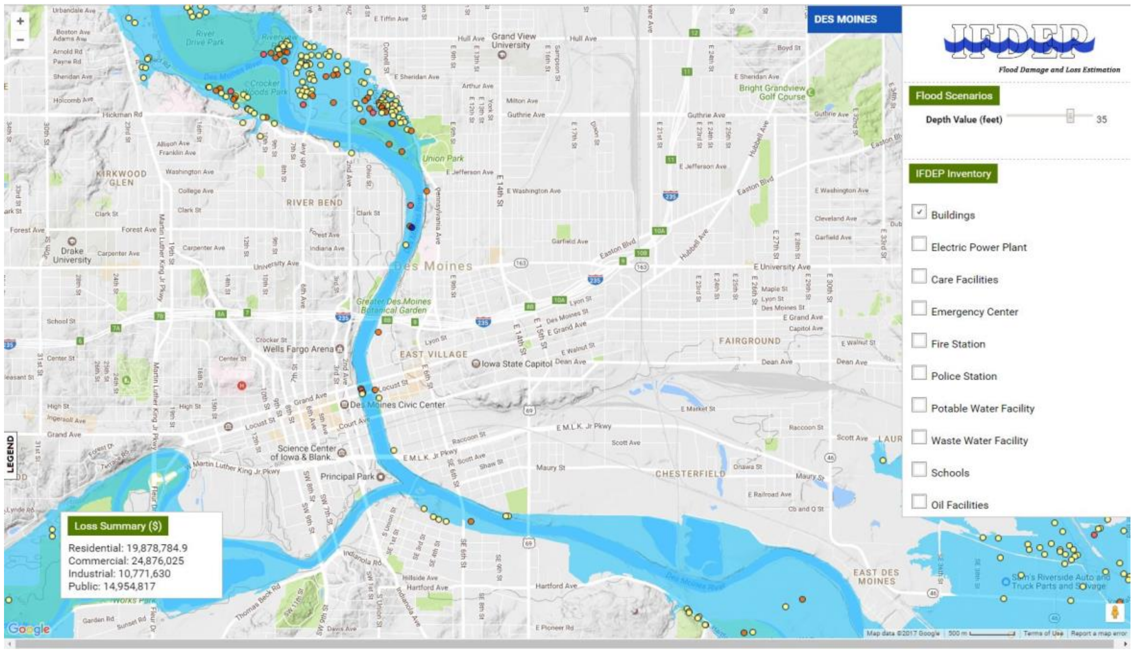

Figure 4.10 Building Conditions in 35 feet Stage Height Flood for Des Moines

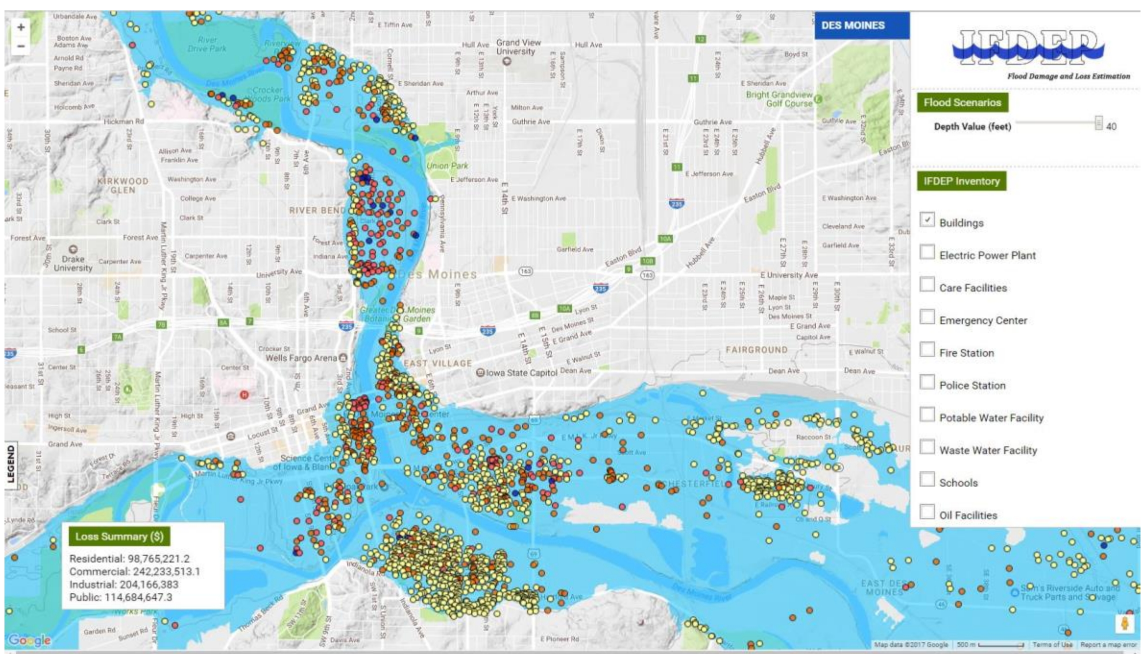

Figure 4.11 Building Conditions in 40 feet Stage Height Flood for Des Moines

In figure 4.12, electric power plant, potable water facilities, wastewater facilities, and schools where under flooding effect were visualized.

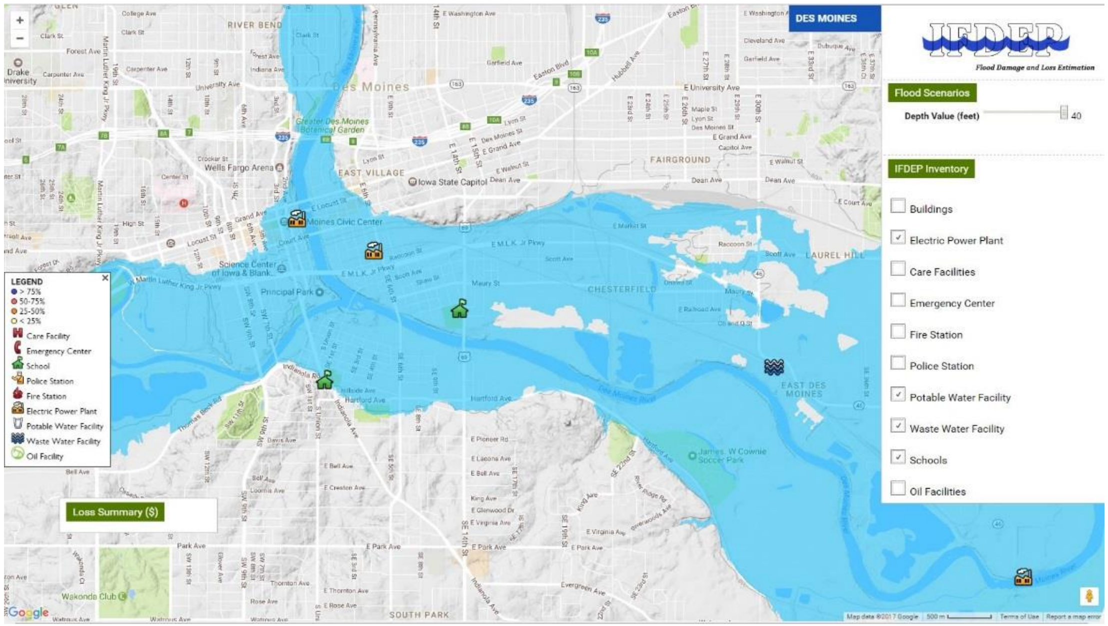

Figure 4.12 Utilities and Schools under 40 feet Stage Height Flood in Des Moines

To make all these visualizations, HTML (Hyper Text Markup Language) is vital for JavaScript because JavaScript resides inside HTML. HTML also useful to create the visualization. In IFDEP, flood slider which allows observing analyses in different scenarios is created using HTML. Coordinated views using HTML and JavaScript make possible to observe different flood scenarios impact on a community in terms of residential commercial, industrial and public. To create better visualization and communication, IFDEP allows showing multiple contents without reloading the web page. Ajax which is part of the JQuery makes possible to achieve this goal. By clicking checkboxes, multiple layers are visualized without refreshing page in a second.

By using the privilege of IFDEP database, same analyses can be visualized in different systems. Figure 4.13 illustrates the implementation of IFDEP analyses on the Iowa Flood Information System.

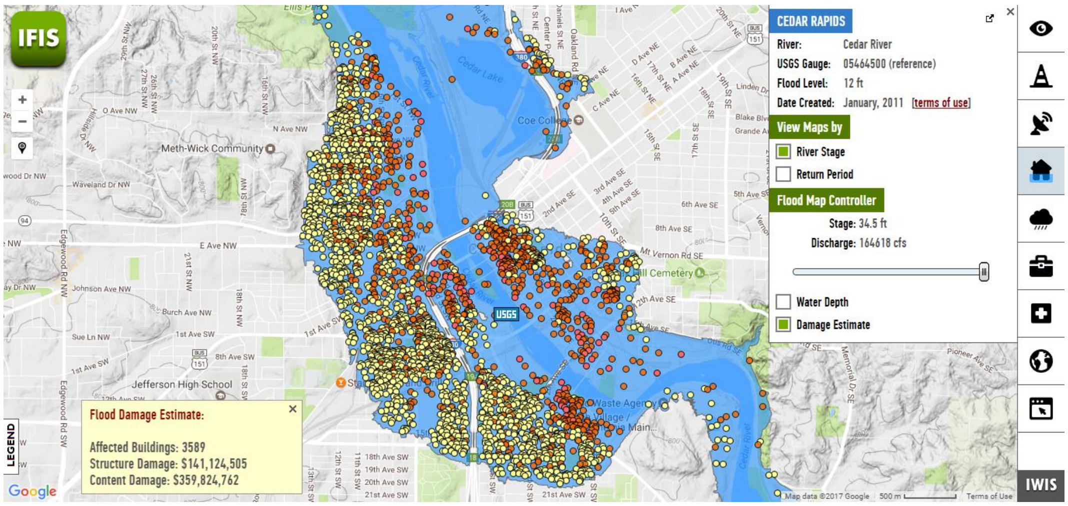

Figure 4.13 IFDEP Implementation on (Iowa Flood Information System) IFIS

Other than web-based visualization, augmented reality technology can be also implemented on IFDEP. For a pilot study, the specific height of flooding was visualized on Cedar Rapids community to observe flooding impact on a community. Microsoft HoloLens has been used for this purpose because of being one of the most comprehensive and powerful devices for this purpose. Using Esri City Engine, 3D building model acquired from the software and transferred to Unity Engine. After processing the 3D model and adding floodplain map, flood damage and loss analyses are available on the device. Furthermore, more interactive and enhanced visualization is presented for flood emergency decision makers.

CHAPTER 5 CONCLUSION AND FUTURE WORK

Overall IFDEP offers a web-based flood damage and loss estimation tool which does not require additional software, and license and make flood-related analysis for both flood emergency decision makers and public. Working as independently from a desktop based software reduce software knowledge requirement. Besides, new data sources can be attached to IFDEP to do better, accurate and more analysis. In SQL part of the IFDEP, generic queries are created to analyze more cities. Real time stream gage data and flood forecast data make possible to evaluate current and prospective flooding situation in the community.

The purpose of creating generic queries rather than pre-calculated analysis on GIS is to make IFDEP extendable for other data resources. Unlike GIS-based desktop software, IFDEP can be easily updated using other data resources. Also, generic queries allow updating analysis in a case of updated floodplain maps. Same update operation in the GIS-based application is possible however time efficiency decreases and much more effort is required.

The Early warning system can prevent deaths and the serious amount of financial loss. Flood forecast system which is developed by National Weather Service is used in IFDEP to create flood alerts. Possible amount of loss and dangerous zone in the floodplain are illustrated in IFDEP. Therefore, flood emergency managers and people can take action in advance. This is one of the most important aspects to making community prepared against flooding.

As a starting point, all analyses are initially planned to run on the fly. However, the size of the raster is considerably high compared to other datasets. For Iowa City case, which can be defined as average scale considering Cedar Rapids and Des Moines, the intersection between the largest raster data and point geometry data take roughly 7 seconds. Due to the situation, database side precalculated data is decided to use. To reduce limitation of precalculated data, more general queries are created for further updates in terms of having new floodplain maps, building data repository, and census data. Using database side precalculated data allows to run the biggest scenario less than 1 seconds. Thus, the user experience is enhanced on the interface.

As explained in previous sections, damage curves which are created by National Flood Insurance Program and U.S Army Corps of Engineers are implemented on IFDEP. However, their credibility can be questioned because these curves are developed in different cities. Furthermore, they may not represent State of Iowa building repository perfectly. For future applications, flood damage curves that are developed uniquely for the State of Iowa can be implemented to IFDEP. Thus, more accurate analyses are possible to make using same general queries. As discussed in the previous section, one of the ways to developed damage curves is one-to-one interviews with landlords. Due to this reason, new damage curves are confidentially protected by governmental agencies. These agencies cooperation is required to obtain new damage curves to implement to the system.

Even though flood analyses using National Structure Inventory give good understanding to evaluate dangerous neighborhood in the community, it may not be hundred percent reliable due to some distortion on the datasets. New structural information is required to analyze flood damage and loss estimation.

5.1 Expanding IFDEP with Additional Data Resources

At present, IFDEP is available for public use with a specific link. The main goal is finalizing queries and visualizations to move every feature to IFIS that is more comprehensive and covers more data. Currently, in IFIS, floodplain maps and raster are available for 22 cities and towns in the State of Iowa. Therefore, same analysis will be done for rest of the cities for number of available scenarios which is shown in Table 7.1

Table 5.1 Future Cities Implementation for IFDEP

Community	**Number of Maps**
Ames	31x28
Cedar Falls	46
Charles City	47
Columbus Junction	20x22
Elkader	43x2
Hills	32
Humboldt	25
Independence	42
Kalona	7
Monticello	37
Maquoketa	28x31
Mason City	30x3
Ottumwa	27
Red Oak	41x5
Spenser	25x27
Waterloo	49
Waverly	37
Total	**3581**

IFDEP can be updated with tax assessor database which is more up-to-date data. Using unique building classes on the database, each building can be connected unique damage curve to estimate flood damage to the system. Also, updated and uniquely created flood depth damage curves can be implemented to do more accurate estimations. As another development, agricultural damage and loss estimation will be implemented. Using agricultural and land use data which are created by National Agricultural Service crop loss analyses due to the flooding can be done using floodplain maps which are created for rural areas.

5.2 Visualization of IFDEP Using Augmented Reality

Accessibility of flood-related data is significant for both flood emergency decision makers on the headquarters and flood emergency crew on the field. In order to conduct the rescue operation, information about disaster area is very important to avoid accidents. I would be helpful to know flood depth in a specific area or number of people who are confined in a specific building. Augment reality technology can be utilized to get information on the field for flood emergency crew.

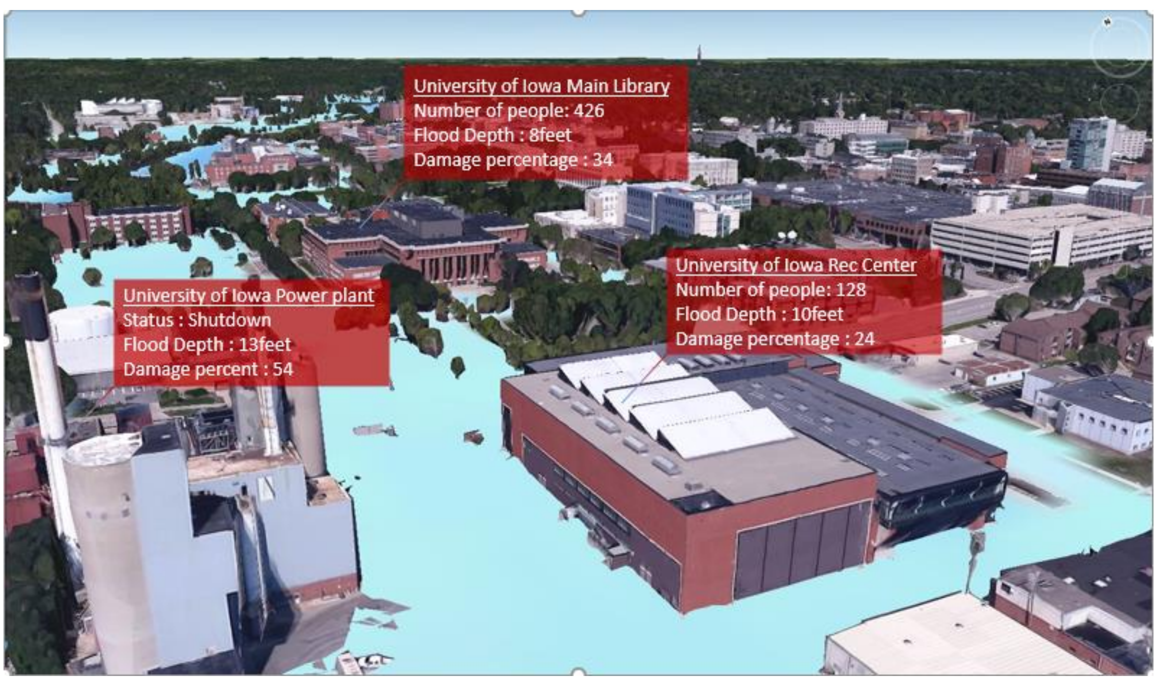

Figure 5.1 Flood Impact Visualization using Augmented Reality

During Texas floods in 2016, 9 soldiers killed in Fort Hood flooding while driving their truck in the floodwaters (Ellis et al., 2016). One of the reasons why this accident happens would be the lack of information about disaster area in real time. To provide flood related information, Microsoft HoloLens can be very helpful. Most of the flood-related information in IFDEP is spatial data. Therefore, HoloLens can be connected with an additional device to get GPS location and a device can access information in IFDEP. In the case of a flooded road, flood emergency crew can access IFDEP to acquire the depth of flooding for that specific location. Thus, this kind of accidents can be avoided.

As another important information that is vital to rescue team to know demographics in a specific location. Most vulnerable age groups regarding flooding are <21 years old and >60 years old (Ashley & Ashley, 2008). Since IFDEP covers demographic information, this information can be visualized on HoloLens and priority for rescue operation can be done with taking advantage of this opportunity.

In conclusion, IFDEP can be expanded using various data sources and better and more accurate analyses can be made and visualized for flood emergency decision makers. Also, augmented reality technologies can be very effective in the future application for better communication and visualization. Since this technology is young and most likely it will be developed, strong flood-related data visualization can be done.

REFERENCES

Abbott, M. B. (1999). Introducing hydroinformatics. *Journal of hydroinformatics*, 1(1), 3-19.

Ashley, S. T., & Ashley, W. S. (2008). Flood fatalities in the United States. *Journal of Applied Meteorology and Climatology*, 47(3), 805-818.

Correia, F. N., Fordham, M., Saraiva, M. G., & Bernardo, F. (1998). Flood hazard assessment and management: Interface with the public. *Water Resources Management*, 12, 209–227.

Davis, S., & Skaggs, L. L. (1992). *Catalog of residential depth-damage functions used by the army corps of engineers in flood damage estimation.* Virginia: USACE (United States Army Corps of Engineers).

Demir. (2010). Integrated Web-based data management, analysis and visualization. *(Doctoral dissertation, uga)*.

Demir, I., & Beck, M. B. (April 27-29, 2009). GWIS: A Prototype Information System for Georgia Watersheds. *Proceedings of Georgia Water Resources Conference: Regional Water Management Opportunities*, Paper 6.6.4.

Demir, I., & Krajewski, W. F. (2013). Towards an integrated flood information system: centralized data access, analysis, and visualization. *Environmental Modelling & Software*, 50, 77-84.

Demir, I., Conover, H., Krajewski, W. F., Seo, B., Goska, R., He, Y., . . . Peterson, W. (2015). Data Enabled Field Experiment Planning, Management, and Research using Cyberinfrastructure. *Journal of Hydrometeorology*, 3, 1155-1170.

Demir, I., Jiang, F., Walker, R. V., Parker, A. K., & Beck, M. B. (October 11-14, 2009). Information Systems and Social Legitimacy: Scientific Visualization of Water Quality. *in Proceedings of IEEE Int. Conference on Systems, Man, and Cybernetics,* (pp. 1093-1098). San Antonio, TX, USA.

Douglas, K., & Douglas, S. (2003). *PostgreSQL: a comprehensive guide to building, programming, and administering PostgresSQL databases.* Indianapolis, Indiana: SAMS publishing.

Ellis, R., Steven, V., & Karimi, F. (2016, June 5). *CNN*. Retrieved from CNN: http://www.cnn.com/2016/06/03/us/texas-floods/

FEMA. (2014, 06 25). *Flood Insurance Requirement*. Retrieved from Federal Emergency Management Agency: https://www.fema.gov/faq-details/Flood-Insurance-Requirement

GEOJSON. (n.d.). *The GeoJSON Format Specification*. Retrieved from GEOJSON: http://geojson.org/geojson-spec.html

Gilles, D., Young, N., Schroeder, H., Piotrowski, J., & Chang, Y. J. (2012). Inundation mapping initiatives of the Iowa Flood Center: statewide coverage and detailed urban flooding analysis. *Water*, 85–106.

Google. (2017, April 7). *Google Maps APIs*. Retrieved from Google Maps APIs: https://developers.google.com/maps/faq#geocoder_queryformat

GoogleDevelopers. (2017, February 15). *Google Maps API Web Services*. Retrieved from Google Maps API: https://developers.google.com/maps/web-services/overview

GoogleDevelopers. (2017, March 17). *Maps JavaScript API*. Retrieved from Google Maps APIs: https://developers.google.com/maps/documentation/javascript/visualization

Hayden, M. H., Drobot, S., Radil, S., Benight, C., Gruntfest, E. C., & Barnes, L. R. (2007). Information sources for flash flood warnings in Denver, CO and Austin, TX. *Environmental Hazards*, 7(3), 211-219.

IFC. (2017). *IOWA FLOOD INFORMATION SYSTEM*. Retrieved from Iowa Flood Center: http://ifis.iowafloodcenter.org/ifis/en/

jQuery. (2017). *jQuery: The write less, do more, JavaScript library*. Retrieved from jQuery: https://jquery.com/

Krajewski, W. F., Ceynar, D., Demir, I., Goska, R., Kruger, A., Langel, C., . . . Young, N. (2017). Real-Time Flood Forecasting and Information System for the State of Iowa. *Bulletin of the American Meteorological Society*, 98, 539–554.

Kumar, P., Folk, M., Markus, M., & Alameda, J. (2005). *Hydroinformatics: Data Integrative Approaches in Computation, Analysis, and Modeling.* CRC Press.

Moffatt, S., & Laefer, D. (2009). An Open-Source Vision for HAZUS. *Journal of Computing in Civil Engineering*, 24(1): 1-2.

NIBS, F. (2003). Multi-Hazard Loss Estimation Methodology. Flood Model. *HAZUS® MH Technical Manual, National Institute of Building Sciences and Federal Emergency Management Agency, Washington, DC*, 3-3.

NOAA. (2009). Central Iowa Floods of 2008. 1.

NOAA. (n.d.). *Flooding in Iowa*. Retrieved from National Oceanic and Atmospheric Administration: http://www.floodsafety.noaa.gov/states/ia-flood.shtml

OSGeo. (2014, Oct 22). *GeoTIFF*. Retrieved from The Open Source Geospatial Foundation: http://trac.osgeo.org/geotiff/

Postgresql. (2015). *About PostgreSQL*. Retrieved from PostgreSQL: http://www.postgresql.org/about/

Scawthorn, C. F., Flores, P., Blais, N., Seligson, H., Tate, E., Chang, S., . . . Lawrence, M. (2006). HAZUS-MH flood loss estimation methodology. II. Damage and loss assessment. *Natural Hazards Review*, 7(2), 72-81.

Scawthorn, C., & et al. (2006). HAZUS-MH flood loss estimation methodology. I: Overview and flood hazard characterization. *Natural Hazards Review*, 7(2), 60-71.

Smith, D. I. (1994). Flood damage estimation- A review of urban stage-damage curves and loss functions. *Water S. A.*, 20(3), 231-238.

Tierney, K. J., & Nigg, J. M. (1995). Business Vulnerability to Disaster-Related Lifeline Disruption.

United States Army Corps of Engineers (USACE). (2005). *Feasibility reportflood damage reduction for Des Moines and Raccoon rivers project.* DesMoines, Iowa: US Army Corps of Engin eers Rock Islan d District.

USACE. (2006). Depth-damage relationships for structures, contents, and vehicle and content-to-structure value ratios (CSVR) in support of the Donaldsville to the golf, Louisiana, Feasibility Study. *Final Report to the New Orleans District*, 2.

Vanderkrimpen, P., Melger, E., & Peeters, P. L. (2009). Flood modeling for risk evaluation: a MIKE FLOOD vs. SOBEK 1D2D benchmark study. *Flood Risk Management: Research and Practice*, 77–84.

Zhou, Z., Zhou, B., Li, W., Griglak, B., Caiseda, C., & Huang, Q. (2009). Evaluating query performance on object-relational spatial databases. *In Computer Science and Information Technology, 2009. ICCSIT 2009. 2nd IEEE International Conference on*, 489-492.

APPENDIX A. QUERY INDEX

Table A.1 to A.9 show details about queries are given such as variables, input, output, and result. Red color represents input and blue color represents output. All results for content loss, structural loss, and damage loss are in thousand dollars.

- Care Facilities

Table A.1 Structural Damage and Loss for Care Facilities

Type	Input	Variable
Structural	Depth map, Care Facility, Damage Curve	bldg_damage_function_id, flBldgStructDmgFn

```
SELECT name, address, city, zipcode, numbeds, ahaid, a.depth, damage as
damage_percentage, cost, damage * cost/100.0 as structure_loss,
ST_AsGeoJSON(geom)::json As geometry
from
(SELECT name, address, city, zipcode, numbeds, ahaid, cost,
bldg_damage_function_id, geom,
round(ST_Value(rast,(ST_Transform(ST_SetSRID(geom,4326), 32615)))::numeric, 0)
AS depth
FROM cedarrapids_depth."depth0060" CROSS JOIN hazus.carefacilities
WHERE ST_INTERSECTS(rast,(ST_Transform(ST_SetSRID(geom,4326), 32615)))
) as a
inner join damage_curves.damage_curves b
on CAST(a.bldg_damage_function_id AS INTEGER) = b.dmgfnid
and a.depth = b.depth
and b.source_table = 'flBldgStructDmgFn'
```

Output: name, address, city, zipcode, number of beds, ahaid* (code for hospital) depth, cost, damage percentage, structure loss

Table A.2 Content Damage and Loss for Care Facilities

Type	Input	Variable
Content	Depth map, Care Facility, Damage Curve	cont_damage_function_id, flBldgContDmgFn

```
SELECT name, address, city, zipcode, numbeds, ahaid, a.depth, damage as
damage_percentage, cost, damage * cost/100.0 as content_loss,
ST_AsGeoJSON(geom)::json As geometry
from
(SELECT name, address, city, zipcode, numbeds, ahaid, cost,
cont_damage_function_id, geom,
round(ST_Value(rast,(ST_Transform(ST_SetSRID(geom,4326), 32615)))::numeric, 0)
AS depth
FROM cedarrapids_depth."depth0060" CROSS JOIN hazus.carefacilities
WHERE ST_INTERSECTS(rast,(ST_Transform(ST_SetSRID(geom,4326), 32615)))
) as a
inner join damage_curves.damage_curves b
on CAST(a.cont_damage_function_id AS INTEGER) = b.dmgfnid
and a.depth = b.depth
and b.source_table = 'flBldgContDmgFn'
```

Output : name, address, city, zipcode, number of beds, depth, ahaid* (code for hospital) cost, damage percentage, content loss

- Emergency Centers

Emergency centers cover emergency centers, fire stations, and police station.

For fire station, this query does not return damage cost because of lacking of cost data.

Table A.3 Structural Damage and Loss for Emergency Centers\

Type	Input	Variable
Structural	Depth map, Emergency Center, Damage Curve	bldg_damage_function_id, flBldgStructDmgFn

```
SELECT name, address, city, zipcode, a.depth, damage as damage_percentage, cost,
damage * cost/100.0 as structure_loss, ST_AsGeoJSON(geom)::json As geometry
from
(SELECT name, address, city, zipcode, cost, bldg_damage_function_id, geom,
round(ST_Value(rast,(ST_Transform(ST_SetSRID(geom,4326), 32615)))::numeric, 0)
AS depth
FROM cedarrapids_depth."depth0043" CROSS JOIN hazus.emergencycenter
WHERE ST_INTERSECTS(rast,(ST_Transform(ST_SetSRID(geom,4326), 32615)))
) as a
```

```
inner join damage_curves.damage_curves b
on CAST(a.bldg_damage_function_id AS INTEGER) = b.dmgfnid
and a.depth = b.depth
and b.source_table = 'flBldgStructDmgFn'
```

Output: name, address, city, zipcode, Cost, damage percentage, structure loss, geometry

Table A.4 Content Damage and Loss for Emergency Centers

Type	Input	Variable
Content	Depth map, Emergency Center, Damage Curve	cont_damage_function_id, flBldgContDmgFn

```
SELECT name, address, city, zipcode, a.depth, damage as damage_percentage, cost,
damage * cost/100.0 as content_loss, ST_AsGeoJSON(geom)::json As geometry
from
(SELECT name, address, city, zipcode, cost, cont_damage_function_id, geom,
round(ST_Value(rast,(ST_Transform(ST_SetSRID(geom,4326), 32615)))::numeric, 0)
AS depth
FROM cedarrapids_depth."depth0043" CROSS JOIN hazus.emergencycenter
WHERE ST_INTERSECTS(rast,(ST_Transform(ST_SetSRID(geom,4326), 32615)))
) as a
inner join damage_curves.damage_curves b
on CAST(a. cont_damage_function_id AS INTEGER) = b.dmgfnid
and a.depth = b.depth
and b.source_table = 'flBldgContDmgFn'
```

Output: name, address, city, zipcode, Cost, damage percentage, content loss, geometry

- Schools

Table A.5 Structural Damage and Loss for Schools

Type	Input	Variable
Structural	Depth map, School, Damage Curve	bldg_damage_function_id, flBldgStructDmgFn

```
SELECT name, address, city, zipcode, numstudent, phonenumbe, damage as
damage_percentage, a.depth, cost, damage * cost/100.0 as structure_loss,
ST_AsGeoJSON(geom)::json As geometry
from
```

```
(SELECT name, address, city, zipcode, numstudent, phonenumbe, cost,
bldg_damage_function_id, geom,
round(ST_Value(rast,(ST_Transform(ST_SetSRID(geom,4326), 32615)))::numeric, 0)
AS depth
FROM desmoines_depth."depth0043" CROSS JOIN hazus.school
WHERE ST_INTERSECTS(rast,(ST_Transform(ST_SetSRID(geom,4326), 32615)))
) as a
inner join damage_curves.damage_curves b
on CAST(a.bldg_damage_function_id AS INTEGER) = b.dmgfnid
and a.depth = b.depth
and b.source_table = 'flBldgStructDmgFn'
```

Output : name, address, city, zipcode, numstudent, phone number, depth, cost, damage percentage, structure loss, geometry

Table A.6 Content Damage and Loss for Schools

Type	Input	Variable
Structural	Depth map, School, Damage Curve	cont_damage_function_id, flBldgContDmgFn

```
SELECT name, address, city, zipcode, numstudent, phonenumbe, damage as
damage_percentage, a.depth, cost, damage * cost/100.0 as content_loss,
ST_AsGeoJSON(geom)::json As geometry
from
(SELECT name, address, city, zipcode, numstudent, phonenumbe, cost,
cont_damage_function_id, geom,
round(ST_Value(rast,(ST_Transform(ST_SetSRID(geom,4326), 32615)))::numeric, 0)
AS depth
FROM desmoines_depth."depth0043" CROSS JOIN hazus.school
WHERE ST_INTERSECTS(rast,(ST_Transform(ST_SetSRID(geom,4326), 32615)))
) as a
inner join damage_curves.damage_curves b
on CAST(a.cont_damage_function_id AS INTEGER) = b.dmgfnid
and a.depth = b.depth
and b.source_table = 'flBldgContDmgFn'
```

Output : name, address, city, zipcode, numstudent, phone number, depth, cost, damage percentage, content loss, geometry

- Damage and Cost Query for Utilities

Table A.7 Damage and Loss for Utilities

<table>
<tr><th>Type</th><th>Input</th><th>Variable</th></tr>
<tr><td>Structural</td><td>Depth map, Utility Facility, Damage Curve</td><td>bldg_damage_function_id</td></tr>
<tr><td colspan="3">SELECT name, address, city, zipcode, a.depth , damage as damage_percentage, cost, damage * cost/100.0 as damage_cost, ST_AsGeoJSON(geom)::json As geometry
from
(SELECT name, address, city, zipcode, cost, occupancy, damage_function_id,
geom ,round(ST_Value(rast,(ST_Transform(ST_SetSRID(geom,4326),
32615)))::numeric, 0) AS depth
FROM desmoines_depth."depth0043" CROSS JOIN hazus.potablewater
WHERE ST_INTERSECTS(rast,(ST_Transform(ST_SetSRID(geom,4326), 32615)))
) as a
inner join damage_curves.damage_curves b
on CAST(a.damage_function_id AS INTEGER) = b.dmgfnid
and a.occupancy = b.occupancy
and a.depth = b.depth</td></tr>
<tr><td colspan="3">Output: name, address, city, zipcode, cost, damage percentage, damage cost</td></tr>
</table>

- Individual Buildings

Table A.8 Structural Damage and Loss

<table>
<tr><th>Type</th><th>Input</th><th>Output</th><th>Variable</th></tr>
<tr><td>Structural</td><td>Depth map, Community Table, Damage Curve</td><td>Gid, Value of Structure, damage percentage, damage cost</td><td>flBldgStructDmgFn</td></tr>
<tr><td colspan="4">SELECT gid, damage as damage_percentage, val_struct, damage * val_struct/100.0 as damage_cost, ST_AsGeoJSON(geom)::json As geometry
from
(SELECT gid, val_struct, occupancy, dmgfnid_bldng, bldng_source_table,
geom ,round(ST_Value(rast,(ST_Transform(ST_SetSRID(geom,4326),
32615)))::numeric, 0) AS depth
FROM iowacity_depth."depth0035" CROSS JOIN community.iowacity
WHERE ST_INTERSECTS(rast,(ST_Transform(ST_SetSRID(geom,4326), 32615)))
) as a
inner join damage_curves.damage_curves b
on CAST(a.dmgfnid_bldng AS INTEGER) = b.dmgfnid</td></tr>
</table>

```
and a.occupancy = b.occupancy
and a.depth = b.depth
and b.source_table = 'flBldgStructDmgFn'
```

Table A.9 Content Damage and Loss

Type	Input	Output	Variable
Content	Depth map, Community Table, Damage Curve	Cost, damage percentage, damage cost	flBldgContDmgFn

```
SELECT gid, damage as damage_percentage, val_struct, damage * val_struct/100.0 as
damage_cost, ST_AsGeoJSON(geom)::json As geometry
from
(SELECT gid, val_struct, occupancy, dmgfnid_cont, cont_source_table,
geom ,round(ST_Value(rast,(ST_Transform(ST_SetSRID(geom,4326),
32615)))::numeric, 0) AS depth
FROM iowacity_depth."depth0035" CROSS JOIN community.iowacity
WHERE ST_INTERSECTS(rast,(ST_Transform(ST_SetSRID(geom,4326), 32615)))
) as a
inner join damage_curves.damage_curves b
on CAST(a.dmgfnid_cont AS INTEGER) = b.dmgfnid
and a.occupancy = b.occupancy
and a.depth = b.depth
and b.source_table = 'flBldgContDmgFn'
```

APPENDIX B. HAZUS DEFAULT DATA CONTENT FOR IOWA

Table B.1 Hazus-MH Default Data for State of Iowa

	Point	Line	Polygon	Census Tract	Census Block	Number of Record for Iowa
SYSTEM BOUNDARIES						
State Boundaries			X			1
County Boundaries			X			99
Census Tract Boundaries			X			216007
STATE BOUNDARIES						
County Boundaries			X			99
Census Tract Boundaries			X			216007
Census Block Boundaries			X			216007
Demographics			X	X	X	216007
Building Count			X	X	X	216007
Building Replacement Value			X	X	X	216007
Content Replacement Value			X	X	X	216007
Square Footage Value			X	X	X	216007
ESSENTIAL FACILITIES						
Flood Specific Care Facilities	X					122
Flood Specific Emergency Center Facilities	X					29
Flood Specific Fire Station Facilities	X					715
Flood Specific Police Station Facilities	X					29
Flood Specific Schools Facilities	X					1758
TRANSPORTATION SYSTEMS						
Airports Feature Class (Facilities)	X					89

Table B.1- continued

	Point	Line	Polygon	Census Tract	Census Block	Number of Record for Iowa
Airport Runways Feature Class (Facilities)	X					147
Bus Facilities Feature Class (Facilities)	X					57
Ferry Facilities Feature Class (Facilities)	X					3
Flood Specific Highway Bridge	X					3181
Highway Roads Feature Class (Segments)		X				3053
Highway Tunnel Feature Class						0
Flood Specific Light Rail Bridge						0
Flood Specific Railway Bridge	X					10
Light Railway Feature Class (Facilities)						0
Light Railway Tracks Feature Class (Segments)						0
Railway Tracks Class (Facilities)	X					72
Railway Tracks Feature Class (Segments)		X				3700
Railway Tunnel Feature Class						0
LIFELINE UTILITY SYSTEMS						
Communication Facilities Feature Class (Facilities)	X					285
Flood Specific Electric Power Facilities	X					83
Flood Specific Natural Gas Facilities	X					28
Flood Specific Natural Gas Pipeline						0

Table B.1- continued

	Point	Line	Polygon	Census Tract	Census Block	Number of Record for Iowa
Flood Specific Natural Gas Pipeline						0
Flood Specific Oil Facilities	X					8
Flood Specific Oil Pipeline						0
Flood Specific Potable Water Facilities	X					15
Flood Specific Potable Water Pipeline						0
Flood Specific Waste Water Facilities	X					771
Flood Specific Waste Water Pipeline						0
HIGH POTENTIAL LOSS FACILITIES						
Dams Feature Class						0
Hazardous Material Facilities Feature Class	X					1345
Levees Feature Class	X					0
Military Facilities Feature Class	X					0
Nuclear Power Plants Feature Class	X					1
AGRICULTURE INVENTORY						
Agriculture Land						9231
Agriculture Inventory			X			2390
VEHICLES INVENTORY						
Nighttime Vehicles			X	X	X	216007
Daytime Vehicles			X	X	X	216007
***Demographic, Building Count, Building Replacement Value, Content Replacement Value, and Square Footage Value have been recorded based on Census Block ID and Census Tract ID. Rest of the data which has been recorded based on their spatial data as point and as line feature, can be connected through their unique ID.						

Table B.2 Fields for demographic analysis

Population	Total population
Households	Total households
GroupQuarters	Total group quarters
Gender	
MaleLess16	Total number of males under 16 years of age
Male16to65	Total number of males aged 16 to 65
FemaleLess16	Total number of females under 16 years of age
Female16to65	Total number of females aged 16 to 65
MalePopulation	Total males
FemalePopulation	Total females
Race	
White	Total white population
Black	Total black population
Income	
IncLess10	Total households with less than $10,000 annual income
Inc10to20	Total households with $10,000 to $20,000 annual income
Commuting	
ResidDay	Total daytime population
ResidNight	Total nighttime population
Hotel	Total population in hotels
Visitor	Visitor population
WorkingCom	Population working in commercial occupations
WorkingInd	Population working in industrial occupations
Commuting5PM	Population commuting at 5:00 p.m.
Property Details	
OwnerSingleUnits	Owner-occupied, single-family units
OwnerMultUnits	Owner-occupied, multifamily units
OwnerMultStructs	Owner-occupied, multifamily structures
OnwerMHs	Owner-occupied, manufactured housing
RenterSingleUnits	Renter-occupied single family units
RenterMultUnits	Renter-occupied, multifamily units
RenterMultStructs	Renter-occupied, multifamily structures
RenterMHs	Renter-occupied, manufactured housing
VacantSingleUnits	Vacant single-family units
VacantMultUnits	Vacant multi-family units

Table B.2 – continued

Building History	
BuiltBefore40	Housing units built before 1940
Built40to49	Housing units built between 1940 and 1949
MedianYearBuilt	Median year housing built
Property Value	
AvgRent	Average cash rent
AvgValue	Average home value
School Population	
SchoolEnrollmentKto12	School enrollment up to high school
SchoolEnrollmentCollege	College and university enrollment