Flood Mitigation Data Analytics and Decision Support Framework: Iowa Middle Cedar Watershed Case Study

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Abstract

Flooding is one of the most frequent natural disasters, causing billions of dollars in damage and threatening vulnerable communities worldwide. Although the impact of flooding can never be diminished, minimizing future losses is possible by taking structural or non-structural mitigation actions. Mitigation applications are often costly practices. However, they can be more feasible for long-term planning and protection. On the other hand, selecting a feasible option requires a comprehensive analysis of potential risk and damages and comparing the costs and benefits of different mitigation types. This paper presents a web-based decision support framework called Mitigation and Damage Assessment System (MiDAS) that analyzes flood risk and mitigation strategies at the community and property-level scopes. The system utilizes regulatory flood inundation maps, damage functions, property information, scenario-based climate projections, and mitigation inputs and guidelines from the Federal Emergency Management Agency (FEMA) and the United States Army Corps of Engineers (USACE). We analyzed the community-level analysis of three major cities in Eastern Iowa: Cedar Falls, Cedar Rapids, and Waterloo. The framework helps users select the appropriate flood mitigation measures based on various characteristics (e.g., foundation type, occupancy, square footage) and provides cost estimates for implementing measures. The system also provides a decision tree algorithm for analyzing and representing the mitigation decision by reviewing existing guidelines (e.g., FEMA, USACE). Implementation of mitigation measures can reduce the property's vulnerability and improve the response to a flooding event.

Keywords: Decision Support, Flood Mitigation, Flood Risk, Floodproofing, Data Analytics

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1. Introduction

Natural disasters (e.g., floods) have increased globally in frequency and magnitude, causing severe damage to socio-economic development. Flooding can result from natural processes, but human activities can significantly contribute to flooding (Allan, 2011). For example, the increase in greenhouse gas emissions has affected rainfall patterns (Zhang & Villarini, 2021) in the last decades. Floods can strike communities causing losses of life and damage to assets. Between 2009 and 2018, floods have caused an annual average of 95 fatalities in the U.S (NOAA, n.d.). The U.S. has experienced 33 costly floods from 1980 to 2019, each event causing an average of $4.6B (NCEI, 2020) damage. Climate change, population growth, and urbanization may further aggravate the effects (Zhang et al., 2018). Iowa is considered one of the top U.S states with the most flood disasters (FEMA, 2020). In 2019, Iowa experienced a flood event along the Missouri River and across the state. As a result, many homes, agricultural lands, businesses, and other infrastructures were submerged, with an estimated $1.6 Billion (Iowa.gov, 2019). Understanding flood risk is critical for effective planning and mitigation.

Federal Emergency Management Agency (FEMA) conducts studies based on probability of exceedance to map out the extent of flood events and identify different levels of flood-risk areas (FEMA, 2015). It sets a 100-year flood return period, a 1% flood chance of occurring in any given year, as a reference for high hazard areas. This elevation is also known as base flood elevation (BFE). FEMA provides the National Flood Insurance Program (NFIP) for floodplain management of communities (FEMA, 2019). Due to limited standards of NFIP for floodplain management and external reasons such as climate change, the adverse effects of flood disasters may not be minimized or eliminated (NAI, 2014). The community rating system (CRS) is another program established by FEMA that encourages communities to implement additional regulations leading to discounts in flood insurance premiums (FEMA, 2018). Each year, this program classifies communities involved in the system from 1 to 9. If the community rating class is improved, they will gain more flood insurance reduction. In Iowa, only ten communities participate in CRS out of 681 NFIP communities in Iowa (FEMA, 2019). For example, Cedar Rapids, the second-largest city in Iowa, obtained class 6 in the CRS, which means a 20% reduction in flood insurance premiums inside BFE areas and a 10% reduction outside of BFE (FEMA, 2019). Additional efforts are required to encourage all communities to join the CRS.

The United States has experienced unusually costly flood disasters because of increased population and development in flood-prone areas (Rosoff &Yager, 2017). Houses located in flood-prone areas are the most vulnerable social infrastructure with more frequent devastating damage, especially those not achieving flood-resistant design. Even though different government levels have made some efforts to reduce the development in flood-prone areas, losses associated with flood damage have increased in the U.S (Lynch et al., 2018). In Iowa, approximately 100,000 people live within the 100-year floodplain (Peri et al., 2017). According to Flood Factor, approximately 390,000 properties in Iowa are at risk of flooding, and the number will increase in the coming years due to environmental changes (Flood Factor, 2020). People who live in these

houses may encounter floods and needed to be evacuated. People face financial losses, including structural and content damage and displacement to temporary places (FEMA, 2012). Besides, indirect losses (e.g., transportation disruptions, contamination) may result from damage (Thieken et al., 2009). Damaged houses need time and an expensive process to be fixed and operated under normal conditions, which will generate indirect effects on the affected people (NAI, 2014). It is important to develop flood mitigation strategies that help reduce damage, recovery time, and financial losses.

Structural and non-structural mitigation measures can enhance the effective response to flooding (National Research Council, 2013). For example, houses around water bodies can be protected by a levee. However, the levee functionality can fail due to unexpected flood patterns (Jia et al.,2010). Although costly structural flood mitigation measures are invested, flood-related consequences continuously occur (CBO, 2019). Non-structural mitigation measures such as flood-resistant materials have been widely used to mitigate flood effects (Ashley et al., 2007). They have been proven to be efficient, cost-effective, recovery time reduction, and minimizing financial losses (FEMA, 2015). Lendering et al. (2016) illustrated that mitigation measures (e.g., sandbags) improve reliability and probability of success during flooding. Combining structural and non-structural measures can enable communities to withstand strongly during flood events (Patel & Dholakia, 2010; Richards et al., 2008).

Since flooding cannot be prevented entirely, implementing flood mitigation measures is critical to minimize property-level flood disruption (Beddoes & Booth, 2011). Several studies have shown the reduction of flood damage with mitigation measures. Wet floodproofing measures can minimize flood damage up to 50% (Attems et al., 2020; ICPR, 2002), while dry proofing can reduce damage from 50 to 80% (Owusu et al., 2015; Kreibich et al., 2015; Lasage et al., 2014). Researchers have proven the cost-effectiveness of using mitigation measures to reduce flood damage at an individual scale (Kreibich et al., 2005; Poussin et al., 2015; Botzen et al., 2019). Communities receive credits to obtain discounts in flood premium insurance once they follow regulations and measures beyond the minimum NFIP specifications (FEMA, 2018). These credits require not only government intervention but also actions from homeowners. For example, properties that are elevated above the BFE can get discounts on flood insurance premiums. Flooded homes without mitigation measures may need additional days or weeks to be restored due to the cleanup and drying process. When a house is mitigated, for example, by raising electrical utilities above risk levels, the likelihood of damage is low. That will avoid the need to fix or replace the utilities, speeding up the recovery process. FEMA (2013) also reports that contamination might occur in flooded houses if not restored within weeks of the flood event. This could help save people's lives, avoid emotional distress, and make communities more resilient (Stanke et al., 2012).

The role of individuals in protecting their homes from disasters is significant (FEMA, 2014). However, FEMA used a survey to illustrate some perceived barriers that may disrupt people's ability to mitigate their homes from disasters, including floods. The cost of the measures is the

most concerning factor for people, along with the absence of awareness of implementing such measures (FEMA, 2014). Some respondents feel they do not have enough time to prepare or get information on what to do in an emergency. Understanding the perceived barriers supports mitigation decisions (Xu et al., 2020) to improve people and infrastructure protection and reduce flood-related damage. Another survey reveals the influence factors for implementing mitigation measures after a flood event (Joseph et al., 2015). The survey illustrated that the awareness of flood risks, consequences, and solutions might encourage people to take action. However, respondents were uncertain about the benefits and cost-affordability of mitigation measures and the authorities responsible for protecting property. The need to increase the awareness of flood mitigation among homeowners is necessary to improve the response to flooding (Owusu et al., 2015).

Flood maps and information, coupled with different models and observations, can translate complex data and information on disasters into a simple and clear picture, allowing the average person to understand and make decisions for mitigation (Sermet et al., 2020). Researchers have studied the potential impacts of flooding, including exploring vulnerable areas (Alabbad et al., 2021; Röthlisberger et al.,2017; Ishaya et al., 2009; Sowmya et al., 2015) and damage estimation (Oubennaceur et al.,2019; Demir et al., 2018; Kellermann et al.,2015; Yildirim, 2017). Besides, several studies presented decision support systems (Ewing and Demir, 2021) for flood risk management, including information on flood warnings (Ford, 2001), emergency activities (Kim et al., 2011; Sahebjamnia et al.,2017), and critical infrastructure (Ghavami, 2019; Irwin et al., 2016). In the context of flood mitigation, Khoury et al. (2018) proposed a new serious game to help communities understand the significant role of flood mitigation options. In Iowa, limited research has explored property-level flood mitigation efforts. Tate et al. (2016) and Yildirim and Demir (2021) have investigated the economic impacts of implementing "buyout" for impacted buildings from flood events in the Middle Cedar River basin. Also, Silver Jackets (2016) generated a report focusing on estimating the flood impact reduction using the elevation and relocation measures for only Charles City, IA. Other major Iowa cities lack comprehensive mitigation analysis, including but not limited to evaluating wet/dry floodproofing to reduce flood impacts, which may be a suitable property-level protection measure for communities with limited resources.

In addition, recent advancements in web technologies allow real-time hydrological analysis (Agliamzanov et al., 2020), mapping (Hu and Demir, 2021), visualization (Demir et al., 2009), and geoprocessing (Sit et al., 2019). Web-based decision support systems offer easily accessible information to help decision-makers be aware of flood impacts and how they can be mitigated (Teague et al., 2021). FEMA interactive maps focus more on delineating flood areas for insurance rating purposes. Also, Texas and North Carolina have developed interactive web tools at community and property-levels to explore flood mitigation benefits (Center for Texas Beaches and Shores, 2021; NC Floodplain Mapping Program, 2021). However, they are limited in scope. In Iowa, Iowa Flood Information System (IFIS; Demir and Krajewski, 2013) provides flood information for the impacted buildings in select communities for many flood scenarios; however, it lacks mitigation analysis at the property-level. Decision on selecting a mitigation measure is

critical in terms of implementation and efficiency (CMSWS, 2019). The benefit-cost ratio can help evaluate mitigation projects (FEMA, 2020). Also, there is a need for a decision tool to facilitate the selection of a property-level flood mitigation technique considering various characteristics related to flood, building, and site. Providing accessible flood information and mitigation can lead to improved public knowledge, enhancing their ability to respond appropriately and, as a result, increased community resilience to flood disasters (Kjellgren, 2013).

Due to the complexity of flood events and knowledge of alternative mitigation applications, flood mitigation analysis is often a challenge for decision-makers and the public to minimize flood impact. Expertise in geographic information systems (GIS), flood map modeling, database management, flood data repositories (Haltas et al., 2021), and mitigation methodology are often required to utilize mitigation analysis at a community and property-level. Decision support systems have promising capabilities to generate insights for mitigation applications by enabling existing guidelines created by the federal authorities (e.g., FEMA, USACE). Artificial intelligence methods (i.e., decision trees) can be helpful for informing users based on mitigation guidelines. Besides, such integrated systems can encourage the public to attend the CRS to support more resilient communities by informing existing methodologies, benefits, and costs. This study proposes a decision support system called the Mitigation and Damage Assessment System (MiDAS) to improve the mitigation decisions for the public and communities towards flood resilience. The system aims to help decision-makers and the public protect their communities and properties by selecting the most feasible options. The mitigation research framework can produce the benefits and costs of mitigation measures and increase knowledge for mitigation practices to reduce flood damage. The research framework also utilizes climate scenario-based streamflow projections to enable long-term mitigation decisions. This work encourages Iowa and other communities across the U.S. to participate in CRS by implementing additional measures above the minimum NFIP standards and obtaining flood insurance discounts in return.

The methodology is described in the next part, which includes datasets, damage and analysis, and the development of the MiDAS framework. The system's capabilities and the case study's findings are then presented. A description of the created automated decision guiding tool follows. The conclusion and future thoughts are provided at the end.

2. Materials and Methods

2.1. Mitigation and Damage Assessment System

The flood risk management process includes identifying the risk, evaluating the risk degree, and then taking actions to plan and control the risk (Bowles et al., 1999). We seek to help with decisions to increase a community's resilience and decrease the vulnerability of floods. A community's resilience during flooding can be defined as the system's ability to stand against the disaster at low adverse impacts (Weber et al., 2018). The social, economic, environmental effects of flooding on properties can lead to analyzing the vulnerability (Tellman et al., 2020).

The framework allows users to quantify damage and generate mitigation options for two geospatial scopes as community and property. The community-level analysis provides damage and mitigation options for Cedar Rapids, Cedar Falls, and Waterloo buildings. The user selects a city, a flood scenario, and an individual building to explore the damage and mitigation analysis. Inundation depths are estimated using a database system and stored in JavaScript Object Notation (JSON) files for each building. By selecting a building, structural and content losses are automatically estimated for the selected scenario. Climate scenario-based projected losses are also given for each building and the community. Then, mitigation options are revealed for users to choose as a protective measure. Based on the selected properties and design level, mitigation costs are calculated for each mitigation option. In Figure 1, the architecture of the cyberinfrastructure framework is presented for data, analysis, and visualization layers.
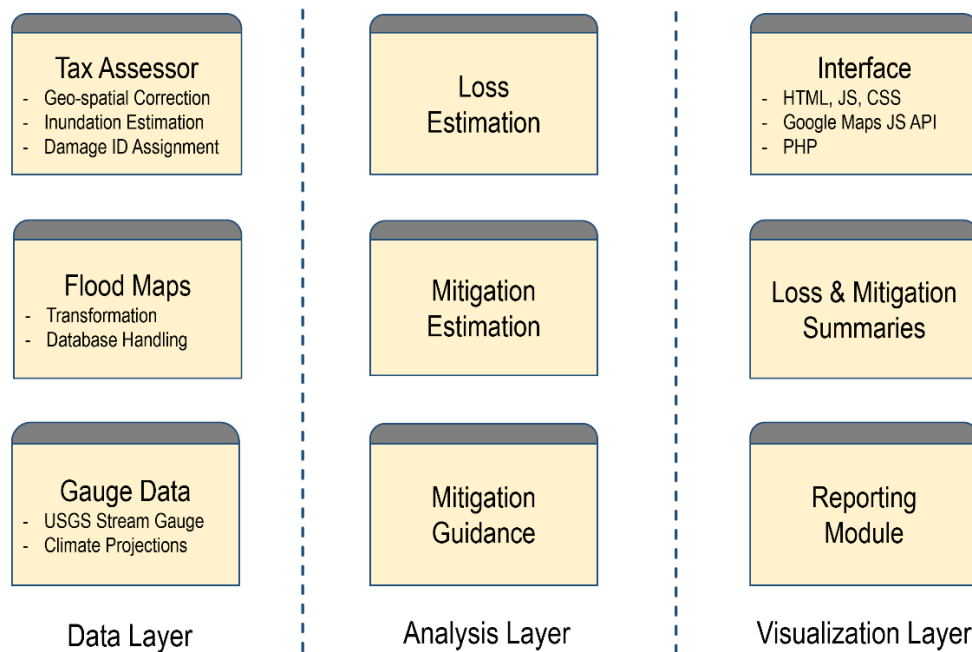

Figure 1. Architecture for the Mitigation and Damage Assessment System (MiDAS) framework

In the beginning, the user enters an address to locate the property by generating latitude and longitude. If Zillow API data is available for the selected address, the framework automatically fills property value, property type, and square footage for the user. After selecting flood depth from the interface, direct losses are calculated, and mitigation options are revealed. In the end, the framework estimates mitigation costs for different options based on the user selection and generates a mitigation report. If required information is not available for property-level analysis from automated sources, user input is required to assess damage and mitigation.

In the data layer, damage functions, flood maps, parcel information, and mitigation options are organized. Geospatial correction of property coordinates, pre-estimation of flood depth, damage function assignment, and footprint area of properties estimations are performed in QGIS and PostgreSQL. The outputs are produced in JavaScript Object Notation (JSON) format to be used

by the data analysis layer. A Hypertext Preprocessor (PHP) file is created to request property data by communicating with the Zillow API for queried addresses.

The data analysis layer processes the user's query, requests the data based on selection, and returns the damage in multiple scenarios and mitigation options. The layer is a map-based environment written in Hypertext Markup Language (HTML), JavaScript, jQuery library, and PHP. Additionally, Google Map JavaScript API and Zillow API are utilized in the data analytics layer. The following sections (2.2 and 2.3) explain the data analysis layer's main components in detail. The layer also provides a decision guidance module, a mitigation option recommendation based on the property and the region's flood characteristics.

The visualization layer receives the query results and returns the summary panel's output to list the damage and mitigation summary. The user interface provides a damage summary at the property and city level. The main panel allows users to select building properties (i.e., structural/content value, area, occupancy) and mitigation options. In community spatial scope, individual buildings are visualized by their flood depths. A printable flood report containing the loss and mitigation summary is also provided for users to export the framework results.

The effectiveness of the mitigation options can be determined to identify the risk via depth, velocity, and duration information of the flood as well as debris impact (FEMA, 2014; USACE,2019). It is also essential to be aware of state and local regulations and the existing home condition's ability, including the design, construction, soil types, and the additional requirements (e.g., stairs for elevation measures) to adapt the mitigation measures.

2.2. Damage and Loss Analysis Module

The damage analysis module estimates direct flood losses in terms of the structure and content of a property. In the estimation methodology, flood damage functions are essential to quantify the loss. The functions give the relation between flood depth and a damage percentage for a property. Thirty-six unique curves or functions are collected from the USACE. The module uses a unique damage function for each occupancy (e.g., residential, commercial, and industrial) to estimate structural and content losses. The curves are converted to a JSON file to enable with data analysis layer. In Figure 2, damage functions for the residential and commercial buildings are illustrated.

Property values are mainly collected from county tax assessors and Zillow Application User Interface (API), a publicly available real estate website. The county assessor's data includes geolocation of a property, structural value, and occupancy type. Public buildings are excluded in the community-based scenario because they are not taxable. So, no structural values are recorded for these buildings. Over ten thousand properties, most of which are residential, are analyzed in the study. Tax assessor data is geo-corrected using Google Maps satellite imagery on Quantum Geographic Information System (QGIS) to get more accurate flood depth for individual structures.

Structural and content losses for each property are estimated to reflect overall flood losses for a community. Flood depths are calculated for each property at the backend using community flood map rasters generated by the Iowa Flood Center (IFC). The maps are based on the United States

Geological Survey (USGS) gauges installed in the city centers. The damage analysis module uses a total of 153 flood inundation maps in the study area. For Cedar Rapids, Cedar Falls, and Waterloo, flood inundation maps are 60, 45, and 48. An address is required as an input to locate the property and call the parcel information from Zillow API for user-base analysis. After the occupancy type, the user completes structural/content value, building area, and flood depth fields, and the loss can be estimated.
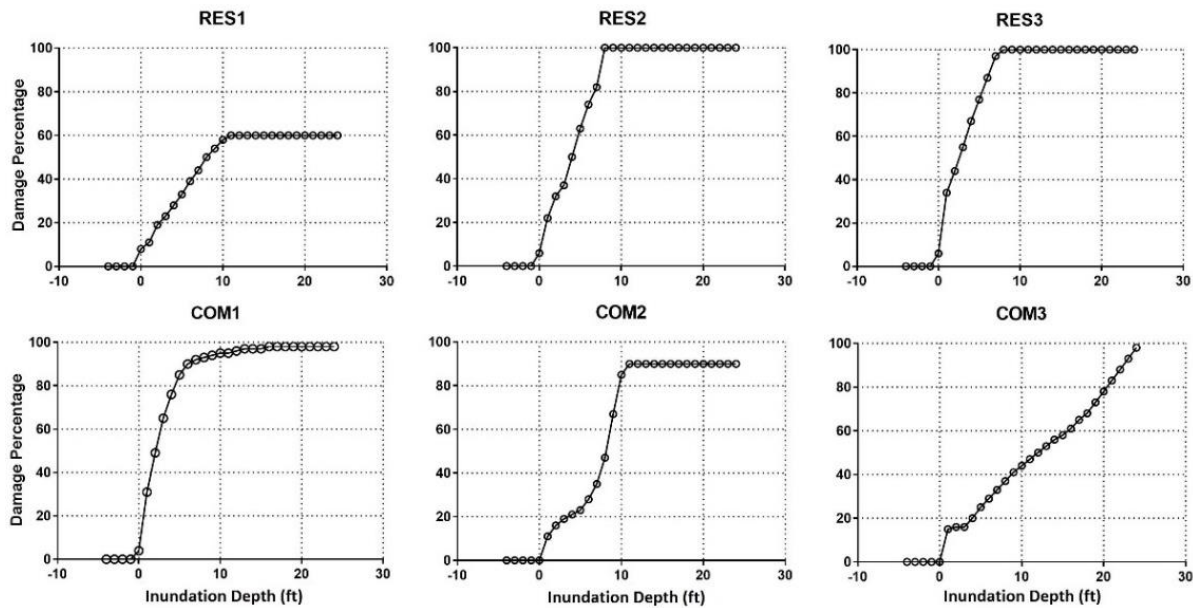

Figure 2. Flood inundation depth–damage (structural) functions (Yildirim & Demir, 2019)

Stream projection data is collected from another study for the studied communities (Quintero et al., 2018). Locations of USGS gauges are used as a reference to produce the data. The projections are generated based on the two climate scenarios, A1FI, and A2 climate scenarios, which are the product of the CCSM3 (Community Climate System Model) model. While the A1FI scenario is created considering fossil-intensive assumptions, the A2 scenario is produced based on lower emissions. So that the system will be able to provide projected losses for two different possibilities. In the study, projections between 2021 and 2050 are employed. More details about the climate scenario-based stream projections can be found in Quintero's study. After that, projected stream data is processed to classify the number of flooding events based on the rating curves developed by the National Weather Service (NWS). Because flood inundation rasters are generated regarding the USGS gauges on the studied sites, flood maps suitable to reflect the classified flood events are selected for the projected loss estimations.

2.3. Mitigation Analysis Module

Reducing flood risk includes not only taking actions by a community (e.g., constructing levees) and societies (e.g., reducing greenhouse gas emission) but also by individuals (Wong-Parodi et al., 2018). A simple step can minimize potential flood impacts. Individual flood mitigation measures

can help to withstand flood events appropriately and reduce potential losses. The benefit-cost ratio is used to determine whether the measure is cost-effective or not, and it divides benefits (avoided damage costs) by the mitigation cost. Once the ratio is greater than one, the action is cost-effective (FEMA, 2020). To estimate the benefit-cost ratio (BCR, Eq. 1):

$$BCR = \frac{Benefits\ (\$\ Avoided\ Damage)}{Cost\ (\$\ Mitigation\ Cost)} \text{ if BCR >1, project is effective} \qquad \text{Eq. 1}$$

Vulnerable homes to flood events can be made less vulnerable through various measures. However, it is essential to identify the proper and effective measures by manipulating multiple data to cope with future flood events. Mitigation solutions can be divided into three categories: avoidance, allowance, and exclusion of floodwater (FEMA, 2009). Some measures can work for 50 years (FEMA, 2015). Each main category has multiple subcategories based on the targeted design and the households' existing condition (Appendix 2). Also, the cost for each measure is represented in the table. Mitigation applications vary by building area and building perimeter. We estimated the area and perimeter using the Microsoft footprint dataset for each building. To calculate BCR, we considered that avoided damage includes content and structure value and the average of the total flood mitigation cost as mitigation cost. We assume that some mitigation measures can prevent damage at 100%, such as elevation and relocation, and others can minimize the damage (e.g., dry floodproofing). We assume 50% structural and content damage reduction for allowance floodwater measures and 80% structure damage reduction with zero content damage for floodwater exclusion measures. Therefore, the benefits will include the expected damage before mitigation minus the expected damage after mitigation.

2.3.1. Avoidance of Floodwater

Elevation: It is to raise the home to a level where the flood risk is zero or low. It seems a costly option. However, once the method is applied appropriately, there will be many advantages, such as damage reduction. It is also recommended to elevate a house above the 100-year flood depth plus a 1-foot freeboard.

Relocation: A vulnerable house can be relocated to a safe location. This measure requires new land to be purchased, which will make the measure expensive. Also, the route to the new location must be accessible.

Reconstruction: Once the home is experienced a flood event, it may be efficient to rebuild it on the same site with appropriate standards, and it will be costly but lead to a free-risk setting.

2.3.2 Allowance of Floodwater

Wet floodproofing: Wet floodproofing measures help floodwater enter a home with low adverse impacts. It requires or recommends being implemented on home parts, not for living space, such as a garage. Its cost seems to be affordable. However, once the flood depth exceeds 3 m, the measure is ineffective. Also, it is practical for the flood duration of less than one day.

2.3.3 Exclusion of Floodwater

Dry floodproofing: It is to prevent water from reaching home. To avoid collapsing, it is practical for flood depths of up to 3 feet and short flood duration (1day) as well as low velocity.

Levee and floodwall: A levee is constructed using compacted soil, while the flood wall is made of concrete or masonry. The height of these measures is limited to 4 and 6 feet. It is important to consider soil types and slopes when building a levee, and it is effective for flood duration up to 4 days.

2.3.4 Limitations

A flood hazard map is the key component in determining risk areas and based on it and other considerations (e.g., building condition), appropriate mitigation plans and measures can be established. It may not be beneficial for a house exposed to a high-water depth to practice mitigation actions (e.g., sandbags), while relocating the building may be the optimal solution. Also, maintenance and enforcement play an essential role in flood mitigation effectiveness (Pilon, 2002). For more information, Appendix 2 clarifies some floodproofing limitations.

2.4. Decision Guidance Module

Not all mitigation actions can be practical to minimize the flood damage (FEMA, 2015). Flood, structure, and site-related characteristics can affect the appropriate selection of mitigation measures and, to some extent, aggravate the flood impacts. For example, the sandbag technique is unsuitable for a building exposed to more than 3 ft flood depth due to its susceptibility to collapsing. Using a "filtering" method with multiple categories of criteria relevant to each mitigation approach is one way to assess the success of flood mitigation strategies for flood-prone properties. The Iterative Dichotomiser 3 (ID3) algorithm (Quinlan,1986) is used for the decision tree analysis from a dataset collected from a variety of sources, including FEMA and USACE (See appendix 2), and implemented using JavaScript language (Lahodiuk, 2018). The decision tree analysis is a supervised machine learning method that can help classify flood mitigation measures following a guideline. It will continuously split the data according to a certain parameter until it reaches the decision variable. The ID3 algorithm is a greedy approach, constructing with a node (feature), a branch (rule), and a leaf (class) and uses information theory metrics (Entropy, Information Gain) to split the dataset on a particular iteration in order to reach the best class.

The dataset used in the decision tree analysis includes six applicable property-level mitigation techniques (Elevation, Relocation, Wet/Dry floodproofing, Levee, Floodwall). The elevation measure consists of six sub-categories (extend foundation, piers, posts, columns, piles, fill compacted). These techniques will be employed in the model as classes. The dataset contains information for the eligibility of implementing each mitigation measure according to flood behavior (depth, velocity, duration, with debris or not), property location, soil type, existing building foundation and condition, expected useful life, and flood insurance premium reduction eligibility. This information will be used as a feature in the decision tree analysis. Figure 3 shows an example of classifying the provided dataset. It starts with a root (feature) that has the most information gain, then the rule, and finally the class. The total of decision trees built in this module

is 57. On the web decision analysis panel, the module enables the user to select nine features as inputs to build the decision tree and, as a result, provide the optimal mitigation measures that match the selected features.
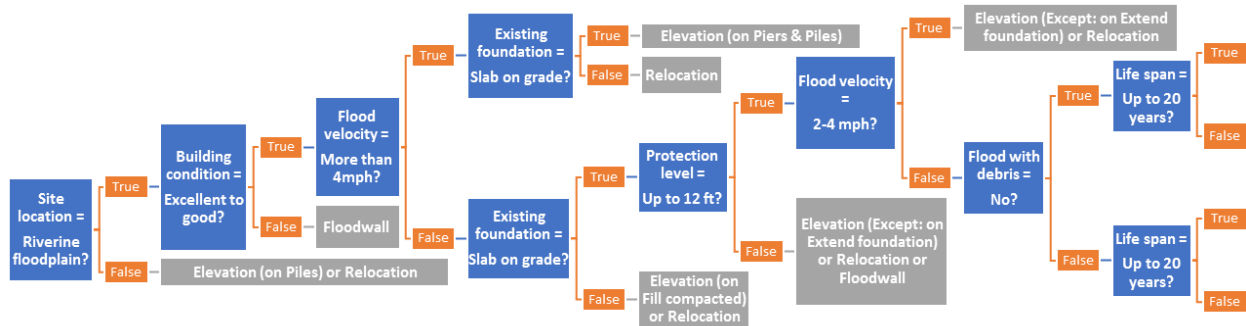

Figure 3. A decision tree example for the flood mitigation decision.

3. Results & Discussions

This section presents the Mitigation and Damage Assessment System's capabilities, and the mitigation analysis results by a comprehensive case study. In section 3.1, the framework functionality and user experience are presented, and analysis and reporting features are discussed. The decision guidance tool is also discussed in section 3.2. Community-based mitigation results for the Middle Cedar case study are shared in section 3.3.

3.1. Mitigation and Damage Assessment System

The MiDAS is a publicly available mitigation framework that can be accessed from the UIHILab server (http://hydroinformatics.uiowa.edu/lab/midas). Brief information is provided on the landing page to inform users about the datasets that have been used and the list of analysis in the system. Figure 4 shows the system's main page that presents the datasets and available analysis. The MiDAS provides the analysis into two spatial scopes, as property and community, respectively. Cedar Falls, Cedar Rapids, and Waterloo communities are analyzed in the Middle Cedar Watershed in community scope. A total of 153 maps are analyzed to estimate direct flood losses for three communities. The damage and loss summary includes flood level, number of affected buildings, and direct structural and content losses. The streamflow projection data based on climate models (Quintero et al., 2018) is adopted to assess future losses of the communities. Two projected loss values are delivered in the MiDAS. The A2 climate scenario is called as "Low emission," and the A1FI climate scenario as "High emission" in the system. This helps possible losses in the future to be reflected by the user for the analyzed community. In figure 5, the city summary is shared for Cedar Rapids under 31.5 feet stage-height flooding in the MiDAS.

The MiDAS provides damage and mitigation summaries in community and property scope. In the community scope, the user selects a scenario to analyze and chooses a building to see the damage and mitigation summary. The projected losses are also visualized for the building by

analyzing the projected stream gauge data. Future losses support mitigation decisions for users to select a costly option to prevent high losses or a less costly option to avoid lower losses.
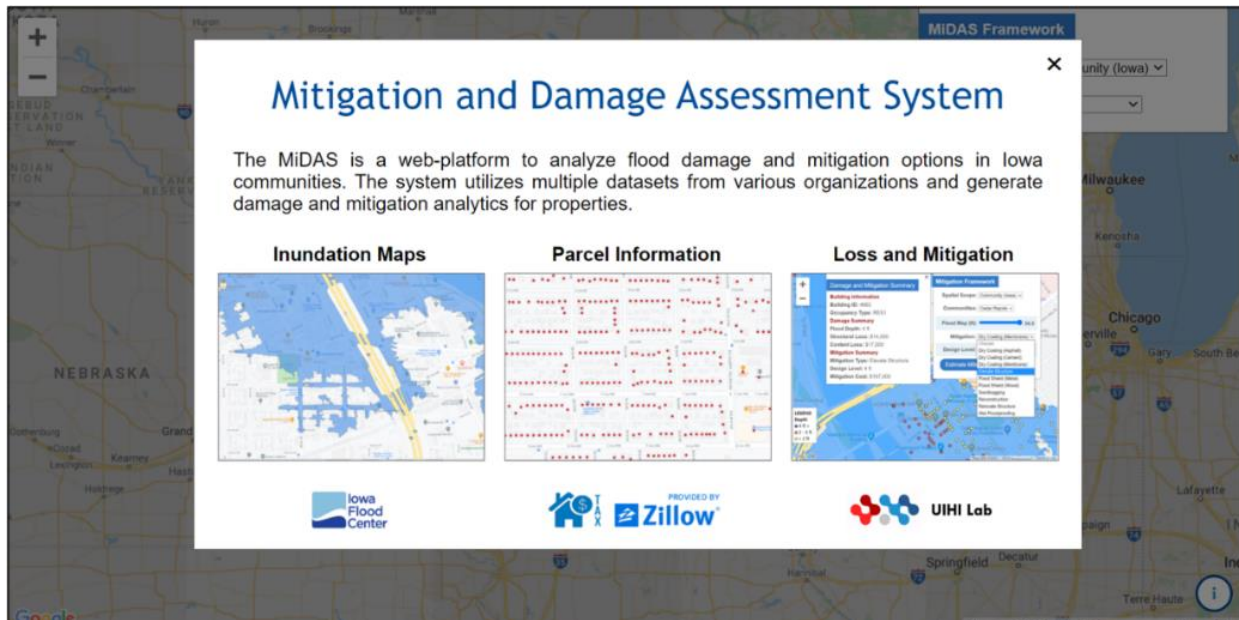

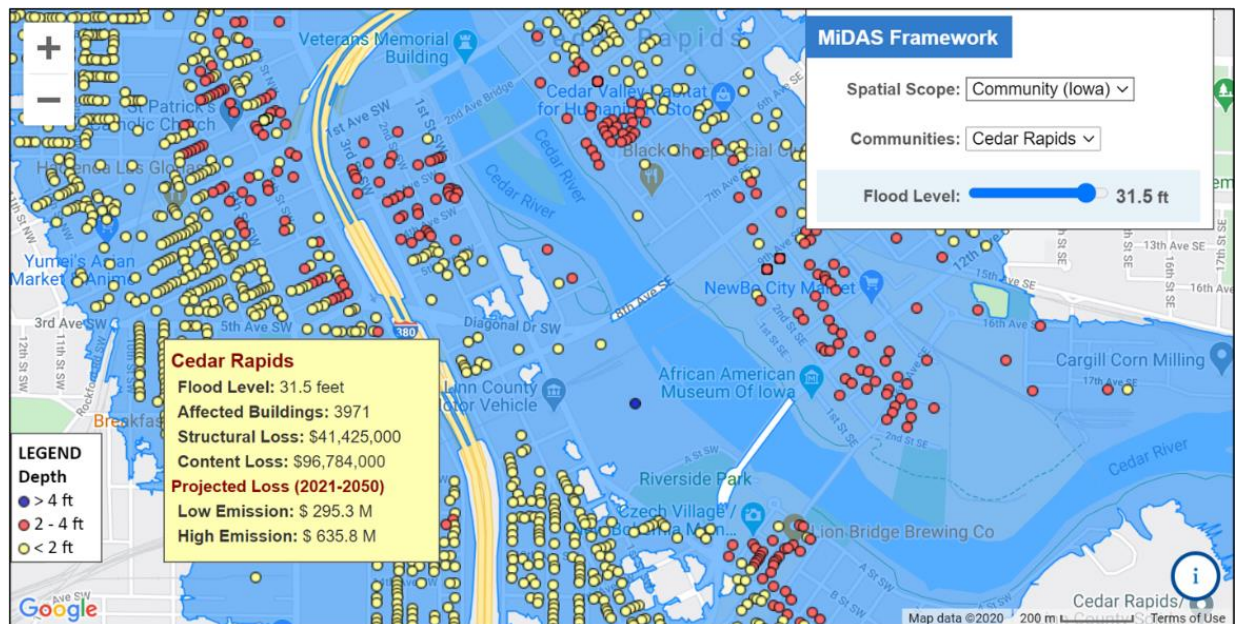**Figure 4**. The landing page for the MiDAS.

Figure 5. Scenario-based inundated properties of Cedar Rapids in community scope.

The MiDAS requests building information, flood depth, and the user's mitigation option in property spatial scope. The system locates the building by using the address that the user provides. Depending on the data availability, the occupancy, structural value, content value, and building area can be automatically filled by Zillow API. If no data is available or the data is not adequate

for the address, the user will have the option to fill or correct the required fields to proceed with the analysis. In Figure 6, the damage and mitigation summary for a community-level analysis and a property-level analysis is demonstrated.
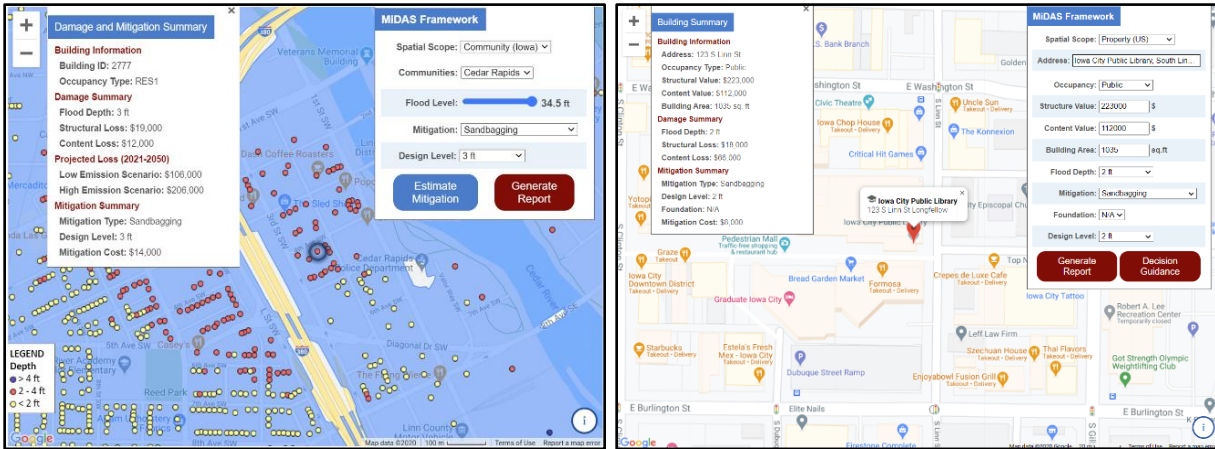

Figure 6. Damage and mitigation summary in community scope (left) and property scope (right)

Figure 7. Mitigation and damage report for a property in community-level scope.

The MiDAS framework also generates detailed flood damage and mitigation reports for all community buildings and the property spatial scope. The report includes the basic property information (e.g., building id, occupancy type, city name, square footage, and property values), damage summary, and alternative mitigation options summary. The damage summary reflects the what-if scenario to estimate flood damage and corresponding mitigation benefits for a specific flood depth. The mitigation summary delivers the cost of each mitigation option for the design

13

level. The report can be printed at the user's request. In figure 7, the mitigation and damage report from the MiDAS is presented to the user.

3.2. Decision Guidance Module

The framework also helps in classifying flood mitigation measures regarding building properties. Then, the properties are iterated on guidelines that FEMA and USACE create in order to return the recommended option. An optimized recommendation for mitigation decisions requires providing questions and inputs that have strong relations with the target. A decision tree algorithm evaluates flood levels, site, building characteristics, and community benefits to help the user decide which measure is feasible (Figure 8).

Figure 8. The decision guidance tool in the MiDAS.

The user can select the protection level for up to 12 ft of flood depth and examine measures to withstand various flood velocities. We provide a range for flood velocity in mile/hour, which may help the user understand the flood velocity as car speed. The flood duration plays an important role in the decision process since some measures can fail to operate long. There will be two options for flood duration, less than and more than one day. Floods with debris restrict the choice for some mitigation actions due to their ability to break the measure and, as a result, increase the consequences of flood impacts. The site location menu will offer two scenarios of flooding: riverine and coastal. Two types of site soil (permeable, impermeable) are considered to categorize the mitigation actions. Also, slab on grade, crawlspace, and basement options are revealed for the user to choose as an existing foundation for a building. The user will specify the building condition from excellent to good or fair to poor. The target life span can be up to 20, 30, or 50 years. In some cases, the user may not know what criteria to select (e.g., flood velocity). Therefore, we provide

the additional option "I don't know", then the system will consider the worst case. Finally, the system will suggest applicable mitigation options based on the provided inputs.

3.3. Middle Cedar Case Study

Middle Cedar watershed, located in eastern Iowa, is selected for the case study region. The region, which hosts some of the largest cities of Iowa (Cedar Falls, Cedar Rapids, Waterloo), have experienced several severe flood events in the last couple of decades. The study region is shown in Figure 9.
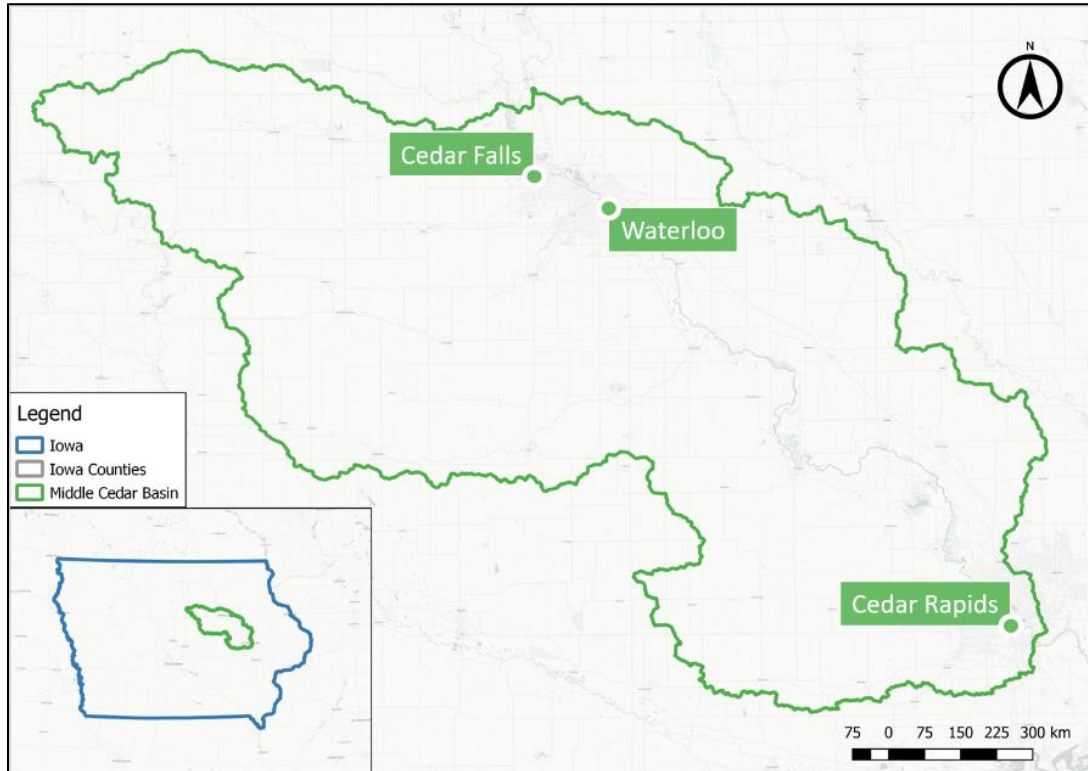
Figure 9. Middle Cedar watershed and studied communities within the boundaries.

Flood inundation maps generated for select USGS gauge records are analyzed to assess flood loss in studied communities. Our results show that the City of Waterloo is substantially protected against most of the flood scenarios. The city's direct loss is estimated at $134 M after the flood level reaches a 29 feet stage height of flooding event. Regarding the rating curve, the 29 feet flood level is statistically between 200 and 500-year flood events. Another sharp increase in the direct loss is estimated for Cedar Rapids in 25 feet flood level. However, the number of affected buildings does not increase to the same degree compared to the direct flood loss. This is an indicator of the existence of vulnerable commercial or industrial properties in the flood-prone area since these buildings tend to have more losses due to containing valuable contents. In the case of Cedar Rapids, the direct loss gradually increases with the flood level. The maximum number of affected buildings for Cedar Falls, Cedar Rapids, and Waterloo is estimated as 4,277, 5,810, and 422, respectively.

Most of the affected buildings are residential properties. In figure 10, flood level and direct flood loss estimates are shared for each community.
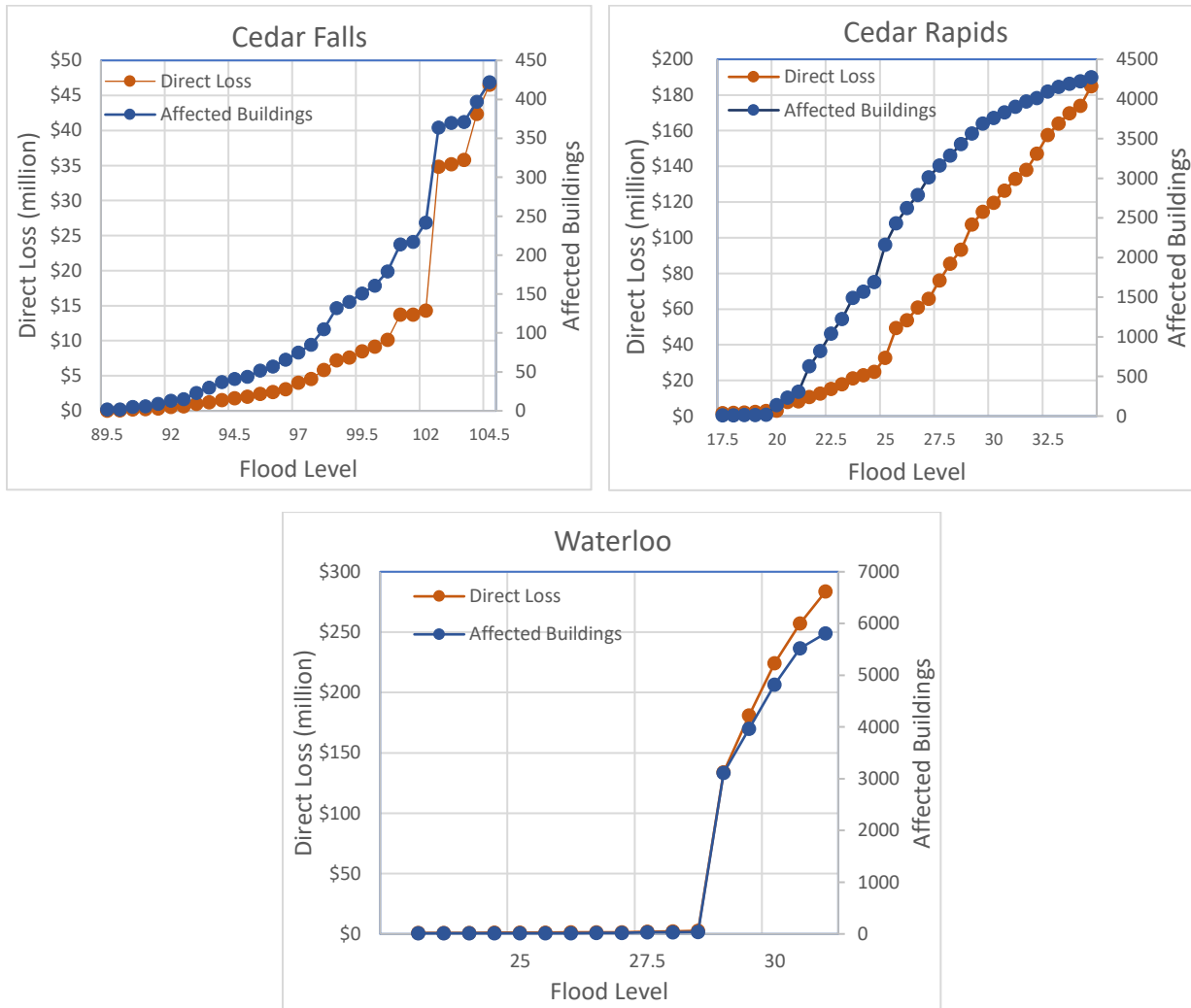
Figure 10. Stage-loss results for communities in the Middle Cedar Basin.

Community-level Flood Mitigation Analysis: Residential buildings are selected to analyze flood mitigation applications due to data availability from county tax assessors. Table 1 shows that direct total loss estimates (e.g., structural and content) in residential regions are provided for the 100 and 500-year flood scenarios in Cedar Rapids, Waterloo, and Cedar Falls. Inundation depth is critical when selecting a mitigation option due to the design level variations in mitigation options. Table 1 summarizes the total loss for each inundation depth in select flood scenarios for three cities. Also, we estimated the total costs of mitigation measures based on both flood levels (Table 2). Because of the lack of information on construction types (e.g., frame, masonry) and existing foundation data (e.g., basement, crawlspace), costs for some mitigation measures are represented as a range. For example, the lowest value of elevating buildings represents the mitigation cost if all buildings are framing construction with basements and incrementally increased with crawl or

slab foundations until the largest value, which is for masonry buildings with slab foundations. We found that elevation and relocation applications are costly for community-level mitigation. These options should be considered for special cases (i.e., repetitive flood damage, low-cost buyout) so that they can be a feasible option in the long-term. On the other hand, dry floodproofing and wet floodproofing seem feasible options for community-level applications. However, maintenance is critical for these applications to keep them as mitigation measures.

Table 1. The total damage for impacted buildings at each flood depth in the study region.

Depth (ft)	Cedar Rapids		Waterloo		Cedar Falls	
	100 yr	500 yr	100 yr	500 yr	100 yr	500 yr
1	$ 12.7 M	$ 27.6 M	$ 79 K	$ 52.3 M	$ 2.6 M	$ 5 M
2	$ 456 K	$ 30.2 M	$ 222 K	$ 35.1 M	$ 862 K	$ 2.5 M
3	$ 70 K	$ 2.2 M	X	$ 13.6 M	$ 967 K	$ 3.2 M
4	$ 123 K	$ 86 K	$ 40 K	$ 944 K	X	$ 225 K
5	X	$ 142 K	X	$ 48 K	X	X

We found some options are not cost-effective if the community experiences the flood event only one time. Table 3 clarifies the number of events that achieve the cost-effectiveness of the mitigation measures. Even though the mitigation measure may not be appropriate for some buildings, this analysis can give an overall cost and effective assessment of implementing flood mitigation at a community level. Different considerations, such as useful life and annual maintenance of flood mitigation, should be considered when taking action. Also, it is important to evaluate the mitigation action by considering its capability not only to avoid damage costs but also to save lives and avoid indirect adverse impacts (e.g., temporary relocation, emotional distress).

Table 2. The cost estimation for flood mitigation measures at a community level.

		Cedar Rapids	Waterloo	Cedar Falls
Elevate Structure	100 yr	$79 M - $251 M	$0.52 M - $1.57 M	$8.7 M - $27 M
	500 yr	$315.7 M - $964.1 M	$247.8 M - $767.1 M	$16.8 M - $51.7 M
Relocation	100 yr	$167.9 M - $335.8 M	$1 M - $2.1 M	$17.9 M - $35.9 M
	500 yr	$636.6 M - $1.3 B	$509.6 M - $1019.2 M	$34.3 M - $68.6 M
Wet floodproofing	100 yr	$1.5 M - $4 M	$0.04 M - $0.06 M	$0.42 M - $0.66 M
	500 yr	$21.3 M - $30 M	$11.5 M - $18.2 M	$0.95 M - $1.4 M
Dry floodproofing	100 yr	$ 5.5 M	$ 0.1 M	$ 1.3 M
	500 yr	$ 25 M	$ 45.4 M	$ 2.4 M
Levee	100 yr	$ 7.77 M	$ 0.02 M	$ 2.2 M
	500 yr	$ 43.7 M	$ 82.2 M	$ 4.41 M
Floodwall	100 yr	$ 17.2 M	$ 0.04 M	$ 4.2 M
	500 yr	$ 84 M	$ 151.2 M	$ 8.2 M

Challenges and Limitations: One of the challenges in the study is property data collection and processing. In Iowa, there is a lack of publicly available and centralized parcel information databases or repositories for researchers. The available datasets also require extensive work quality checks such as geospatial correction, structural and content value assignment, and data cleaning. Although the framework is developed to be easily scalable for any region, the data challenges are a big hurdle for expanding the framework. Furthermore, updating damage functions can improve the accuracy of the results. Although the functions are critical to deriving depth-damage relations, custom functions are needed for site-specific and reliable results. When it comes to mitigation analysis, flood characteristics are important for choosing the feasible mitigation measure. However, it may be a challenge to be determined by a non-technical person. For example, sandbags are not an appropriate option in flash flood areas due to time limitations. A comprehensive historical flood events database can provide the knowledge of flood characteristics to support mitigation decisions.

Table 3. Number of flooding events to achieve cost effectiveness for each mitigation measure.

	Elevation		Relocation		Wet Proofing		Dry Proofing		Levee		Floodwall	
	100yr	500yr	100yr	500yr	100yr	500yr	100yr	500r	100yr	500yr	100yr	500yr
Cedar Rapids	13	11	19	16	1	1	1	1	1	1	2	2
Waterloo	3	6	5	8	1	1	1	1	1	1	1	2
Cedar Falls	4	4	5	5	1	1	1	1	1	1	1	1

4. Conclusion

This study presents a web-based flood damage and mitigation system (MiDAS) and comprehensive analysis of community and property-level damage and mitigation analysis for the Middle Cedar basin. The system utilizes flood maps, damage functions, property datasets and generates damage analysis and mitigation assessments. A mitigation guidance tool to support mitigation decisions based on the FEMA and USACE mitigation guidelines is developed. The MiDAS delivers the damage and mitigation assessment at the community and property spatial scope. In community scope, the city of Cedar Falls, Cedar Rapids, and Waterloo in Iowa are analyzed. A damage and mitigation summary is generated for each building with a selected flood scenario for each geospatial scope. A detailed report that covers multiple damage and mitigation scenarios is also provided in the system. The mitigation information is collected from an extensive literature review and guidelines from federal agencies. The system can increase the awareness of property flood mitigation measures, minimize flood damage, and speed up recovery time. Climate change, urban development, and population growth promise to bring more flood events to communities with severe consequences. Even though there are government efforts and incentives

for implementing flood mitigation measures (e.g., levee), the role of individuals to protect their houses has become more important to minimize the impact.

Our results indicate that low-cost mitigation options such as dry floodproofing and wet floodproofing applications are feasible options for mitigating flooding impact quickly. However, elevation and relocation are also viable solutions for a permanent reduction in the long term. Projected losses show promising results for encouraging relocation or elevation as a mitigation choice. In the United States, relocation is often supported by federal programs through voluntary buyouts. So, property owners are needed to be informed about future losses so that long-term or permanent mitigation can be achieved. Although projected losses are estimated based on direct flood losses, estimation of indirect flood losses can be another essential input to support these decisions.

The MiDAS framework is aimed at being expanded to other regions in Iowa in the future. Analyzing other communities in the state can create insight for prioritizing feasible options for mitigation purposes. Besides, selecting the most feasible mitigation options for a whole community can be a great challenge due to the flood's chaotic nature. Life span, application time, cost, and design levels vary by mitigation options. Machine learning-based approaches can be a useful tool to select mitigation options for multiple properties. Data-driven methods can optimize mitigation costs for thousands of buildings by comparing the benefits and costs of mitigations. The property scope analysis can be integrated with a flood map API that allows querying flood depth with a custom scenario for queried coordinates. So that multiple regions can be analyzed automatically in the future. To choose an effective mitigation alternative, historical flood data and social media datasets can be analyzed to explore spatial locations' flood characteristics.

References

Aerts, J. C. (2018). A review of cost estimates for flood adaptation. Water, 10(11), 1646.

Agliamzanov, R., Sit, M., & Demir, I. (2020). Hydrology@ Home: a distributed volunteer computing framework for hydrological research and applications. Journal of Hydroinformatics, 22(2), 235-248. https://doi.org/10.3390/w10111646

Alabbad, Y., Mount, J., Campbell, A. M., & Demir, I. (2021). Assessment of transportation system disruption and accessibility to critical amenities during flooding: Iowa case study. Science of The Total Environment, 148476. https://doi.org/10.1016/j.scitotenv.2021.148476

Allan, R. P. (2011). Human influence on rainfall. Nature, 470(7334), 344-345.

Ashley, R., Garvin, S., Pasche, E., Vassilopoulos, A., & Zevenbergen, C. (Eds.). (2007). Advances in urban flood management. CRC Press. https://doi.org/10.1038/470344a

Attems, M. S., Thaler, T., Genovese, E., & Fuchs, S. (2020). Implementation of property-level flood risk adaptation (PLFRA) measures: Choices and decisions. Wiley Interdisciplinary Reviews: Water, 7(1), e1404. https://doi.org/10.1002/wat2.1404

Beddoes, D. W., & Booth, C. A. (2011). Property level flood adaptation measures: a novel approach. International Journal of Safety and Security Engineering, 1(2). https://www.witpress.com/elibrary/sse/1/2/525

Botzen, W. W., Kunreuther, H., Czajkowski, J., & de Moel, H. (2019). Adoption of Individual Flood Damage Mitigation Measures in New York City: An Extension of Protection Motivation Theory. Risk Analysis, 39(10), 2143-2159. https://doi.org/10.1111/risa.13318

Bowles, D.S., Parsons, A.M., Anderson, L.R., & Glover, T.F. (1999). Portfolio risk assessment of SA Water's large dams. ANCOLD Bulletin, 112, 27-39.

CBO. (2019). Expected Costs of Damage From Hurricane Winds and Storm-Related Flooding. Retrieved from Congressional Budget Office: https://www.cbo.gov/system/files/2019-04/55019-ExpectedCostsFromWindStorm.pdf

Center for Texas Beaches and Shores. (2021). Interactive Database Webtools. Retrieved from https://www.tamug.edu/ctbs/web-tools.html.

Charlotte-Mecklenburg Storm Water Services (CMSWS). (2019). Flood Risk Assessment and Reduction Community Guidebook. Retrieved from https://www.dhs.gov/sites/default/files/publications/rarr_cmntygdbkfinal_clean_006_508_mitigation.pdf.

Demir, I., Jiang, F., Walker, R. V., Parker, A. K., & Beck, M. B. (2009). Information systems and social legitimacy scientific visualization of water quality. In 2009 IEEE International Conference on Systems, Man and Cybernetics (pp. 1067-1072). IEEE. https://doi.org/10.1109/ICSMC.2009.5345985

Demir, I., & Krajewski, W. F. (2013). Towards an integrated flood information system: centralized data access, analysis, and visualization. Environmental Modelling & Software, 50, 77-84. https://doi.org/10.1016/j.envsoft.2013.08.009

Demir, I., Yildirim, E., Sermet, Y., & Sit, M. A. (2018). FLOODSS: Iowa flood information system as a generalized flood cyberinfrastructure. International journal of river basin management, 16(3), 393-400. https://doi.org/10.1080/15715124.2017.1411927

Ewing, G., & Demir, I. (2021). An ethical decision-making framework with serious gaming: a smart water case study on flooding. Journal of Hydroinformatics, 23(3), 466-482. https://doi.org/10.2166/hydro.2021.097

FEMA Flood Map Service Center: Search by Address. Retrieved from https://msc.fema.gov/portal/search.

FEMA. (2020). Benefit-Cost Analysis. retrieved from https://www.fema.gov/benefit-cost-analysis.

FEMA. (2020). Disaster Declarations for States and Counties. Retrieved from https://www.fema.gov/data-visualization/disaster-declarations-states-and-counties .

FEMA. (2019). Hazard Mitigation Grant Program. Retrieved from https://www.fema.gov/hazard-mitigation-grant-program.

FEMA. (2019). Top 50 National Flood Program (NFIP) Policy Count Communities and Community Rating System (CRS) Participation. Retrieved from https://crsresources.org/ .

FEMA. (2018). Community Rating System. Retrieved from https://www.fema.gov/media-library-data/1535126505943-439b296e7778b037d05f698f65c7891b/2018NFIP_CRS_Brochure_June_2018_508OK.pdf.

FEMA. (2015). Flood Hazard Elevation and Siting Criteria for Residential Safe Rooms. Retrieved from https://www.fema.gov/media-library-data/1592392367022-53baf152908a365f0f1b4fecafb798b4/Qguide_Flood_Siting_SR_Res_508.pdf .

FEMA. (2015). Reducing Flood Risk to Residential Buildings That Cannot Be Elevated. Retrieved from https://www.fema.gov/media-library-data/1443014398612-a4dfc0f86711bc72434b82c4b100a677/revFEMA_HMA_Grants_4pg_2015_508.pdf

FEMA. (2014). Preparedness in America. retrieved from https://www.fema.gov/media-librarydata/14090008880261e8abc820153a6c8cde24ce42c16e857/20140825_Preparedness_in_America_August_2014_Update_508.pdf

FEMA. (2014). Homeowner's Guide to Retrofitting. Retrieved from https://www.fema.gov .

FEMA. (2013). Cleaning Flooded Buildings.Retrieved from https://www.fema.gov .

FEMA. (2012). Engineering Principles and Practices for Retrofitting Flood-Prone Residential Structures. (Third Edition). Retrieved from https://www.fema.gov/media-library-data/20130726-1506-20490-2593/fema259_complete_rev.pdf.

FEMA. (2009). Homeowner's Guide to Retrofitting. Six Ways to Protect Your Home From Flooding. Retrieved from https://www.austintexas.gov/sites/default/files/files/Watershed/flood/fema_p312_a.pdf .

FEMA. (1998). Homeowners Guide to Retrofitting. Retrieved from https://www.lakecountyil.gov/DocumentCenter/View/3086/Homeowners-Guide-to-Retrofitting-PDF.

Flood Factor. (2020). Flood risk is increasing for Iowa. Retrieved from https://floodfactor.com/state/iowa/19_fsid

Ford, D. T. (2001). Flood-warning decision-support system for Sacramento, California. Journal of Water Resources Planning and Management, 127(4), 254-260.

Ghavami, S. M. (2019). Multi-criteria spatial decision support system for identifying strategic roads in disaster situations. International Journal of Critical Infrastructure Protection, 24, 23-36. https://doi.org/10.1016/j.ijcip.2018.10.004

Haltas, I., Yildirim, E., Oztas, F., & Demir, I. (2021). A comprehensive flood event specification and inventory: 1930–2020 Turkey case study. International Journal of Disaster Risk Reduction, 56, 102086. https://doi.org/10.1016/j.ijdrr.2021.102086

Heckman, Kurt. (2020). Sandbag Wall (1 bag deep). Retrieved from https://www.vcalc.com/wiki/KurtHeckman/Sandbag+Wall+%281+bag+deep%29 .

Hu, A., & Demir, I. (2021). Real-Time Flood Mapping on Client-Side Web Systems Using HAND Model. Hydrology, 8(2), 65. https://doi.org/10.3390/hydrology8020065

ICPR (International Commission for the Protection of the Rhine). (2002). Non structural flood plain management—measures and their effectiveness. ICPR, Koblenz, Germany

Iowa.gov. (2019). Office of The Governor of Iowa. Retrieved from https://governor.iowa.gov .

Iowa Flood Information System (IFIS). (2021). Retrieved from https://ifis.iowafloodcenter.org/

Ishaya, S., Ifatimehin, O. O., & Abaje, I. B. (2009). Mapping flood vulnerable areas in a developing urban centre of Nigeria. Journal of Sustainable Development in Africa, 11(4), 180-194.

Irwin, S., Schardong, A., Simonovic, S. P., & Nirupama, N. (2016). ResilSIM—a decision support tool for estimating resilience of urban systems. Water, 8(9), 377. https://doi.org/10.3390/w8090377

Jia, Y., Hossain, A., & Chao, X. (2010). Computational Modeling of Midwest Flood 2008: Levee Breaching and Flood Propagation. In World Environmental and Water Resources Congress 2010: Challenges of Change (pp. 1298-1303). https://doi.org/10.1061/41114(371)139

Joseph, R., Proverbs, D., Lamond, J., Joseph, R., Proverbs, D., & Lamond, J. (2015). Homeowners' perceptions of property-level flood risk adaptation (PLFRA) measures: The case of the summer 2007 flood event in England. International Journal of Safety and Security Engineering, 5(3). https://doi.org/10.2495/SAFE-V5-N3-251-265

Kellermann, P., Schöbel, A., Kundela, G., & Thieken, A. H. (2015). Estimating flood damage to railway infrastructure–the case study of the March River flood in 2006 at the Austrian Northern Railway. Nat. Hazards Earth Syst. Sci, 15(11), 2485-2496. https://doi.org/10.5194/nhess-15-2485-2015

Khoury, M., Gibson, M. J., Savic, D., Chen, A. S., Vamvakeridou-Lyroudia, L., Langford, H., & Wigley, S. (2018). A serious game designed to explore and understand the complexities of flood mitigation options in urban–rural catchments. Water, 10(12), 1885. https://doi.org/10.3390/w10121885

Kim, J., Kuwahara, Y., & Kumar, M. (2011). A DEM-based evaluation of potential flood risk to enhance decision support system for safe evacuation. Natural hazards, 59(3), 1561-1572. https://doi.org/10.1007/s11069-011-9852-2

Kjellgren, S. (2013). Exploring local risk managers' use of flood hazard maps for risk communication purposes in Baden-Württemberg. Natural Hazards and Earth System Sciences, 13(7), 1857-1872. https://doi.org/10.5194/nhess-13-1857-2013

Kreibich, H., Thieken, A. H., Petrow, T., Muller, M., & Merz, B. ¨ (2005). Flood loss reduction of private households due to building precautionary measures: Lessons learned from the Elbe flood in August 2002. Natural Hazards and Earth System Sciences, 5(1), 117–126. https://doi.org/10.5194/nhess-5-117-2005

Kreibich, H., Bubeck, P., Van Vliet, M., & De Moel, H. (2015). A review of damage-reducing measures to manage fluvial flood risks in a changing climate. Mitigation and adaptation strategies for global change, 20(6), 967-989. https://doi.org/10.1007/s11027-014-9629-5

Lahodiuk, Y. (2018). Decision-tree-js. Retrieved from https://github.com/lagodiuk .

Lasage, R., Veldkamp, T. I. E., De Moel, H., Van, T. C., Phi, H. L., Vellinga, P., & Aerts, J. C. J. H. (2014). Assessment of the effectiveness of flood adaptation strategies for HCMC. Natural Hazards and Earth System Sciences, 14(6), 1441. https://doi.org/10.5194/nhess-14-1441-2014

Lendering, K. T., Jonkman, S. N., & Kok, M. (2016). Effectiveness of emergency measures for flood prevention. Journal of Flood Risk Management, 9(4), 320-334. https://doi.org/10.1111/jfr3.12185

Lynch, P., Presnail, M., Shillcox, J., Lokkesmoe, K. (2018). Minnesota's Flood Hazard Mitigation Grant Assistance Program. Retrieved from https://www.leg.state.mn.us/docs/2018/other/180969.pdf

NAI. (2014). How-to Guide for Infrastructure. Retrieved from https://asfpm-library.s3-us-west-2.amazonaws.com/FSC/NAI/ASFPM_NAI_Infrastructure_2016.pdf

National Research Council. (2013). Levees and the national flood insurance program: improving policies and practices. National Academies Press. http://www.nationalacademies.org/

NC Floodplain Mapping Program. (2021). The Flood Risk Information System. Retrieved from https://flood.nc.gov/ncflood/index.html .

NOAA. (n.d.). Weather Related Fatality and Injury Statistics. Retrieved from https://www.weather.gov/hazstat/.

NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2020). https://www.ncdc.noaa.gov/billions , DOI: 10.25921/stkw-7w73.

Oubennaceur, K., Chokmani, K., Nastev, M., Lhissou, R., & El Alem, A. (2019). Flood risk mapping for direct damage to residential buildings in Quebec, Canada. International journal of disaster risk reduction, 33, 44-54. https://doi.org/10.1016/j.ijdrr.2018.09.007

Owusu, S., Wright, G., & Arthur, S. (2015). Public attitudes towards flooding and property-level flood protection measures. Natural Hazards, 77(3), 1963-1978. https://doi.org/10.1007/s11069-015-1686-x

Patel, D. P., & Dholakia, M. B. (2010). Feasible structural and non-structural measures to minimize effect of flood in Lower Tapi Basin. WSEAS Trans Fluid Mech, 3, 104-121.

Peri,C., Rosoff,S., Yager,J.(2017). Population in the U.S. Floodplains. Retrieved from https://furmancenter.org/files/Floodplain_PopulationBrief_12DEC2017.pdf

Pilon, P. J. (2002). Guidelines for reducing flood losses. United Nations International Strategy for Disaster Reduction (UNISDR). https://www.undrr.org/

Poussin, J. K., Botzen, W. J. W., & Aerts, J. C. J. H. (2015). Effectiveness of flood damage mitigation measures: Empirical evidence from French flood disasters. Global Environmental Change, 31, 74–84. https://doi.org/10.1016/j.gloenvcha.2014.12.007

Quinlan, J. R. (1986). Induction of decision trees. Machine learning, 1(1), 81-106. https://doi.org/10.1007/BF00116251

Quintero, F., Mantilla, R., Anderson, C., Claman, D., & Krajewski, W. (2018). Assessment of changes in flood frequency due to the effects of climate change: Implications for engineering design. Hydrology, 5(1), 19. https://doi.org/10.3390/hydrology5010019

Richards, J., White, I., & Carter, J. (2008). Local planning practice and flood risk management in England: is there a collective implementation deficit? Urban Environment, 2, 11-20. https://doi.org/10.7202/019218ar

Rosoff,S., Yager,J. (2017). Housing in the U.S. Floodplains. Retrieved from https://furmancenter.org/files/NYUFurmanCenter_HousingInTheFloodplain_May2017.pdf

Röthlisberger, V., Zischg, A. P., & Keiler, M. (2017). Identifying spatial clusters of flood exposure to support decision making in risk management. Science of the total environment, 598, 593-603. https://doi.org/10.1016/j.scitotenv.2017.03.216

Sahebjamnia, N., Torabi, S. A., & Mansouri, S. A. (2017). A hybrid decision support system for managing humanitarian relief chains. Decision Support Systems, 95, 12-26. https://doi.org/10.1016/j.dss.2016.11.006

Sermet, Y., Demir, I., & Muste, M. (2020). A serious gaming framework for decision support on hydrological hazards. Science of The Total Environment, 728, 138895. https://doi.org/10.1016/j.scitotenv.2020.138895

Silver Jackets. (2016). Non-Structural Landuse Change Impacts on Structure Losses in Cedar River Communities. Retrieved from https://silverjackets.nfrmp.us/Portals/0/doc/Iowa/FY14_IA_NSM_Pilot_CedarCommun_Report_Final.pdf.

Sit, M., Sermet, Y., & Demir, I. (2019). Optimized watershed delineation library for server-side and client-side web applications. Open Geospatial Data, Software and Standards, 4(1), 1-10. https://doi.org/10.1186/s40965-019-0068-9

Southern Tier Central Regional Planning and Development Board. (2019). Selecting Floodproofing Techniques – Technical Considerations. Retrieved from https://www.stcplanning.org/wp-content/uploads/2020/09/FProof_09_Technical_Considerations.pdf

Sowmya, K., John, C. M., & Shrivasthava, N. K. (2015). Urban flood vulnerability zoning of Cochin City, southwest coast of India, using remote sensing and GIS. Natural Hazards, 75(2), 1271-1286. https://doi.org/10.1007/s11069-014-1372-4

Stanke, C., Murray, V., Amlôt, R., Nurse, J., & Williams, R. (2012). The effects of flooding on mental health: Outcomes and recommendations from a review of the literature. PLoS currents, 4. https://dx.doi.org/10.1371%2F4f9f1fa9c3cae

Tate, E., Strong, A., Kraus, T., & Xiong, H. (2016). Flood recovery and property acquisition in Cedar Rapids, Iowa. Natural Hazards, 80(3), 2055-2079. https://doi.org/10.1007/s11069-015-2060-8

Teague, A., Sermet, Y., Demir, I., & Muste, M. (2021). A collaborative serious game for water resources planning and hazard mitigation. International Journal of Disaster Risk Reduction, 53, 101977. https://doi.org/10.1016/j.ijdrr.2020.101977

Tellman, B., Schank, C., Schwarz, B., Howe, P. D., & de Sherbinin, A. (2020). Using Disaster Outcomes to Validate Components of Social Vulnerability to Floods: Flood Deaths and Property Damage across the USA. Sustainability, 12(15), 6006. https://doi.org/10.3390/su12156006

The US Inflation Calculator. (2020). Inflation Calculator. Retrieved from https://www.usinflationcalculator.com/.

Thieken, A. H., Ackermann, V., Elmer, F., Kreibich, H., Kuhlmann, B., Kunert, U., ... & Schwarz, J. (2009). Methods for the evaluation of direct and indirect flood losses. In RIMAX Contributions at the 4th International Symposium on Flood Defence (ISFD4). Deutsches GeoForschungsZentrum GFZ. https://gfzpublic.gfz-potsdam.de/pubman/item/item_6063

USACE. (2015). Nonstructural flood risk management: National Nonstructural Committee. Retrieved from https://usace.contentdm.oclc.org/digital/collection/p16021coll11/id/708/ .

USACE. (1998). Flood proofing performance: Successes & failures. Washington, DC: United States Army Corps of Engineers. Retrieved from https://usace.contentdm.oclc.org/digital/collection/p16021coll11/id/357/

Weber, L. J., Muste, M., Bradley, A. A., Amado, A. A., Demir, I., Drake, C. W., ... & Thomas, N. W. (2018). The Iowa Watersheds Project: Iowa's prototype for engaging communities and professionals in watershed hazard mitigation. International journal of river basin management, 16(3), 315-328. https://doi.org/10.1080/15715124.2017.1387127

Wong-Parodi, G., Fischhoff, B., & Strauss, B. (2018). Effect of risk and protective decision aids on flood preparation in vulnerable communities. Weather, climate, and society, 10(3), 401-417. https://doi.org/10.1175/WCAS-D-17-0069.1

Xu, H., Windsor, M., Muste, M., & Demir, I. (2020). A web-based decision support system for collaborative mitigation of multiple water-related hazards using serious gaming. Journal of environmental management, 255, 109887. https://doi.org/10.1016/j.jenvman.2019.109887

Yildirim, E., (2017). Hazus-MH flood loss estimation on a Web-based system. Master's Thesis. University of Iowa.

Yildirim, E., & Demir, I. (2019). An integrated web framework for HAZUS-MH flood loss estimation analysis. Natural Hazards, 99(1), 275-286. https://doi.org/10.1007/s11069-019-03738-6

Yildirim, E., & Demir, I. (2021). An Integrated Flood Risk Assessment and Mitigation Framework: A Case Study for Middle Cedar River Basin, Iowa, US. International Journal of Disaster Risk Reduction, 56, 102113. https://doi.org/10.1016/j.ijdrr.2021.102113

Zhang, W., Villarini, G., Vecchi, G. A., & Smith, J. A. (2018). Urbanization exacerbated the rainfall and flooding caused by hurricane Harvey in Houston. Nature, 563(7731), 384-388. https://doi.org/10.1038/s41586-018-0676-z

Zhang, W., & Villarini, G. (2021). Greenhouse gases drove the increasing trends in spring precipitation across the central USA. Philosophical Transactions of the Royal Society A, 379(2195), 20190553. https://doi.org/10.1098/rsta.2019.0553

Appendix 1. Flood Mitigation Measures

Measure	Design Level	Construction Type	Existing Foundation	Cost[1]	Cost Adjusted (2020)[2]
Floodwater Avoidance					
Elevation add $1.60/sq. ft for each additional foot of elevation.	2ft	frame	Basement or Crawlspace	29/sq. ft	35/sq. ft
	4ft	frame	Basement or Crawlspace	32/sq. ft	38.65/sq. ft
	8ft	frame	Basement or Crawlspace	37/sq. ft	44.69/sq. ft
	2ft	frame	Slab-on-Grade	80/sq. ft	96.62/sq. ft
	4ft	frame	Slab-on-Grade	83/sq. ft	100.24/sq. ft
	8ft	frame	Slab-on-Grade	88/sq. ft	106.28/sq. ft
	2ft	masonry	Basement or Crawlspace	60/sq. ft	72.46/sq. ft
	4ft	masonry	Basement or Crawlspace	63/sq. ft	76.09/sq. ft
	8ft	masonry	Basement or Crawlspace	68/sq. ft	82.13/sq. ft
	2ft	masonry	Slab-on-Grade	88/sq. ft	106.28/sq. ft
	4ft	masonry	Slab-on-Grade	91/sq. ft	109.9/sq. ft
	8ft	masonry	Slab-on-Grade	96/sq. ft	115.94/sq. ft
Relocation costs include: disconnect the home from its foundation, moving and installing the home at a new location and connecting all utilities.	N/A	frame	Basement	67/sq. ft	80.92/sq. ft
	N/A	frame	Crawlspace	58/sq. ft	70/sq. ft
	N/A	frame	Slab-on-Grade	99/sq. ft	119.56/sq. ft
	N/A	masonry	Basement	96/sq. ft	115.94/sq. ft
	N/A	masonry	Crawlspace	67/sq. ft	80.92/sq. ft
	N/A	masonry	Slab-on-Grade	116/sq. ft	140/sq. ft
Reconstruction Costs include: Demolition the home and rebuild it on the same site.	elevated 2-4ft	frame	closed foundation	110/sq. ft	132.85/sq. ft
	elevated 10 ft	frame	closed foundation	129/sq. ft	155.8/sq. ft
	elevated 2-4ft	frame	open foundation	119/sq. ft	143.72/sq. ft

	elevated 10 ft	frame	open foundation	125/sq. ft	150.97/sq. ft
Allowance of floodwater					
Wet Floodproofing	2ft from basement floor	Frame or Masonry	Basement	$2.9/sq. ft	$3.50/sq. ft
Costs include: Openings Pumps Utility relocation	2ft from the lowest adjacent grade	Frame or Masonry	Crawlspace	$2.204/sq. ft	$2.66/sq. ft
	4ft from basement floor	Frame or Masonry	Basement	$6/sq. ft	$7.25/sq. ft
	4ft from the lowest adjacent grade	Frame or Masonry	Crawlspace	$5.608/sq. ft	$6.76/sq. ft
	8ft from basement floor	Frame or Masonry	Basement	$17/sq. ft	$20.50/sq. ft
	8ft from the lowest adjacent grade	Frame or Masonry	Crawlspace	**N/A**	**N/A**
Waterflood Exclusion					
Dry Floodproofing					
Sprayed-on Cement (above grade)	3 ft	**N/A**	**N/A**	$16.80/Linear Foot of Wall Covered	$20.30/Linear Foot of Wall Covered
Waterproof Membrane (above grade)	3 ft	**N/A**	**N/A**	$5.70/Linear Foot of Wall Covered	$6.88/Linear Foot of Wall Covered
Asphalt (two coats on foundation up to 2 feet below grade)	3 ft	**N/A**	**N/A**	$12/Linear Foot of Wall Covered	$14.50/Linear Foot of Wall Covered
Drainage Line Around Perimeter of House	3 ft	**N/A**	**N/A**	$31/Linear Foot	$37.44/Linear Foot
Plumbing Check Valve	3 ft	**N/A**	**N/A**	$1,060/Each	$1.280/Each

Sump and Sump Pump (with backup battery)	3 ft	**N/A**	**N/A**	$1,710/Lump Sum	$2065/Lump Sum
Metal Flood Shield	3 ft	**N/A**	**N/A**	$375/Linear Foot of Shield Surface	$452.90/Linear Foot of Shield Surface
Wood Flood Shield	3 ft	**N/A**	**N/A**	$117/Linear Foot of Shield Surface	$141.30/Linear Foot of Shield Surface
Sandbag 1 ft height (6 bags)[4]	3 ft	**N/A**	**N/A**	$30/linear foot (bag =$5)[5]	$33/linear foot (bag =$5.50)
Levee	2 ft	**N/A**	**N/A**	$63/Linear Foot	$76.09/Linear Foot
Levee	4 ft	**N/A**	**N/A**	$118/Linear Foot	$142.50/Linear Foot
Levee	6 ft	**N/A**	**N/A**	$197/Linear Foot	$237.92/Linear Foot
Floodwall	2 ft	**N/A**	**N/A**	$145/Linear Foot	$175.12/Linear Foot
Floodwall	4 ft	**N/A**	**N/A**	$212/Linear Foot	$256/Linear Foot
Levees and Floodwalls	Interior Drainage System	**N/A**	**N/A**	$7200/Lump Sum	$8695/Lump Sum
[1] FEMA (2009) [2] US Inflation Calculator (2020) [3] FEMA (1998) [4] Heckman (2020) [5] Aerts (2018)					

Appendix 2. *Flood Mitigation Guidelines*

Feature	Description	Elevation						Relocation	Wet-floodproofing	Dry-floodproofing	Levee	Floodwall
		On Extend Foundation	On Piers	On Posts	On Columns	On Piles	On Fill compacted					
Protection level[1,2,3,4,5]	Up to 3 ft											
	Up to 6 ft									X		
	Up to 12									X	X	X
Flood velocity[1,3,4,5]	Less than 2 mph											
	2 -6 mph	X							X	X	X	
	More than 6 mph	X		X	X		X		X	X	X	X
Flood duration[2,6]	Less than one day											
	More than one day								X	X	X	
Flood with debris/Ice flow[1,4,5]	Yes	X		X	X				X	X		
	No											
Site location[1,3,4,5]	Riverine											
	Beach	X	X	X	X		X		X	X	X	X
Soil Type[1,3,4,5]	Permeable									X	X	
	Impermeable											
Existing Foundation [1,3,4,5]	Slab on Grade											
	Crawlspace or Basement	X	X	X	X	X				X		
Building condition[1,3,4,5]	Excellent to good											
	Fair to poor	X	X	X	X	X	X	X	X	X		
Life span[2,6]	Up to 20											
	Up to 30									X		
	Up to 50									X	X	
	Yes									X	X	X	X

Premium Insurance reduction[1,5]	No												

[1]USACE (2019) [2]FEMA (2015) [3]FEMA (2007) [4]Southern Tier Central Regional Planning and Development Board (2019) [5]USACE (2015) [6]FEMA (2009)