ABSTRACT

Title of Dissertation: PROPOSING A REALISTIC INTERACTIVE VISUALIZATION MODEL AND TESTING ITS EFFECTIVENESS IN COMMUNICATING FLOOD RISK

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This project advances the field of flood risk management by using technology to bridge the gap between science and local community decision-making. Currently, flood risk management meetings use a computer-assisted decision support system (DSS) to illustrate various flood scenarios and facilitate collaborative discussions among participants. The DSS is a set of sophisticated models structured by geographic information systems (GIS) technicians.

This study proposed a “stakeholder-built” DSS. Stakeholders are defined here as those directly at risk of flooding. This method utilized improved user interface capabilities while retaining the technical rigor and robustness of a Nationally-recognized GIS software package. There are times when a simple model may serve as an introduction to GIS technology. There are also situations where the cost of the sophisticated models may place them out of reach. The stakeholder-built DSS was

proposed as a compliment to the sophisticated models by providing greater access to a DSS for end-users.

The stakeholder-built DSS, in which stakeholders construct their own models, uses realistic interactive visualization as a learning tool. Realistic visualization represents information using virtual reality. The intent is to trigger awareness of risk through emotional response to images. Stakeholders use interactive visualization when constructing the model. Awareness of the flood scenario is enhanced by the constant attention required of the model-builder as they make connections between hand-eye coordinated motions and the cognitive information they are modeling. Knowledge accumulates as multiple steps are completed.

The effectiveness of the stakeholder-built DSS was tested during community flood risk management meetings in Federal Emergency Management Agency Region III, the mid-Atlantic area. A DSS based on a Nationally-recognized GIS software package was also tested to serve as a comparison. Data were collected in pre- and post-surveys and follow-up interviews.

The stakeholder-built and national GIS software DSS both performed equally well in communicating knowledge of flood risk and risk-reduction options, resulting in significant learning outcomes. To maximize the intent by stakeholders to take actions to reduce risk, meetings using the stakeholder-built DSS in high-quality meeting facilities performed best. In addition, the stakeholder-built model was less expensive and found to be more user-friendly for stakeholders.

PROPOSING A REALISTIC INTERACTIVE VISUALIZATION MODEL AND TESTING ITS EFFECTIVENESS IN COMMUNICATING FLOOD RISK

by

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Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2014

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Dedications

Hiller Olsen, Ucheoma Akobundu and Brant Olsen for all their moral support and Lieutenant Robert P. Mueck of the University of Maryland College Park (UMCP) Department of Public Safety Police Services Bureau for keeping me alive through a rough first semester at UMCP.

Acknowledgements

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Funding provided by:

U.S. Army Corps Engineers Institute for Water Resources (IWR) and the National Institute for Water Resources (NIWR) Grant, U.S. Geological Survey Award No. G12AP20058. “The Effectiveness of a Computer-Assisted Decision Support System using Realistic Interactive Visualization as a Learning Tool in Flood Risk Management” March 1, 2012 – November 30, 2014.

Maryland Water Resources Research Center Grant No. 2012MD270B. “An Innovative Learning Tool in Communicating Flood Risk Management” January 2, 2012 – June 12, 2014.

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Abbreviations

BFE - base flood elevation as recommended by Federal Emergency Management Agency National Flood Insurance Program floodplain management requirements

DEM - United States Geological Survey Digital Elevation Model

DFIRM – Federal Emergency Management Agency digital Flood Insurance Risk Maps

DSS – computer-assisted decision support system

ESRI ArcGIS - geographic information systems software designed by Environmental Systems Research Institute, Inc.

FEMA – Federal Emergency Management Agency

FIRM – Federal Emergency Management Agency Flood Insurance Risk Maps

GIS – geographic information systems

HVAC - heating, ventilation, and air conditioning systems

HAZUS – Federal Emergency Management Agency Multi-hazard Loss Estimation Methodology

HUC – United States Geological Survey unique hydrologic unit code

IPCC - Intergovernmental Panel on Climate Change

IRB - Institutional Review Board

KML - Keyhole markup language file

KMZ - Keyhole markup language zipped file

MCCC - Maryland Commission on Climate Change

NED - United States Geological Survey National Elevation Dataset

NFHL – Federal Emergency Management Agency National Flood Hazard Layer

NFIP – Federal Emergency Management Agency National Flood Insurance Program

NOAA – National Oceanic and Atmospheric Administration

NOS - National Oceanic and Atmospheric Administration National Ocean Service gauge stations

NSF - National Science Foundation

NSTC – United States National Science and Technology Council

SAS - Statistic Analysis System software

SLOSH - National Oceanic and Atmospheric Administration Sea, Lake and Overland Surges from Hurricanes model

SWAN – National Oceanic and Atmospheric Administration Simulating Waves Near-shore model

TIGER – United States Census Bureau Topologically Integrated Geographic Encoding and Referencing files

USCB - United States Census Bureau

USGS - United States Geological Survey

Chapter I: Introduction

Defining disaster

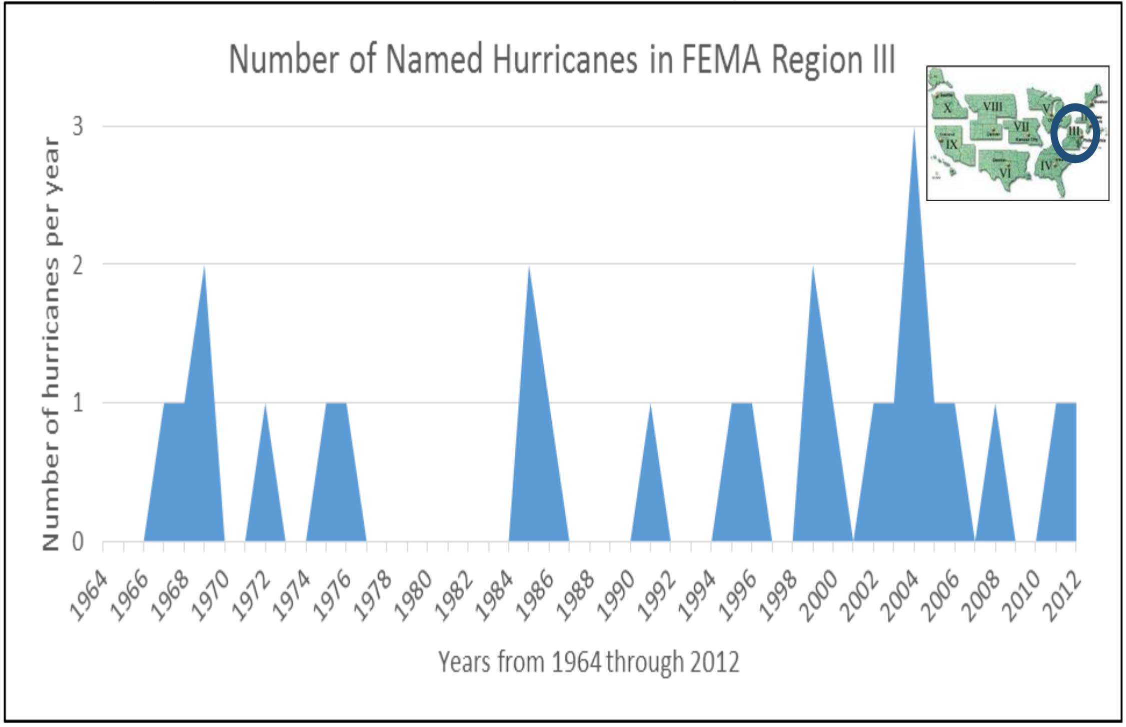
Typhoon Haiyan, which hit the Philippines in 2013 is an example of the devastation that results when a natural hazard clashes with human populations. A natural process becomes a disaster when it affects lives and property (Berke and Beatley 1997, Ibarrarian and Ruth 2009). Floods cause deaths, strain medical facilities, destroy property, and disrupt commerce for those that remain in harm's way (IPCC 2014). Coastal populations have always been at risk, but sea level rise and increases in frequency of extreme precipitation events resulting from climate change as well as an increase in the density of human populations in coastal areas means many are at greater risk (IPCC 2014).

This research focused on communication of flood risk in order to reduce exposure in the U.S. Federal Emergency Management Agency (FEMA) Region III. This is the mid-Atlantic region of the United States encompassing Washington, D.C. and the states of Delaware, Maryland, Pennsylvania, Virginia and West Virginia (Figure 1).

Figure 1: Map of the Federal Emergency Management Agency Regions: Region III circled (FEMA 2014c)

This region is not generally associated with hurricanes, yet within the past 50 years, FEMA Region III experienced direct hits that included Hurricanes Isabel in 2003, and Irene in 2011(NOAA 2014) (Figure 2). All resulted in flooding in areas predicted to have less than or equal to a 1% chance of flooding per year, often referred to as “100-year floods” (FEMA 2010c). These floods are usually caused by an extreme precipitation event that has a low frequency of occurrence, but when it does occur, it inundates a large portion of the area (Hayes 2011).

Figure 2: Federal Emergency Management Agency Region III named hurricanes within the past 50 years (NOAA 2014) with inserted map of Region III (FEMA 2014c)



FEMA Region III is projected to experience sea level rise, resulting in higher tides and higher storm surges. Precipitation is projected to increase during the winter but become more episodic overall with more intense winter snow and rain events occurring (Boesch, Atkinson et al. 2013, IPCC 2014). Larger early spring riverine flooding is also anticipated, fueled by the first large rain storms in early spring that result in large-volume runoff due to the combination of heavy rainfall and snow melt (Boesch, Atkinson et al. 2013). Summers are expected to experience more episodic precipitation events, with prolonged droughts in between tropical downpours (Griffin, Boesch et al. 2010, Boesch, Atkinson et al. 2013, IPCC 2013, IPCC 2014).

Risk communication

Reducing exposure may be approached at three stages: increasing preparedness before, improving resistance during, and increasing resilience following an event

(Pulwarty and Riebsame 1997, FEMA 1999, Burby 2001, Cockerill, Tidwell et al. 2004, NSTC 2005, IPET 2009, Malone and Brenkert 2009). In 2007, the National Science Foundation National Science Board rated "investment in human behavior and risk planning with regard to preparedness and response measures" as a high priority within its "Research Imperatives." The Board stated that, "Research is needed to identify methods and tools for increasing the likelihood that people, businesses, and communities fully understand and appropriately consider risks when planning homes, facilities and communities. . ." (NSF 2007). Risk communication professionals need to ensure that knowledge is transferred from the scientific community to stakeholders using the most effective method of communication available. Stakeholders, as defined here, are individuals or a group affected by past and/or potential flooding directly or indirectly through physical injury or illness, loss of life, loss of personal income and/or property, or reduced efficiency in job performance.

Information presented in brochures and on websites is an inexpensive means of disseminating information because it is not labor-intensive. However, it requires initiative on the part of stakeholders to seek out the information. Lecture-style teaching places information delivery on the lecturer, increasing the likelihood that stakeholders will receive it (Mayberry, Crocker et al. 2009), but this method is found to be limited in its effectiveness (Holling 1995, D'Avanzo 2003, Stieff and Wilensky 2003, Handelsman, Ebert-May et al. 2004, Vogel, Vogel et al. 2006, Dino and Wayne 2007, Devetak, Hajzeri et al. 2010). Conversely, collaborative learning in which information is disseminated using a method that emphasizes stakeholder-centered problem-solving teams with a facilitator to guide the discussions has been effective in a number of studies (Holling

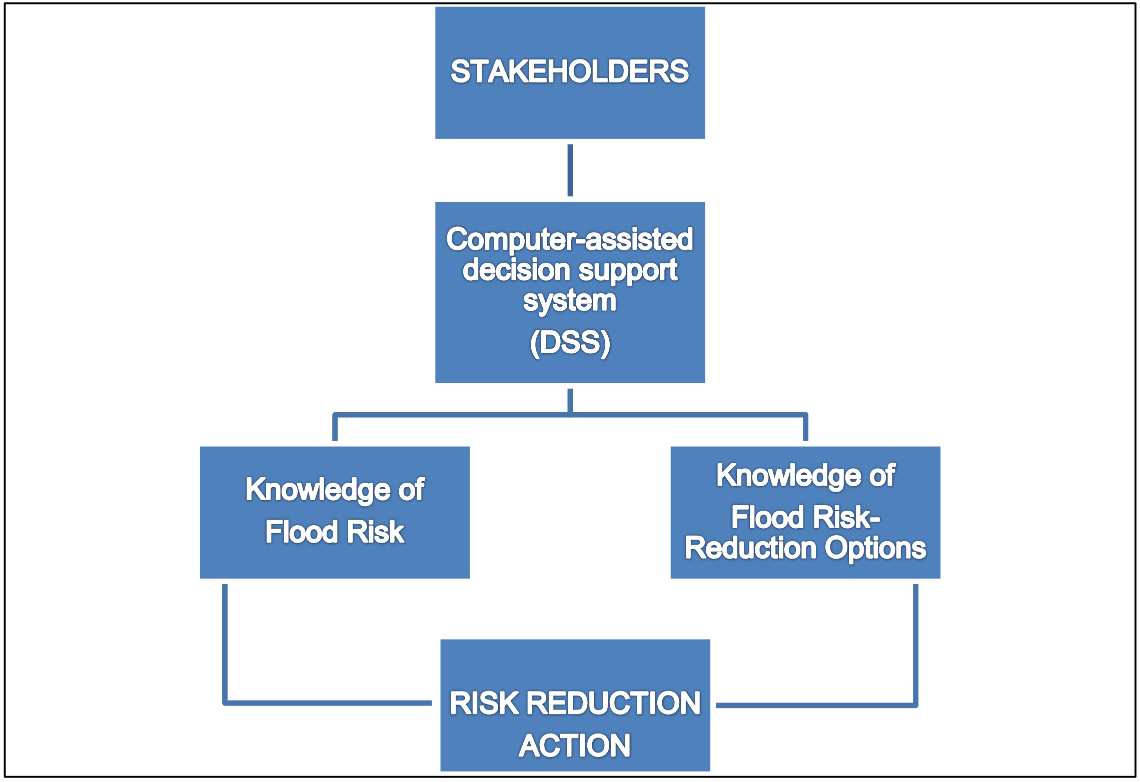
1995, D'Avanzo 2003, Handelsman, Ebert-May et al. 2004, Tanner and Allen 2004, van den Belt 2004, Allen and Tanner 2005, Beall 2007, Suarez, Ribot et al. 2009, Maskiewicz 2010). Collaborative learning allows stakeholders to formulate their own set of questions, emphasizing their personal wants and needs related to flood risk (Michael 1995, Beall 2007, Langsdale 2007). Using a computer-assisted decision support system (DSS) increases the effectiveness of collaborative learning (Costanza and Ruth 1998, Goran, Holland et al. 1999, van den Belt 2000, Bullinger, Ziegler et al. 2002, Seely, Nelson et al. 2004, van den Belt 2004, Sheppard and Meitner 2005, Cockerill, Passell et al. 2006, Beall 2007, Cockerill, Tidwell et al. 2007, Langsdale 2007, Finan and Nelson 2009, Ploetzner, Lippitsch et al. 2009, Stave 2010, Schwamborn, Thillmann et al. 2011). The DSS plays the dual role of information manager and conflict-resolution facilitator. (van den Belt 2000, Seely, Nelson et al. 2004, van den Belt 2004, Muggleton 2006, Szalay 2006, IWR 2009). The DSS is used as a tool to store and integrate data and present management scenarios and alternatives visually, usually in a geographic information systems (GIS) format. The DSS computer model can quickly and easily handle the iterative decision-making process that allows stakeholders to run a series of "practice decisions." These scenarios facilitate brain-storming sessions and promote understanding of the consequences of a variety of choices through visual computer screen displays.

The other interesting role the DSS plays is that of conflict-resolution facilitator. Different stakeholder groups often come to the table with preconceived ideas associated with a water resource issue, the benefits and costs from their isolated perspective, and fixed solutions they plan to promote (Francis and Regier 1995, Jansson and Velner 1995, Lee 1995, Light, Gunderson et al. 1995, van den Belt 2000, van den Belt 2004, IWR

2009). DSS strategies bring stakeholders into the process of assessing risk when decision-making begins. The disadvantage of this approach is that early involvement of so many stakeholders slows the initial process (van den Belt 2000). The advantage is that conflict resolution and consensus-building are introduced early in the planning process when the plan design is most flexible and can most easily take these issues into consideration. This increases the chance the plan will be accepted in the final stage by all stakeholder groups (van den Belt 2004). As participants share their ideas for solutions, conflicts may arise. These conflicts may result from false assumptions about how the physical system works or may be caused by differences in values or interests (Gunderson, Hollings et al. 1995, Davis 1999, D'Avanzo 2003, Seely, Nelson et al. 2004, Finan and Nelson 2009, Devetak, Hajzeri et al. 2010). Actively engaging the participants in model development allows them to test their assumptions and helps to reduce conflicts based on misinformation. By focusing attention on delivering ideas through the DSS, conflicts take on a less personal approach. The computer simulations of various scenarios under different decision-making criteria allow all participants to visually observe the mutual consequences. This can reduce misconceptions about the distribution of costs and benefits among stakeholders and build empathy among groups. Through this learning process, stakeholders are given the opportunity to broaden their perspectives, which can facilitate consensus-building among groups with diverse interests. The collaboration between groups from the very beginning of the process to its completion, and the transparency throughout the process, builds trust among stakeholders and trust in the government agency and the official policymakers overseeing the project. (van den Belt 2004, IWR 2009)

This communication framework (Figure 3) delivers information about flood risk and risk-reduction options to stakeholders with the intention of initiating action on their part to reduce flood risk in their community as a whole and in their individual circumstances.

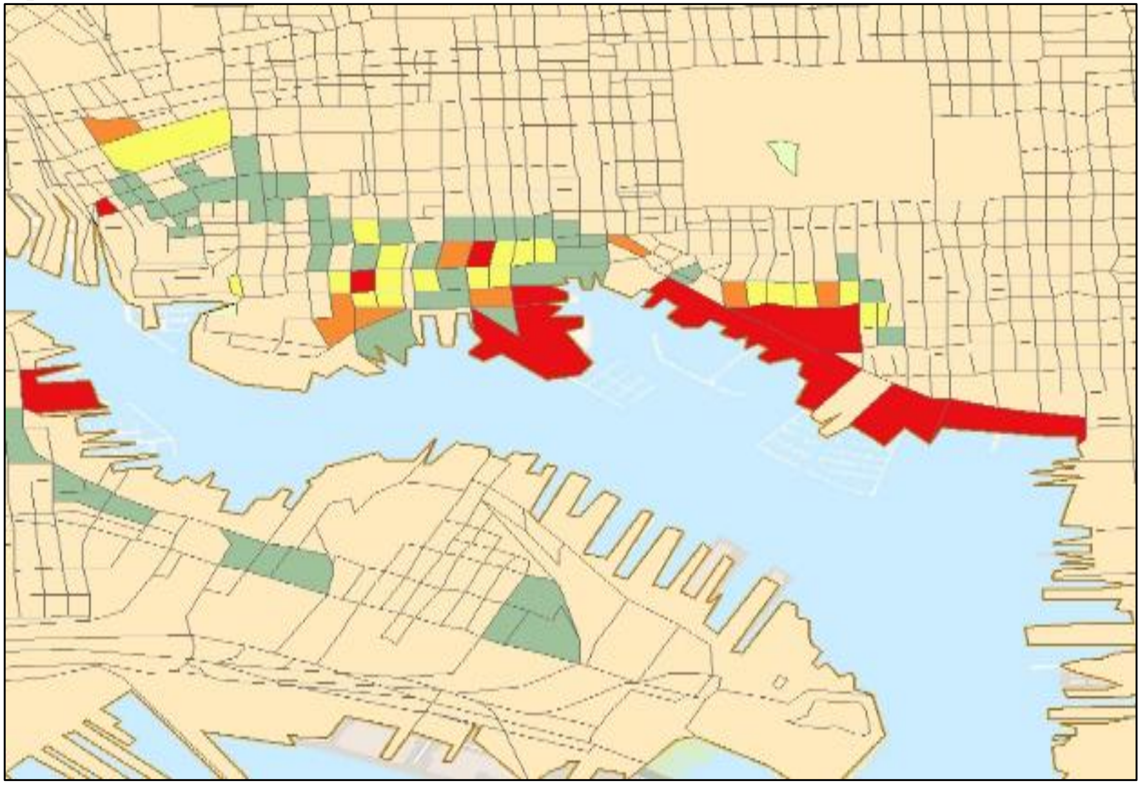
Figure 3: Communication framework for flood risk management meetings



Decision support systems

Currently, most computer-assisted decision support systems (DSS) are sophisticated dynamic computer models structured by a trained geographic information systems (GIS) technician in response to requests from stakeholders and meeting facilitators during decision-making sessions (Beall 2007). The DSS illustrates various flood scenarios and facilitates collaborative discussions among participants. The complexity of the data linkages and relationships are beyond the ability of humans to handle efficiently without the assistance of the high storage-capacity and computational speed of modern computers (Costanza and Greer 1995, Light, Gunderson et al. 1995, van den Belt 2000, Seely, Nelson et al. 2004, van den Belt 2004, Muggleton 2006, Szalay 2006, IWR 2009). An example is the nationally-recognized Multi-hazard Loss Estimation Methodology (HAZUS) designed for the Federal Emergency Management Agency (FEMA) by the National Institute of Building Sciences (Figure 4). HAZUS represents the gold standard in a flood risk management DSS. It is presently used by both FEMA and the U.S. Army Corps of Engineers. This set of dynamic models, based on Environmental Systems Research Institute, Inc. (ESRI) ArcGIS^{TM} software (ESRI 2012), is designed to predict losses due to major hazards, including flooding, for the purposes of risk-management planning at the regional level (FEMA 2009). In HAZUS, current scientific and engineering knowledge is coupled with the latest GIS technology to produce estimates of hazard-related damage before, or after, a disaster occurs (FEMA 2009). Technical manuals supply a detailed description of each component in the model, including equations used to describe each element of the system's behavior and the relative probability that the data accurately predicts that behavior (FEMA 2009). The metadata used in making decisions as to what components to include and how to characterize them is also described (FEMA 2009). GIS technicians can substitute local data to customize a regional HAZUS model to more accurately represent smaller geographical areas (FEMA 2009, McCoy 2013, Bollinger 2013b). The set of HAZUS models used in this research, hereafter referred to as the national GIS software DSS method, model flood risk scenarios at the community level (Figure 4).

Figure 4: A Multi-hazard Loss Estimation Methodology (HAZUS) model customized to show flooding potential at the local community level. Red polygons represented highest risk. Orange, yellow and green represented lower risk, in that order. The tan area represented areas where data were not available.



Sophisticated technician-structured modeling software programs such as HAZUS are capable of accurately illustrating a wide range of flood scenarios for a variety of purposes. However, when communicating flood risk information to those unfamiliar with GIS technology, the sophistication of these models may be intimidating. Simple models with a small learning-curve can enhance the transfer of subject knowledge (Bullinger, Ziegler et al. 2002, Hegarty 2004, Chandler 2009, Ploetzner, Lippitsch et al. 2009, Schwamborn, Thillmann et al. 2011). However, the user-friendly model must retain the technical rigor and robustness of HAZUS to ensure accurate representation of science-based flood scenarios.

There are also situations where the cost of the sophisticated models may place them out of reach for end-users, the stakeholders in flood risk management. The HAZUS software is offered free-of-charge through the FEMA online library (FEMA 2014b). However, the ESRI ArcGIS™ software needed to run HAZUS (ESRI 2012) is expensive. Both HAZUS and ESRI ArcGIS™ require high-capacity laptop computers to run the software. Since most stakeholders do not have GIS training, the sophisticated models require employing a GIS technician to manipulate the visual scenarios. The GIS experts add high cost due to salary and time for developing community-specific models. The requirements of expensive hardware and software as well as GIS-trained technicians to run the DSS can be a barrier to use as a flood risk communication tool for end-users.

To address these concerns, a simplified DSS method was designed for use in this research. This methodology, referred to as the stakeholder-built DSS, utilized improved user interface capabilities while retaining the technical rigor and robustness of the national GIS software model. This method was proposed as a compliment to the sophisticated models by providing greater access to a DSS for end-users. Time and money could be saved if stakeholders directly participated in constructing and manipulating the computer models on their own equipment, eliminating the need for a GIS technician and high-capacity laptops. For the stakeholder-built DSS to be effective, it was essential that the software be familiar to the user (Vinge 2006). To accomplish this, Google Earth™ maps and drawing tools (GoogleEarth™ 2013) were used. The FEMA "Stay Dry" Google Earth™ application (U.S._State_Department_Geographer, EuropaTechnologies™ et al. 2011, U.S._State_Department_Geographer, EuropaTechnologies™ et al. 2013) and FEMA National Flood Hazard Layer in Keyhole

Markup Language zipped files (FEMA and GoogleEarth™ 2011, FEMA and GoogleEarth™ 2013) provided the technical rigor to ensure accurate representation of science-based flood scenarios.

Google Earth™ is an assemblage of pictures layered one upon another. The stakeholder views these applications as a single interface in Google Earth™. These “maps” are stored and accessed using cloud-computing. Cloud-computing stores large data files and memory-intensive software on a network of servers and allows user-access through a web browser. The use of small blocks of cloud memory is available to noncommercial users free-of-charge. These services are accessible from any electronic device connected to the Internet. In the stakeholder-built DSS method, stakeholders built their own geo-spatial flood risk scenarios using these resources. Computer-savvy stakeholders ran the program on stakeholders' laptops or computer tablets. Computer-savvy stakeholders were individuals who self-identified as familiar with navigating a cursor on Google Earth™ maps and using drawing tools in programs such as MicroSoft PowerPoint™ (Microsoft 2007).

The stakeholder-built DSS method introduced realistic interactive visualization (Bullinger, Ziegler et al. 2002, Lewis, Sheppard et al. 2004, Sheppard 2005, Sheppard and Meitner 2005, Sheppard and Cizek 2009, Kearney and Levine 2014) as part of the learning experience. Realistic visualization, described by Sheppard and Meitner in 2005 (Sheppard and Meitner 2005), represents scientific information using virtual reality scenarios. The intent is to add drama to the scenarios while adhering to representation of accurate scientific information. This DSS method is thought to trigger stakeholder awareness of risk, based primarily on emotional response to the images and secondarily on cognitive absorption of the scientific information presented (Sheppard 2005). Although the emphasis is on the dramatic effects, a meta-study of computer science classroom teaching methods comparing realistic photos and pictures to unrealistic numbers, lines and graphs found that as the realism of a DSS increased, the amount of knowledge gained by learners also increased (Vogel, Vogel et al. 2006). The appeal of Google Earth™ lies in the realism portrayed by the virtual globe (Figure 5).

Figure 5: Google Earth™ image of housing near a Federal Emergency Management Agency flood hazard zone represented by red hatching (GoogleEarth™ and EuropaTechnologies™ 2011)

An additional attribute of the stakeholder-built DSS method is that the stakeholders, by participating directly in the development of their models, are using a method for which there is evidence that learners' understanding of concepts and retention of that information are increased as compared to other methods of communication (Hansen, Narayanan et al. 2000, Vogel, Vogel et al. 2006, Chandler 2009). This direct participation by learners as model-builders is referred to as interactive visualization (Figure 6), a term first coined by Bullinger, et.al in 2002 (Bullinger, Ziegler et al. 2002). This method allows the learner to match the visual representation of the activity to her/his mental representation through awareness, metacognition and reflexive learning in order to improve the individual or group understanding of concepts (Bullinger, Ziegler et al. 2002, Clauzel, Sehaba et al. 2011). Awareness of the scenario being modeled is enhanced by the constant attention required of the model-builder during construction. Metacognition results from the accumulation of knowledge about the scenarios within the memory of the model-builder as multiple steps are completed during model construction. Reflexive learning occurs as the model-builder repeatedly makes neurological connections between hand-eye coordinated motions and the cognitive information about the scenario being modeled.

Figure 6: Stakeholder-built computer-assisted decision support system method showing anticipated future flood risk - Google Earth™ image with the Federal Emergency Management Agency 1% annual flood risk area shown in the blue layer. The yellow line was added by the stakeholder using the Google Earth™ drawing tool guided by Google Earth™ elevation data. This represented anticipated flood risk within the next 50 years. The area below the yellow line represented property expected to experience flooding.

The concept of interactive visualization has been tested in fields outside of flood risk management. For example, in the field of chemistry education, individuals directly participated in modeling the structure of crystals. These students had significantly higher knowledge test scores as compared to those learning from a lecturer presenting the same information using pre-constructed models. This was found to be the case when tested immediately following their learning experience and also in delayed testing (Devetak, Hajzeri et al. 2010). There are at least nine other case studies (Hansen, Narayanan et al. 2000, Hundhausen, Douglas et al. 2002, Stieff and Wilensky 2003, Vogel, Vogel et al. 2006, Chandler 2009, Devetak, Hajzeri et al. 2010, McClintock and Poncelet 2011) and two meta-analyses (Hundhausen, Douglas et al. 2002, Vogel, Vogel et al. 2006) in fields outside of flood risk management that evaluated the effectiveness of interactive visualization. All found the method superior to the presentation of material in the form of pre-constructed models in communicating scientific information to individual participants. Interactive visualization has been tested only on hypothetical problems in situations where it was used to increase the knowledge of individual learners (Hansen, Narayanan et al. 2000, Chandler 2009, Ploetzner, Lippitsch et al. 2009, Clauzel, Sehaba et al. 2011, Schwamborn, Thillmann et al. 2011).

Prior to this research, a DSS that used realistic interactive visualization as a teaching tool in risk management had not been experimentally tested on a regional scale. The goal of the research was to determine if a communication method using realistic interactive visualization and collaborative learning increased stakeholders' scientific literacy in flood risk management and was the method an effective tool for initiating stakeholders' action toward reducing that risk. A DSS based on a nationally-recognized GIS software package was also tested to serve as a comparison. HAZUS was used to represent the state-of-the-art in a national GIS software DSS. Chapter II of this dissertation describes the methods in detail.

Testing the effectiveness of each stage in the communication framework

The pathway connecting stakeholders with the scientific information they need to make informed decisions about taking action to reduce risk must be effective at each stage in the process (Figure 3). Therefore, this research tested the efficacy of each stage in the communication framework:

- Chapter III: Do all demographic sectors of the population have access to information through participation in community-level flood risk management meetings?

- Chapter IV: Does realistic interactive visualization increase knowledge of flood risk communicated to stakeholders?
- Chapter V: Does realistic interactive visualization increase knowledge of flood risk-reduction options communicated to stakeholders?
- Chapter VI: Does realistic interactive visualization increase stakeholders’ intent to take action to reduce flood risk among stakeholders?

Chapter II: Methods

The stakeholder-built computer-assisted decision support system (DSS) that uses realistic interactive visualization was tested and compared alongside a national geographic information systems (GIS) software DSS. This DSS was represented by the Multi-hazard Loss Estimation Methodology (HAZUS) presently used by the Federal Emergency Management Agency (FEMA). In this research, the two models were tested for their effectiveness at communicating flood risk information to end-users, the stakeholders affected by flooding.

Beyond this use, the HAZUS set of models offers a much wider array of applications to GIS technicians and flood management professionals than does the stakeholder-built DSS methodology. Attributes of each method are compared in Table 1.

Table 1: Comparison of attributes of the Multi-hazard Loss Estimation Methodology (HAZUS) and stakeholder-built flood models

HAZUS model (FEMA 2009)	Stakeholder-built model
Accuracy is dependent on the most recent U.S. Census Bureau data and national flood hazard data incorporated into the HAZUS software package.	Accuracy is dependent on the most recent photographs of a community available on Google Earth^{TM} and the most recent U.S. Federal Emergency Management Agency (FEMA) flood zone information entered into the National Flood Hazard Layer (NFHL) keyhole markup language zipped (KMZ) file. The FEMA NFHL KMZ file displays in Google Earth^{TM} as a geographic information systems (GIS) layer in raster format the 1% annual return period for flood events (FEMA 2014d).
The default data resolution is at the regional level. GIS technicians can substitute local data, if available.	The default data resolution for the NFHL KMZ file is at an elevation of less than 4000 feet distance from the “Earth” surface (FEMA 2014d). This is approximately at the community-level. The Google Earth^{TM} images for

	communities where the NFHL is available are at a higher resolution, usually at the individual structure level of clarity.
The HAZUS hurricane simulation methodology models the probable track of a tropical storm in the Atlantic basin. This is based on past storm tracks, within which the hurricane climatology can vary significantly at the resolution of a local community.	This model does not account for the probable track a hurricane may take (FEMA 2014d).
In the HAZUS for Floods model, the hazard analysis characterizes frequency, discharge, and ground elevation to model the spatial variation in flood depth and velocity.	The NFHL KMZ file used as a GIS layer in Google Earth^{TM} is based on FEMA's flood hazard map data and includes the hazard analyses for frequency, discharge, and ground elevation to model the spatial variation in flood depth (FEMA 2014d). Flood velocity is included in the calculations of the extent of flooding predicted due to wave action in the flood zone adjacent to the highest flood hazard zone (FEMA 2014d). These characteristics are visible to users as a single interface illustrated as semi-transparent two-dimensional flood hazard polygons layered over the Google Earth^{TM} images. The NFHL shows the areal extent of flooding based on these calculations.
In the HAZUS hurricane model, the model is capable of providing reasonable rainfall rate predictions in a hurricane. However, the model has limited success estimating the rainfall intensity and location associated with the hurricane.	This model does not predict rainfall rates or rainfall intensity (FEMA 2014d). It does simulate locations of runoff accumulation based on elevation differences near the flood hazard zones.
The HAZUS hurricane model estimates physical damage to residential and commercial buildings, schools, critical facilities, and infrastructure. While the HAZUS model can be used to estimate losses for an individual building, the results are based on an average for a group	This model can be used to estimate the number of buildings and locations of infrastructure such as roads and bridges that will be exposed to flooding that covers the ground at the base of the structures. It shows the areal extent of flooding only and does not estimate the

of similar buildings. Similar buildings have experienced vastly different damage and losses during a hurricane. The building exterior damage cost estimates are based primarily on past flood insurance claims. The interior damage loss estimates are developed primarily on the basis of the experience and judgment of professionals with knowledge of past losses due to floods.	inundation level. Therefore, it cannot be used to calculate physical damage estimates to the exterior or interior of the structures.
The HAZUS for Floods model provides an estimate of aggregated losses such as the total cost of damage and numbers of casualties. HAZUS does not do well at estimating more detailed results, such as the number of buildings or bridges experiencing different degrees of damage, which depend heavily upon accurate inventories not presently available in HAZUS.	Because this model shows only the areal extent of flooding and not inundation levels, it cannot be used to calculate physical damage estimates to the exterior or the interior of the structures (see notes in box above) nor can it be used to estimate numbers of casualties. This model can be used as an initial assessment of places within the community where further investigation of flood risk is advisable.
HAZUS estimates indirect economic losses, including lost jobs, business interruptions, and repair and reconstruction costs.	This model does not estimate indirect economic losses. It can be used to make an initial assessment of whether an area warrants closer investigation into potential flooding impacts. It can be used to show an overview of areas at very low risk of flooding and areas that may experience at least some flooding during precipitation events. It is not designed to function as the final assessment tool when emergency management plans are developed for a community.
HAZUS estimates social impacts, including estimates of shelter requirements, displaced households, and population exposed to flood scenarios.	This model does not estimate social impacts. It can be used to make an initial assessment of whether an area warrants closer investigation into potential flooding impacts (see notes in box above).
The HAZUS hurricane model estimates the decay in intensity of a hurricane, including wind speeds, as it travels across	This methodology does not model hurricane intensity, wind speed or central pressure (FEMA 2014d)

land. It also estimates changes in central pressure based on factors including sea surface temperature, storm heading, and speed.	
HAZUS does not have adequate land-use databases for use in its models. The national data sets that have been available to-date are either very coarse or are substantially out of date and thus have limited use in the HAZUS models.	This model can be used to obtain a rough overview of the type of land-use in and adjacent to the flood hazard zones based on the Google Earth^{TM} images. Accuracy is dependent on how recently the images were photographed.

Table 1 shows the wider range of specific information that can be generated by a trained GIS technician using the HAZUS model. In the stakeholder-built model, the range of specific information available to the user is more limited. The stakeholder-built model has the advantage when engaging end-users, the stakeholders affected by flooding, in that it offers a more realistic image and can be built by those without formal GIS training.

FEMA provides the data for both the HAZUS model (FEMA 2009) and the National Flood Hazard layer (NFHL) used in conjunction with Google Earth^{TM} (FEMA 2014d). The NFHL delineates the 1% annual flood risk presently set by FEMA. To test how closely the delineation of the flood zones matched in the two models, this study compared the location of properties with respect to the hazard zone with a 1% annual risk of flooding using both the HAZUS and stakeholder-built models. This was performed for 97 property addresses within the ten communities that received flood risk management meetings during the study. Properties were located similarly with respect to the floodplain for both models in 76% of the cases. Where differences were found, approximately three-quarters of the properties were located within the flood hazard zone when the stakeholder-built model was used and outside the hazard zone when the

HAZUS model was used. One community showed opposite results for the location of all property addresses with respect to the flood hazard zone in each model. This community was one of five located in a tidal bay area near the mouth of a large river where the terrain consisted of low-elevation and the natural habitat consisted primarily of marsh vegetation. The HAZUS model protocol appropriate for this terrain is a combined coastal and riverine model (Appendix 1). However, while the other four tidal bay communities in this study were modeled using the combined coastal-riverine model protocol, this particular community was not recognized by the HAZUS model as a coastal area. Therefore, a riverine hydrological model was the only choice available for modeling flooding in HAZUS. In the stakeholder-built model the FEMA NFHL recognized the community as coastal and mapped the flood hazard zone accordingly. If this community is considered an outlier, the property locations for the other nine communities have an 83% match between the HAZUS and stakeholder-built models. With this outlier removed, where differences were found, roughly half of the properties were located within the flood hazard zone when the stakeholder-built model was used and outside the hazard zone when the HAZUS model was used, and vice versa.

Experimental design

The computer-assisted decision support system (DSS) methods, the stakeholder-built and the national geographic information systems (GIS) software DSS represented by the Multi-hazard Loss Estimation Methodology (HAZUS), were tested at local community flood risk management meetings in ten randomly-selected communities in the Federal Emergency Management Agency (FEMA) Region III (Figure 1). Their effectiveness at communicating to stakeholders (1) knowledge of flood risk; (2)

knowledge of risk-reduction options; and (3) intention to implement risk-reduction actions were measured.

Each flood risk management meeting was two hours in duration. At each, the research project was introduced and three scenarios, past, present, and future flood risk, were modeled. Following discussions among the participants about their flood risk, risk-reduction options were introduced and a discussion of the costs and benefits of implementing these options was facilitated by the lead researcher.

In the meetings, past flood risk was represented by a recent flood event that most participants would remember. The historic flood event was chosen based on exploratory interviews with key community leaders conducted prior to the meeting (Appendix 5). This historic flood scenario was designed to encourage confidence in the models. If the model illustrated flooding the participants remembered in the past, it was reasoned they would trust the model when probabilistic flood predictions for the future were introduced. Instructions for building the national GIS software model of a past flood are provided in Appendix 1 with an example illustrated in Figure 8A. Instructions for constructing the stakeholder-built model of a past flood event are provided in Figure 7 with an example illustrated in Figure 8B. In the instructions for the stakeholder-built model, steps 7 and 8 (Figure 7) refer to U.S. Geological Survey stream or U.S. National Oceanic and Atmospheric Administration tidal gauges used to estimate the flood stage in the community during the historic storm. Details on how these gauge readings were obtained and applied in the flood risk management meetings using the stakeholder-built DSS method are located in Appendix 2.

Figure 7: Instructions for the stakeholder-built computer-assisted decision support system model of an historic (past) flood event. These instructions were used by the geographic information systems technicians to build the model in advance of the community flood risk management meeting.

INSTRUCTIONS FOR THE STAKEHOLDER-BUILT
COMPUTER-ASSISTED DECISION SUPPORT SYSTEM MODEL
OF AN HISTORIC (PAST) FLOOD EVENT

INSTALL GOOGLE EARTH™

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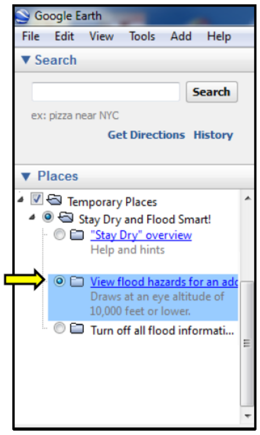
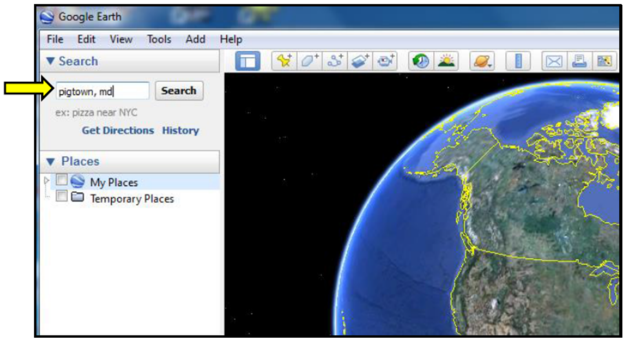
The FEMA “Stay Dry” overview appears on the screen. Remove this overview by navigating to the left side pane under “Places” and click the empty circle by “View flood hazards for an address”.

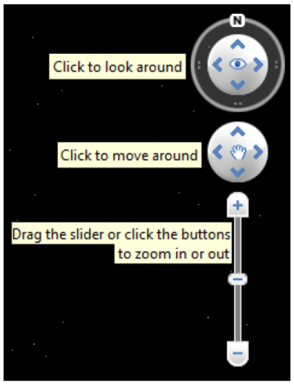


USING THE STAKEHOLDER-BUILT MODEL

1) On the top left corner of the Google Earth™ window, type “[town and state address]” in the search box. Click “enter” on the keyboard.

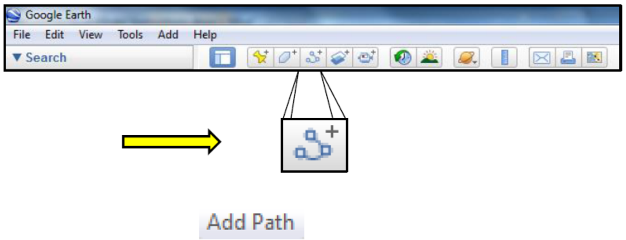

pigtown, md

2) Google Earth™ will “fly” to the address. Pan and zoom in to an area of interest within the community, such as a home or business. The following tools on the upper right side of the window will assist with:

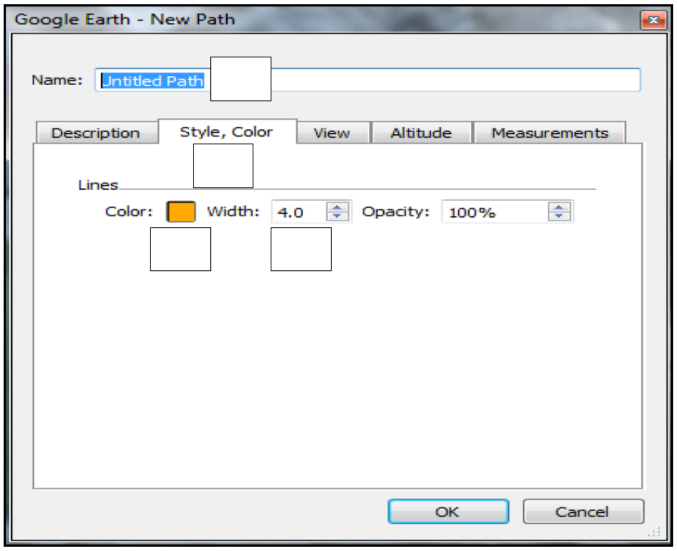


a. Looking around.
b. Moving around.
c. Zooming in and out

3) Once the property of interest is identified, draw the flood reach corresponding to the historic flood hazard elevation. Click on the “add path” button located at the top of the toolbar or hold down “CTRL” + “SHIFT” + “T” simultaneously.



4) The “new path” window will appear.


Google Earth - New Path

Name: Untitled Path

Lines

Color: 🟧 Width: 4.0 Opacity: 100%

a. Change “untitled path” name to a desired name.

b. Click on the “Style, Color” tab to match the figure above.

c. Adjust the color square within the “Style, Color” tab from white to orange by clicking on the color square and choosing an orange color. Then click “OK” to match the figure above.

d. Adjust the width within the “Style, Color” tab from 1.0 to 4.0 to match the figure above.

5) Move the “new path” window so that a flood reach can be drawn on the map behind it. <u>DO NOT CLOSE</u> the “new path” window. Move the window by clicking and holding down the “new path” window title with the computer cursor until the window is out of the way.

6) Move the cursor to the center of a nearby high flood hazard zone as provided by the FEMA “Stay Dry” “Flood Risk Areas” color key and note the elevation height in feet (ft) at the bottom right side of the Google Earth™ window. In the image below, the elevation at which the cursor is placed on the map is 13 ft.

39°16'31.28" N 76°37'51.41" W elev 13 ft eye alt 3994 ft

7) The Meeting Facilitator will provide a U.S. Geological Survey (USGS) stream or National Oceanic and Atmospheric Administration (NOAA) tidal gauge reading from the closest gauge that was active during the historic flood event being mapped.

8) Move the cursor from the center of the high flood hazard zone toward your property of interest until the elevation displayed at the bottom right edge of the Google Earth™ window reads the elevation of the USGS stream or NOAA tidal gauge during the historic flood event. This is called the historic flood hazard elevation.

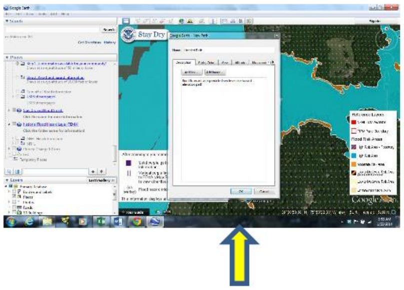
9) Click once at this position. This is the first point on the path that will delineate the approximate surface area that experienced flooding during the historic storm.

10) Continue to move the cursor so that the elevation remains identical to the historic flood hazard elevation (see steps 8 and 9 above). Then click to add another point to the path.

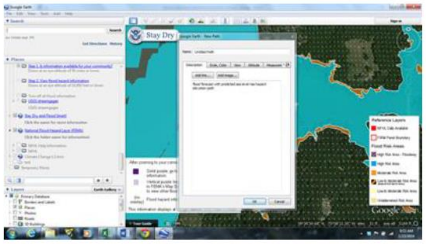
Do this several times. Note the closer the points are together, the more precise the flood delineation will be. An example is provided below:

To remove the last point on the path, right click on the mouse pad.

11) When the path delineates the extent of flooding on all sides of the property of interest, it is complete. Go to the "new path" window and click "OK."



The path name will appear in the column on the left side panel of the Google Earth™ screen as a saved path.



The historic flood hazard elevation path is now completed.

Present flood risk was represented in both the national GIS software and stakeholder-built DSS methods by the FEMA digital Flood Insurance Rate Map (DFIRM) flood hazard zone delineations for the 1% annual flood risk, previously known as the 100-year flood risk. Instructions for building the national GIS software model of a flood based on FEMA DFIRM 1% annual risk are provided in Appendix 1 with an example illustrated in Figure 8C. Instructions for constructing the stakeholder-built model of a flood event based on FEMA DFIRM 1% annual risk are provided in Figure 9 with an example illustrated in Figure 8D.

Figure 8: Model output illustrating an historic (past) flooding scenario is shown using (A) the national GIS software computer-assisted decision support system (DSS) method and (B) the stakeholder-built DSS method. Model output illustrating present 1% annual flood risk is shown using (C) the national GIS software DSS method and (D) the stakeholder-built DSS method. In (A) and (C), red indicated greatest damage resulting from the flood scenario. Orange, yellow and green indicated decreasing levels of damage in that order. Tan indicated areas where data were not available. The stakeholder-built DSS method showed (B) historic (past) and (D) present flood risk using Google Earth™ images. In (B), the yellow line represented the estimated upper limit of flood waters during the historic storm event. The area between the yellow line and the image of water (black area) represented the area flooded during the historic event. In (D), present flood risk was illustrated in the Google Earth™ image with the Federal Emergency Management Agency National Flood Hazard Layer high risk zone in blue (FEMA and GoogleEarth™ 2013).

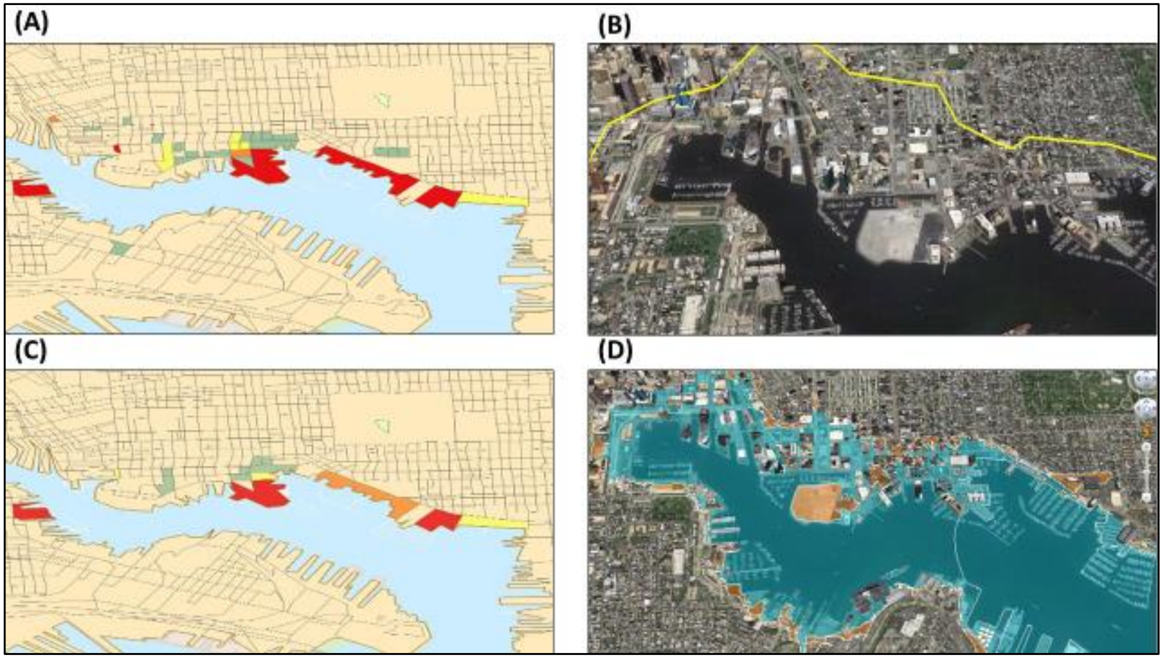


Figure 9: Instructions for the stakeholder-built computer-assisted decision support system model of present flood risk. These instructions were used by the geographic information systems technicians to build the model in advance of the community flood risk management meeting.

INSTRUCTIONS FOR THE STAKEHOLDER-BUILT COMPUTER-ASSISTED DECISION SUPPORT SYSTEM MODEL OF PRESENT FLOOD RISK

INSTALLATION OF GOOGLE EARTH™

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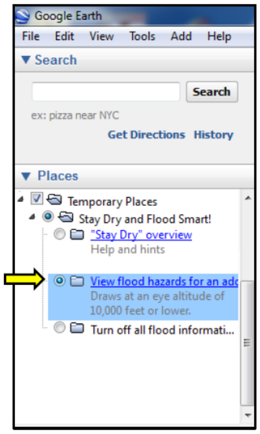
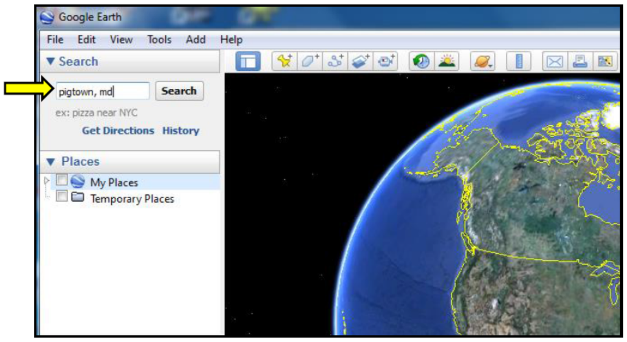
The FEMA "Stay Dry" overview appears on the screen. Remove this overview by navigating to the left side pane under "Places" and click the empty circle by "View flood hazards for an address".

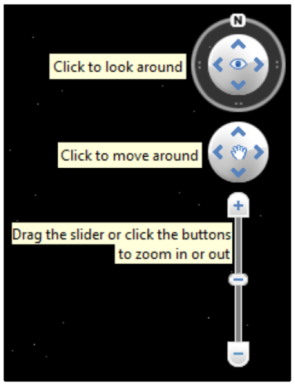


USING THE STAKEHOLDER BUILT MODEL

1) On the top left corner of the Google Earth™ window, type "[town and state address]" in the search box. Click "enter" on the keyboard.

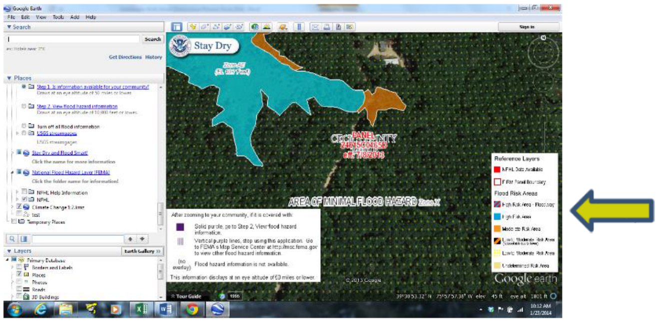

pigtown, md

2) Google Earth^{TM} will “fly” to the address. Pan and zoom in to an area of interest within the community, such as a home or business. The following tools on the upper right side of the window will assist with:



a. Looking around.
b. Moving around.
c. Zooming in and out

3) Once the property of interest is identified, locate the nearest high risk flood area. Using the FEMA Stay Dry “Reference Layers” color key provided on the right side of the screen, identify the flood risk for the property of interest. If the property is located outside an area of high risk, use the cursor to scroll to the nearest high risk zone.



The zones identify the 1% annual flood risk for the property as set by FEMA. The assessment of present flood risk for the property of interest is now complete.

Anticipated future flood risk was determined based on the best available data from multiple sources. Sources included in this determination were:

1. The Intergovernmental Panel on Climate Change Working Group II 2013 Report (IPCC 2013)
2. Report of the Maryland Commission on Climate Change “Adaptation and Response” and “Scientific and Technical” Working Groups 2010 Phase II Report (Griffin, Boesch et al. 2010)
3. FEMA recommendation to raise structures to a two-foot freeboard above FEMA base flood elevation as a precautionary measure in addressing future flood risk (Bollinger 2013b). Freeboard is the space between the expected flood height and the lowest horizontal component of the structure (FEMA 2010b).
4. The opinion of the city or county municipal planning department flood risk manager(s) based on their knowledge of flood risk within their jurisdiction.

Information from all of the above sources (Table 2) was combined to determine the scenario that best illustrates the anticipated future flood risk projected over the next 50 years during the flood risk management meetings.

Table 2: Factors included in determining the anticipated future flood risk projected over the next 50 years

Drivers of projected climate change-related flooding in U.S. Federal Emergency Management Agency Region III	Source
Sea level rise of 0.5 to 3 feet projected by 2050 in coastal waters due mainly to ocean warming	Intergovernmental Panel on Climate Change (IPCC 2013) (IPCC) Maryland Commission on Climate Change (Griffin, Boesch et al. 2010) (MCCC)
Higher storm surges due mainly to sea level rise	IPCC MCCC City/county flood risk manager(s)
Increase in high tides in the bays and tidal rivers due mainly to sea level rise	IPCC MCCC City/county flood risk manager(s)
Land subsidence due mainly to Greenland glacier melt and groundwater depletion	IPCC MCCC
Increases in frequency and intensity of winter snow and rain events	IPCC MCCC
Larger early spring riverine flooding (high velocity and volume of water in streams, rivers and bays due to run-off from snow and rain during the first large rain storms in early spring)	MCCC
In the summer, more episodic tropical downpours occurring between periods of drought	IPCC MCCC
Increases in stormwater runoff due mainly to increases in intensity of winter rain events, larger early spring riverine flooding, summer tropical downpours, and changes in land-use resulting in increases in impermeable surfaces and decreases in vegetative riparian and coastal buffers.	IPCC MCCC City/county flood risk manager(s)

In the stakeholder-built DSS, anticipated future flood risk projected over the next 50 years was represented by a two to three-foot increase in flood elevation above the FEMA DFIRM 1% annual flood hazard zone. Anticipated future flood risk was represented in the national GIS software DSS by the FEMA 0.2% annual flood risk, previously known as the 500-year flood risk. In practice flood scenario modeling sessions, the national GIS software maps of the FEMA 0.2% annual flood risk were similar to the flooding shown in the stakeholder-built maps of a two to three-foot increase in flood elevation above the FEMA DFIRM 1% annual flood hazard zone. These decisions were made after discussing in coordination with the city or county planning department flood risk manager(s), the FEMA Region III Mitigation Outreach Coordinator, and the researcher leading this project. This was quantitatively a very rough estimate of anticipated future flooding. The importance of illustrating an estimated increase in flooding was mainly to communicate to the meeting participants the general concept of probable changes in future flood patterns based on the information in Table 2 and to generate discussion of ways to prepare for possible changes. The meeting facilitator emphasized that precise levels of anticipated flooding were not possible based on the scientific data presently available. It was explained to the meeting participants that future changes were also dependent upon choices made by the local and global communities, such as land-use changes and changes in atmospheric emissions of gasses contributing to climate change.

Instructions for building the national GIS software model of anticipated future flooding over the next 50 years are provided in Appendix 1 with an example illustrated in Figure 10A. Instructions for constructing the stakeholder-built model of anticipated future flooding over the next 50 years are provided in Figure 11 with an example illustrated in Figure 10B.

Figure 10: Model output illustrating scenarios for the anticipated future flood risk projected over the next 50 years is shown using (A) the national GIS software computer-assisted decision support system (DSS) method and (B) the stakeholder-built DSS method. In (A), red indicated greatest damage resulting from the flood scenario. Orange, yellow and green indicated decreasing levels of damage in that order. Tan indicated areas where data are not available. In (B), the Google Earth™ image showed the Federal Emergency Management Agency National Flood Hazard Layer 1% annual flood risk hazard area as the blue layer (FEMA and GoogleEarth™ 2013). The yellow line was added by the stakeholder using the Google Earth™ drawing tool guided by Google Earth™ elevation data and represented anticipated flood risk within the next 50 years. The area below the yellow line represented property anticipated to experience flooding.

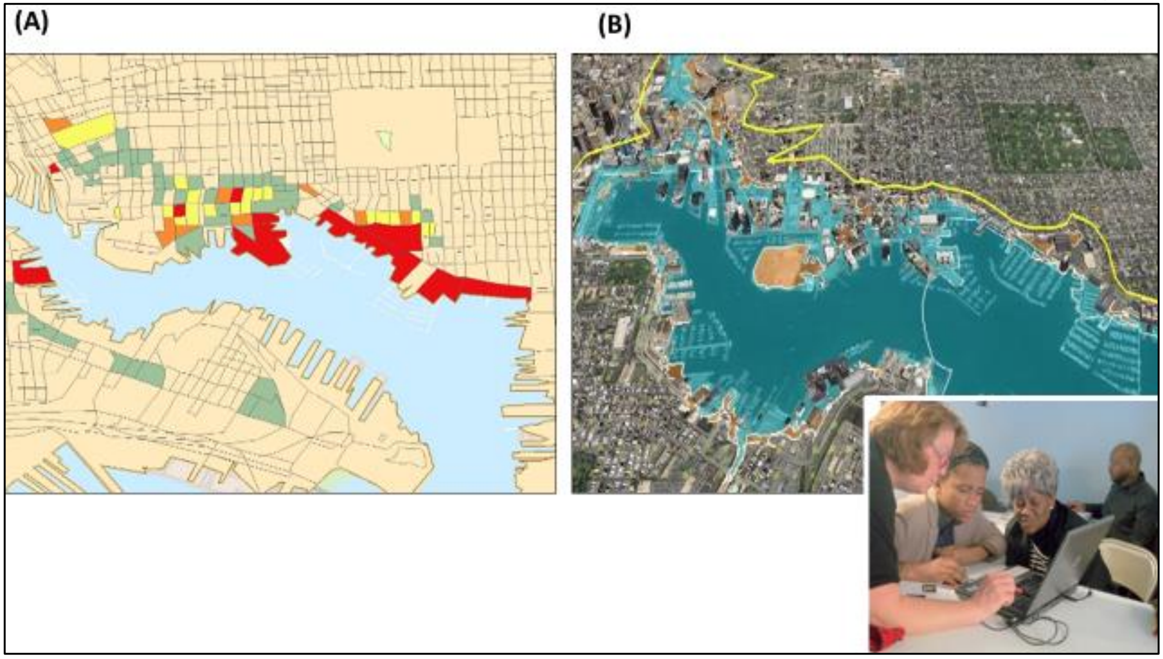


Figure 11: Instructions for the stakeholder-built computer-assisted decision support system model of anticipated future flood risk. These instructions were used by the meeting participants to build the model during the community flood risk management meeting. Participants also received detailed instructions as to how to install Google Earth^{TM} and download the Federal Emergency Management Agency National Flood Hazard Layer. In addition, the geographic information systems technicians used the instructions to pre-construct a model to use as an example during the flood risk

management meeting.

INSTRUCTIONS FOR THE STAKEHOLDER-BUILT COMPUTER-ASSISTED DECISION SUPPORT SYSTEM MODEL OF ANTICIPATED FUTURE FLOOD RISK

INSTALLATION OF GOOGLE EARTH™

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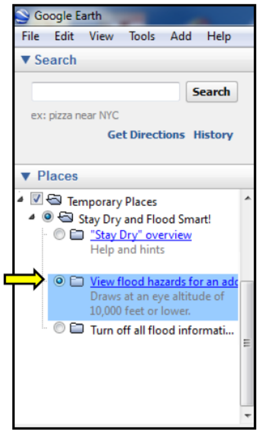
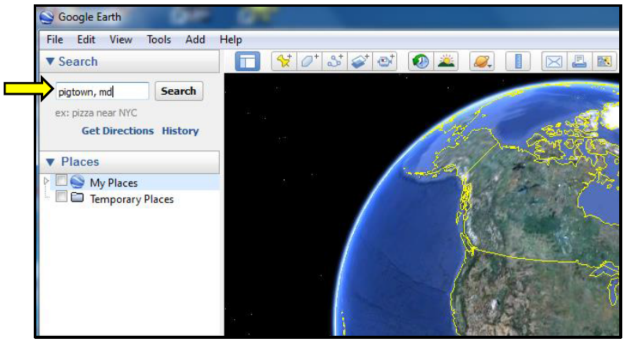
The “Stay Dry” overview appears on the screen. Remove this overview by navigating to the left side pane under “Places” and click the empty circle by “View flood hazards for an address”.

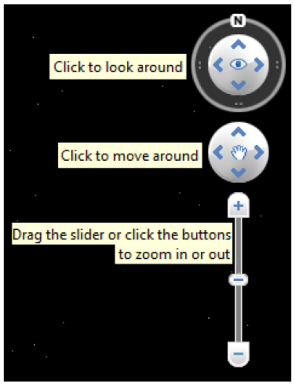


USING THE STAKEHOLDER-BUILT MODEL

1) On the top left corner of the Google Earth™ window, type “[town and state address]” in the search box. Click “enter” on the keyboard.

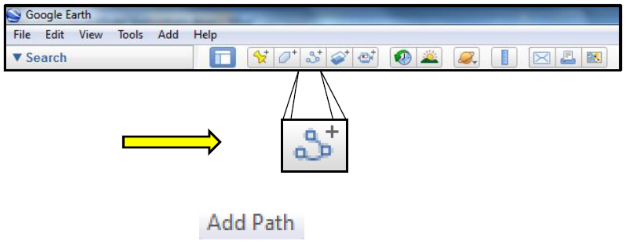

pigtown, md

2) Google Earth™ will “fly” to the address. Pan and zoom in to an area of interest within the community, such as a home or business. The following tools on the upper right side of the window will assist with:

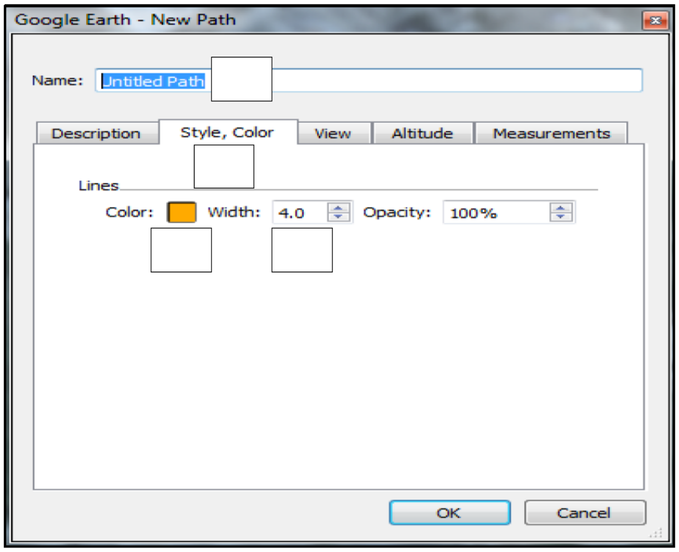


a. Looking around.
b. Moving around.
c. Zooming in and out

3) Once the property of interest is identified, draw the flood reach corresponding to the anticipated future flood hazard elevation. Click on the “add path” button located at the top of the toolbar or hold down “CTRL” + “SHIFT” + “T” simultaneously.



4) The “new path” window will appear.



Name: Untitled Path

Color: 🟧 Width: 4.0 Opacity: 100%

a. Change "untitled path" name to a desired name.

b. Click on the "Style, Color" tab to match the figure above.

c. Adjust the color square within the "Style, Color" tab from white to orange by clicking on the color square and choosing an orange color. Then click "OK" to match the figure above.

d. Adjust the width within the "Style, Color" tab from 1.0 to 4.0 to match the figure above.

5) Move the "new path" window so that a flood reach can be drawn on the map behind it. <u>DO NOT CLOSE</u> the "new path" window. Move the window by clicking and holding down the "new path" window title with the computer cursor until the window is out of the way.

6) Move the cursor to the center of a nearby high flood hazard zone as provided by the FEMA “Stay Dry” “Flood Risk Areas” color key and note the elevation height in feet (ft) at the bottom right side of the Google Earth™ window. In the image below, the elevation at which the cursor is placed on the map is 13 ft.

39°16'31.28" N 76°37'51.41" W elev 13 ft eye alt 3994 ft

With an anticipated future flood hazard elevation increase of 3 feet (ft), the edge of this flood zone will increase to 16 ft (13 ft + 3 ft).

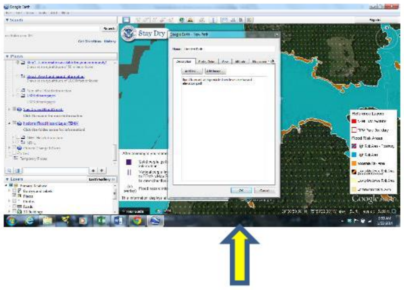
7) Move the cursor in any direction away from the high flood hazard zone until the elevation displayed at the bottom right hand of the Google Earth™ window reads the current elevation at the edge of a nearby FEMA high flood hazard zone PLUS the anticipated future flood level rise. This is called the anticipated future flood hazard elevation and can be expressed as: flood forecast with anticipated future hazard elevation = elevation at edge of FEMA high flood hazard zone + anticipated flood level rise (3 ft in illustration above). For example, if the current elevation at the edge of a nearby FEMA flood hazard zone is 13 ft, then you would move the cursor in any direction away from the edge until the elevation displayed is 16 ft. You may adjust the “anticipated flood level rise” based on your specific location and the best available data on the anticipated effects of climate change and other factors on flood levels for that location.

8) Click once at this position. This is the first point on the path that will delineate the approximate surface area that is anticipated to experience flooding in the future.

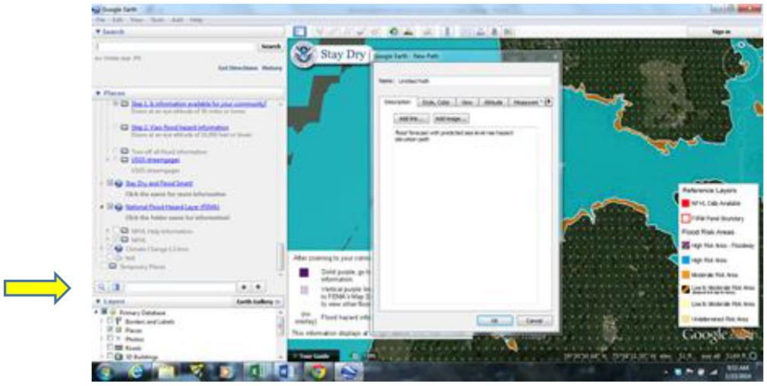
9) Continue to move the cursor so that the elevation remains identical to the anticipated future flood hazard elevation (see steps 7 and 8 above). Then click to add another point to the path. Do this several times. Note the closer the points are together, the more precise the flood delineation will be. An example is provided below:

To remove the last point on the path, right click on the mouse pad.

10) When the path delineates the extent of flooding on all sides of the property of interest, it is complete. Go to the "new path" window and click "OK."



The path name will appear in the column on the left side panel of the Google Earth^{TM} screen as a saved path.



The anticipated future hazard elevation path is now complete.

When the national GIS software DSS method was used, all three scenarios were run prior to the community flood risk management meeting and displayed during the stakeholder discussions of flood risk. The national GIS software model produced maps of flooding (Figures 8A, 8C and 10A) and generated summary reports describing the extent of damage at the resolution of U.S. Census Bureau blocks (FEMA 2009, Moore, Bohn et al. 2012) (Appendix 1). For the community flood risk management meetings, modeling of the damage was shown using the total residential economic loss in year 2000 U.S. dollars (Moore, Bohn et al. 2012) measured by loss to residential structures and loss to their contents. Residential loss was chosen because, based on exploratory interview feedback collected prior to the meetings (Appendix 5), most of the meeting participants were expected to be residents of the communities.

When the stakeholder-built DSS method was used, flood information was limited to showing the areal extent of flooding, without information about inundation levels. Thus, the number of buildings subjected to ground-level flooding was illustrated, but the damage costs in dollars were not calculated. When the stakeholder-built DSS method was used, the past and present flood risk scenarios (Figures 8B and 8D) were constructed in advance and displayed during the stakeholder discussions. The past flood risk from an historic event was constructed by the GIS technicians using the Google Earth™ drawing tool guided by Google Earth™ elevation data (Figure 7 and Appendix 2). Present flood risk was constructed using a Google Earth™ image with the FEMA National Flood Hazard Layer (NFHL) applications in a keyhole markup language zipped files (KMZ) (FEMA and GoogleEarth™ 2011, FEMA and GoogleEarth™ 2013) GIS layer (Figure 9). The FEMA NFHL KMZ displays in raster format the 1% annual return period for flood events (FEMA 2014d). These were prepared in advance so that each meeting could be completed within the two hours allotted by the community organizers.

The third scenario illustrating anticipated future flood risk projected over the next 50 years (Figure 10B) was built by the stakeholders during the meeting. Instructions for building the model were provided verbally by the meeting facilitator, illustrated on a large projector screen by the GIS technician, and provided in written format (Figure 11) in each community meeting. Six to seven laptop computers, pre-installed with Google Earth™ (GoogleEarth™ 2013) and the FEMA NFHL KMZ (FEMA and GoogleEarth™ 2011, FEMA and GoogleEarth™ 2013), were available for use by meeting participants. For participants who brought their own laptops, the meeting assistants and GIS technician installed the software, with permission from the laptop owner, on the day of the meeting.

Participants were asked to locate the FEMA NFHL "High Risk Area" nearest their property of interest, which was usually their home. The meeting facilitator gave instructions for opening and formatting a "new path" using the Google Earth™ drawing tool. Participants were then asked to place their computer cursor over the "High Risk Area" polygon edge nearest their property and read the elevation shown in the Google Earth™ window. Next they were asked to add either two or three feet to the elevation to simulate future flood risk and move their cursor so that the elevation window matched their calculation. Here they clicked to record the first point on their "anticipated future flood risk projected over the next 50 years" path. They were instructed to repeat the steps until they drew a path that delineated future flooding on all sides of their property. Meeting assistants and the GIS technician were allowed to assist with re-installing the software and repeating the instructions to individual participants. They were not allowed to move the cursor or draw the path for the participants. The interactive visualization methodology requires the learner to build the model themselves. By the close of this exercise, all participants successfully drew a model showing their future anticipated flood risk that resembled the demonstration model completed by the GIS technician and shown at the close of the exercise on the large projection screen (Figure 10B).

Using the stakeholder-built DSS method, the first two scenarios showing past and present flood risk tested the effectiveness of realistic visualization (Figures 8B and 8D). The third scenario, showing future flood risk, tested the effectiveness of realistic and interactive visualization combined (Figure 10B).

Sampling protocol

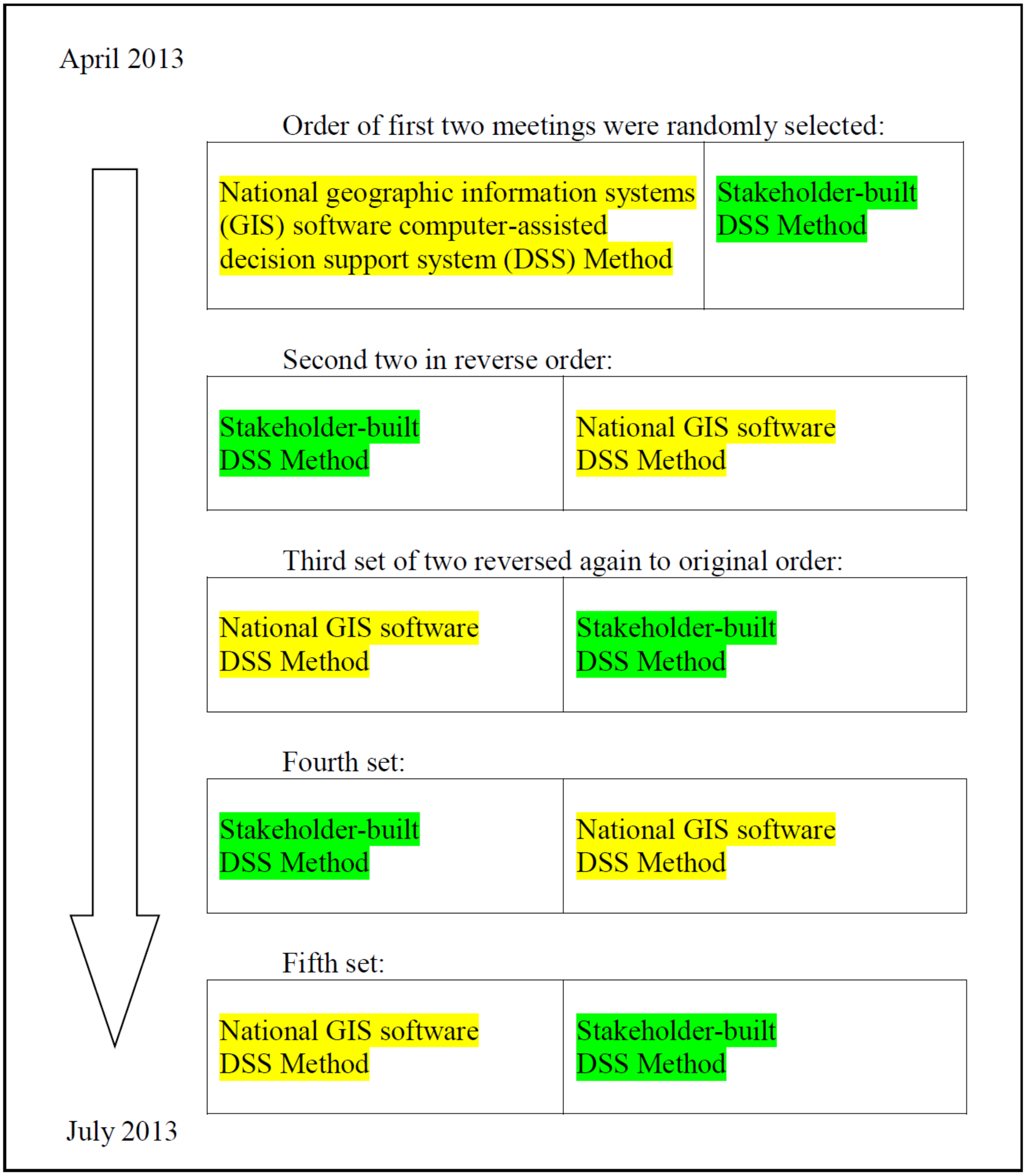
The selection of Federal Emergency Management Agency (FEMA) Region III communities for participation in the research was conducted in conjunction with FEMA Community Coordination and Outreach (CCO) meetings scheduled between 2012 and 2013. CCO meetings introduce the most recent digital Flood Insurance Rate Map (DFIRM) updates (Janowicz 2011, Bollinger 2013b) at the city or county municipal level. Because flood insurance rates and municipal building code requirements are tied to the DFIRM, property values are influenced by location on these maps. Communities scheduled for DFIRM updates were chosen because the updates served as an introduction to the topic of flood risk management. With awareness of the revised DFIRM, stakeholders in these communities were primed for the prospect of insurance rate changes and were therefore likely to have the incentive to attend meetings that provided information about their flood risk.

The FEMA Region III Mitigation Outreach Coordinator introduced the lead researcher during city and county-level municipal CCO meetings and endorsed the flood risk management meetings as a method by which the municipal leaders could disseminate flood risk information to the local communities within their jurisdiction. The municipalities could earn points toward their National Flood Insurance Program Community Rating System, which has the potential to reduce flood insurance rates throughout the city or county, for participating in flood risk management meetings. The researcher presented a brief overview of the benefits of participation in the flood risk management meetings and the commitment required of the municipal leaders and the community participants. The municipal leaders were directed to the website:

https://sites.google.com/site/floodmodeling1/ for additional information about the research. They were then asked to contact community organizers to arrange for a local community introductory presentation by the researcher.

Following this local introduction to the project, community leaders were asked to arrange a time and place for a flood risk management meeting where the data-collection for the research would take place. They were asked to advertise the event to stakeholders in the community. The first ten communities in FEMA Region III to schedule a date and time for a flood risk management meeting were included in the research. The DSS methods were assigned in alternating order (Figure 12).

Figure 12: Sampling order for the flood risk management meetings where the data-collection for this research took place. The research tested the effectiveness of the national geographic information systems software and stakeholder-built computer-assisted decision support systems at communicating information about flood risk and initiating risk-reduction action among stakeholders, those at risk of flooding.



This experimental design was used because the community meetings were spread over four months, during which flooding events may occur. Past studies show recent flood events can strongly influence the receptivity of stakeholders to risk and risk reduction information (Sheppard 2005, Keller, Siegrist et al. 2006, Hayes 2011). For example, a community hit by a flood event during which no structures in the area are damaged, results in stakeholders perceiving their risk to be much lower than is indicated by past data and probabilistic modeling of future flood risk (Hayes 2011). Conversely, when stakeholders witness a flooding event in a nearby community where structures are damaged, stakeholders perceive their risk to be much greater than is indicated by past data and probabilistic modeling of future flood risk (Hayes 2011). If either situation occurred during this study, the altered perception of risk may influence stakeholders' interest in participating in the meetings and may also change the responses on the surveys and in the follow-up interviews. If random assignment of the two DSS methods, by chance, placed all communities that were assigned one DSS method in the time frame prior to the flood event and all of those assigned the other DSS method after the flood event, the exposure to the flood event may have a significant effect on the results of the study. To avoid this situation, the assignment of DSS methods was alternated (Figure 12). There were also likely to be differences in the quality of the presentation over time as the meeting facilitator, geographic information systems technician, and other members of the research team improved their presentation skills. Alternating the assignment of DSS methods reduced the effect of this potential covariate as well.

A total of 98 participants were clustered within the ten communities selected to receive flood risk management meetings. To detect the effect of each computer-assisted decision support system (DSS) method on the learning that took place during the flood risk management meetings, a non-equivalent control group design was used. This means each participant served as a control prior to the start of the meeting and as a member of the treatment group at the close of the meeting. The treatment in this experimental design is exposure to one of the two DSS methods. At the start, each participant was given a survey and at the end, the same individual was given an identical post-survey (Appendices 3 and 4). Three to six of the participants at each meeting were randomly selected to receive follow-up interviews (Appendix 6). The pre-survey was used as a covariate in the analyses and the post-survey and follow-up interviews were the response variables. This method was used to distinguish between the flood risk knowledge gained during the meeting and the knowledge each participant possessed prior to the meeting.

Exploratory interviews

Prior to each scheduled flood risk management meeting, key informants in each community were identified. Key informants are defined in the social sciences as well-established members of a community knowledgeable in the subject of flood risk management who are observant, reflective, articulate, and are somewhat cynical about their own local culture (Bernard 2002). Exploratory interviews were conducted with these individuals to identify any cultural nuances and/or community-wide experiences that may influence the quality or content of responses received from stakeholders during the study (Paolisso 2010). County or city planners involved in the Federal Emergency Management Agency (FEMA) digital Flood Insurance Rate Map (DFIRM) updates for their municipalities identified key informants in each community. The municipal planners work with community organizers when scheduling the county and city-wide FEMA DFIRM updates and, in most cases, worked with these individuals in prior years introducing the National Flood Insurance Program to the communities (Bellomo 2010).

This collaboration gave them insight into the social structure of the communities, which provided the experience needed to identify key informants.

The exploratory interviews consisted of eleven open-ended questions (Bernard 2002) about the key informant's perception of the general attitude of their community toward flood risk; interest in initiating risk-reduction actions; and familiarity and acceptance of computer simulations as a learning tool (Appendix 5). The open-ended format allowed informants to expand upon concepts they believed to be important in their community's attitude toward flood risk management. One to three informants in each community were interviewed. The exploratory interviews assisted in anticipating some aspects of community dynamics during the data-collection meetings. This information was used to make subtle adjustments to the meeting presentation with the intent of increasing interest in the session by capturing the character of individual communities and incorporating that into the presentation. When available, local photographs of past storms provided by the key informants were included in the flood risk management meeting presentation. If not available, photographs of areas identified by the key informants as flood-prone were taken and included in the presentation.

Training of flood risk management meeting facilitators and geographic information systems technicians

Prior to the flood risk management meetings, four research assistants were trained to use the national geographic information systems (GIS) software models represented by the Federal Emergency Management Agency (FEMA) Multi-hazard Loss Estimation Methodology (HAZUS) (Appendix 1 and 5) and the stakeholder-built (Figures 7, 9, and 11 and Appendix 2) computer-assisted decision support systems (DSS) methods. These GIS technicians were cross-trained as meeting facilitators (Appendix 7) and meeting assistants (Appendix 8). Training sessions included a detailed written description of the protocol and a series of practice sessions designed to standardize the flood risk management meetings across communities. Emphasis was placed on:

- Adhering to the order of activities.
- Standardizing the information presented on flood risk.
- Controlling inflections in tone of voice in order to avoid leading the participants in a particular direction during discussions.
- Adherence to any cultural nuances identified during exploratory interviews (Appendix 5) as important to assuring consistency in the quality of participant interaction during the meeting.

Individuals functioning as meeting facilitators were assigned paired meetings. Each facilitated a meeting using one DSS followed by facilitation of a meeting using the alternative DSS. The individual assigned to function as the meeting GIS technician and the number of meeting assistants attending each flood risk management meeting were random. All available research assistants not assigned to function as the meeting facilitator or GIS technician filled the role of meeting assistant. This resulted in an uneven distribution of meeting assistants. Both DSS methods had one meeting each where no meeting assistants were available. At these meetings, the lead researcher, meeting facilitator, and meeting GIS technician performed the duties of the meeting assistant (Appendix 8) as well as their own. All other meetings had one to two meeting assistants.

The individuals serving in these roles and the number of individuals available during meetings had the potential to influence the learning outcomes. Therefore, the following were included in the analyses as covariates:

- Individuals serving as the meeting facilitator
- Individuals serving as the meeting GIS technician
- Number of meeting assistants in attendance

Flood risk management meeting protocol

A. Selection of follow-up interviewees

Prior to the start of the meeting, assistants selected individuals to participate in follow-up interviews (Appendices 6 and 8).

B. Meeting introduction and completion of consent forms and pre-surveys

The lead researcher:

1. Introduced the project to the stakeholders and explained the positive impact their participation will have on their community and society as a whole.
2. Described the meeting agenda.
3. Gave instructions for completing the Institutional Review Board (IRB)-required consent form and the surveys (Appendices 3, 4 and 10). Further information on the IRB protocol used to protect the participants' privacy is located in Appendix 9.
4. Distributed the consent form followed by the survey and gave the audience time to complete each. Meeting assistants helped with this process. Participants' names and information about the geo-location of their community were recorded on the consent form only. Each community was assigned a randomly-generated number used as a unique identification code on the surveys. Each individual participant was assigned a randomly-generated number used as a unique identification code

on their survey.

5. Asked the participants to deposit their completed consent form and survey in the envelopes marked for each. Meeting assistants helped with this process.
6. Introduced the meeting facilitator.

C. Presentation of community-specific flood risk information

The meeting facilitator:

1. Introduced the stakeholders to flood risk modeling by discussing historic (past) flood events they were likely to remember. Specific flood events were chosen based on information gained during exploratory interviews (Appendix 5). Geographic information systems (GIS) technicians entered this data and ran the scenarios in advance of the stakeholder meeting. Detailed descriptions of the protocol followed when producing maps of the historic flood events are located in Appendices 1 and 2 and Figure 7. Images were shown of the community's historic storm flooding using the computer-assisted decision support system (DSS) modeling method assigned to the community (Figure 8A and 8B). Participants were encouraged to discuss how well the model illustrated the flooding they recalled from their memory of the event.
2. Introduced to the stakeholders the concept of flood risk analysis and explained how that differs from historical flood data.
3. Modeled the most recent risk analysis shown on the FEMA digital Flood Insurance Rate Map (DFIRM) and re-emphasized how risk calculations differ from historical data. Present flood risk was represented by the FEMA DFIRM flood hazard zone delineations for the 1% annual flood risk, formerly known as

the 100-year flood risk (Figure 8C and 8D). GIS technicians entered this data and ran the scenario in advance of the stakeholder meeting. Detailed descriptions of the protocol followed when producing maps of the 1% annual flood risk presently set by FEMA are located in Appendix 1 and Figure 9. Participants discussed flood risk to their properties based on the model.

4. Modeled anticipated flood risk within the next 50 years (Griffin, Boesch et al. 2010, IPCC 2013). The facilitator explained that this was quantitatively a very rough estimate of anticipated future flooding. The importance of illustrating an estimated increase in flooding was mainly to communicate to the meeting participants the general concept of probable changes in future flood patterns based on the information in Table 2 and to generate discussion of ways to prepare for changes. The meeting facilitator emphasized that precise levels of anticipated flooding were not possible based on the scientific data presently available. The facilitator explained that future changes were also dependent upon choices made by the local and global communities, such as changes in land-use. If exploratory interview responses (Appendix 5) indicated the community was interested, the facilitator discussed this in the context of climate change.
    a. Future flood risk was represented in the national GIS software DSS by the FEMA 0.2% annual flood risk (Figure 10A). GIS technicians entered this data and ran the scenario in advance of the stakeholder meeting. Detailed descriptions of the protocol followed when producing these maps are located in Appendix 1.
    b. For the stakeholder-built DSS method, participants were divided into small

    groups of two to three individuals, ideally grouped with those living closest together. If available, at least one computer-savvy person was included in each group. Participants used their own laptop computers or laptops the research team provided. They linked to Google Earth™ maps (GoogleEarth™ 2013) and the FEMA National Flood Hazard Layer (NFHL) Google Earth™ application (FEMA and GoogleEarth™ 2011, FEMA and GoogleEarth™ 2013). Using the data provided and the Google Earth™ drawing tool, participants built a model showing the relationship between their property location, the FEMA NFHL, and anticipated increases in flood elevation over the next 50 years. Future flood risk was represented in the stakeholder-built DSS by a two to three-foot increase in flood elevation above the DFIRM 1% annual flood risk levels. Detailed descriptions of the protocol followed by the stakeholders when producing these maps are located in Figure11. Members of the group assisted one another in building their model (Figure 10B).

    c. Stakeholders discussed flood risk to their properties based on the model.

5. Facilitated a stakeholder discussion of the advantages and disadvantages of maintaining the status quo in flood risk management in their community.
6. Summarized the highlights of the flood risk discussions.
7. Introduced the lead researcher for a discussion of risk-reduction options.

D. Presentation of community-specific risk-reduction options

The lead researcher:

1. Introduced flood risk-reduction options. Initially, four to seven risk-reduction options were selected by the lead researcher to include in the presentation. Options from which the researcher chose included:
    - Purchase flood Insurance (FEMA 2011a) that covers:
        - Structural damage - property owners
        - Damage to contents – everyone
        - Cost of alternative housing - everyone
    - Digitize photos and important documents
    - Keep storm drains free of leaves and other debris
    - Determine emergency evacuation routes
    - Move vehicles to high ground before flood waters rise
    - Sign up for flood notification through email or phone
    - Plant and/or preserve forest buffers adjacent to community waterways
    - Buy and install sump pumps with back-up power
    - Install sewer backflow valves
    - Build a floodwall - using sandbags or permanent structures
    - elevate structures above the FEMA base flood level
    - Have a licensed electrician raise electric components (switches, sockets, circuit breakers and wiring) at least 12" above your home's projected flood elevation
    - flood proof heating, ventilation and air conditioning systems
    - Anchor fuel tanks
    - Keep hazardous chemicals out of floodwaters

Whenever possible, photographs were included that showed locations within each community where these options were presently in place or where damage from flooding had occurred that could be prevented by implementing one or more of the risk-reduction options. The list of options included in the presentation varied depending on the level of flood risk associated with the community. Where the model showed very low risk of floods, emphasis was placed on options such as preparing emergency kits for sheltering in place and locating emergency evacuation routes that would be unlikely to flood. In communities where the model showed very high risk of flooding, the discussion included the purchase of flood insurance and introduced some of the more costly options such as raising structures to a two-foot freeboard above FEMA base flood elevation. Freeboard is the space between the expected flood height and the lowest horizontal component of the structure (FEMA 2010b).

2. Facilitated participants' discussion of the costs and benefits associated with implementing the risk reduction options presented.
3. Gave participants the opportunity to discuss possible risk-reduction options that were not introduced initially in the presentation.

E. Discussion of costs and benefits of potential risk-reduction actions

1. Each participant was given the opportunity to suggest which risk-reduction options, if any, they recommend the community and/or individual stakeholders implement and how they recommend the implementation be accomplished.
2. Lead researcher summarized conclusions of the group.

F. Meeting conclusion and completion of post-surveys

1. Lead research thanked participants for their time and reminded them to complete

the post-survey before leaving.

2. Meeting assistants collected completed surveys.

G. Completion of follow-up interviews

Within the week following the meeting, the lead researcher interviewed those selected for follow-up questioning (Appendix 6).

Written copies of the scripts followed by the lead researcher and meeting facilitator are available upon request. Copies of the templates used for the flood risk management meeting slide presentations are also available upon request.

Table 3: Overview of the stakeholder-built and national geographic information systems (GIS) software computer-assisted decision support system (DSS) methods within the context of the flood risk management meetings

Attributes	Stakeholder-built DSS	National GIS software DSS
Participants completed a pre-survey describing their demographic characteristics	Yes	Yes
Learning was measured using pre- and post-surveys and follow-up interviews	Yes	Yes
Technology/Computers used in model-building	Participants brought their own laptops and tablets to share with partners. The research team supplied additional laptops with a minimum of a 500-megabyte (MB) harddrive, 512-MB system memory, and central processing unit (CPU) speed of 500 megahertz (MHz) or 0.5 gigahertz (GHz) (Google 2013)	GIS technicians used laptops and/or desktop computers with a minimum of a 10-gigabyte (GB) harddrive (10,240 MB), 2-GB system memory (2,048 MB), and CPU speed of 2.2 GHz (2,200 MHz) (FEMA 2009)
Meeting facilitators introduced participants to community-specific flood risk factors and risk-reduction options.	Yes	Yes
Participants engaged in collaborative learning using a	Yes	Yes

DSS and discussed the costs and benefits of flood risk-reduction actions specific to their community needs.		
To learn about past and present flood risk, participants viewed models constructed by GIS-trained technicians.	Participants engaged in realistic visualization, viewing pre-constructed models that used the stakeholder-built technique: GoogleEarth™ and the Federal Emergency Management Agency National Flood Hazard Layer	Participants viewed pre-constructed models that used the national GIS software method.
Participants learned about anticipated future flood risk.	Participants engaged in realistic interactive visualization, building their own model.	Participants viewed pre-constructed models that used the national GIS software method. Model-building was performed by GIS-trained technicians.

Analysis of the survey responses

The demographic information provided by meeting participants in the pre-surveys was used in the analyses in Chapter III. Pre- and post-survey responses to a series of questions about flood risk, risk-reduction options, and intent to take action to reduce risk were used in the analyses in Chapters IV, V, and VI, respectively. Statistical analyses to determine if other factors influenced the effectiveness of each computer-assisted decision support system (DSS) method were also performed. These factors, described in Table 4, were analyzed in Chapters IV, V, and VI.

Table 4: Factors that may influence performance of the computer-assisted decision support system: Potential covariates in the analyses

Factors	Variation among flood risk management meetings
Participants' prior geographic information system (GIS) experience (Bullinger, Ziegler et al. 2002, Hegarty 2004, Vinge 2006, Chandler 2009, Ploetzner, Lippitsch et al. 2009, Schwamborn, Thillmann et al. 2011)	79% of participants reported having no prior GIS knowledge, 17% reported having some prior GIS knowledge, and 4 % reported having a high level of prior GIS knowledge.
Individuals serving as the meeting facilitator (Maskiewicz et al. 2010)	Two of the research assistants served as meeting facilitators. One facilitated two meetings, one of each DSS method. The other facilitated eight meetings, four of each DSS method.
Individuals serving as the meeting GIS technician	This role was assigned to whomever volunteered for the position. Two different individuals served as the GIS technician at the national GIS software DSS meetings. Three individuals served at Stakeholder-built DSS meetings.
Number of meeting assistants in attendance	Both DSS methods had one meeting each where no meeting assistants were available. All other meetings had one to two meeting assistants.
Presence or absence of a municipal planning department representative during the meeting (Ibarrarian and Ruth 2009)	60% of the meetings had municipal planners available to answer questions about flood risk-reduction options available to the community.
Type of community: rural, suburban or urban (Cutter, Mitchell et al. 2000, Cutter, Boruff et al. 2003, Cutter, Burton et al. 2010)	50% of the communities were located in a large city. 10% were in a small-size city. 30% were rural. 10% were suburban.
Quality of the meeting facility (whether or not the room provided a distraction-free environment)	50% of the meetings were held in high-quality facilities. 30% were held in poor-quality facilities and 20% in medium-quality facilities.

In Chapters IV, V and IV, to find where differences were significant, the Statistic Analysis System^{TM} (SAS) 9.3 GLIMMIX Procedure with a negative binomial response distribution was used to perform an F-test for analysis of variance (SAS 2012). The SAS GLIMMIX Procedure is used for statistical modeling of categorical data and is ideal for analyzing data that are not normally distributed. This describes the distribution of participant responses on the surveys in this study.

In the analyses where there were no significant differences between the two DSS methods in their effect on learning outcomes, t-tests were performed to find where outcomes were significant as a result of participation in the community flood risk management meetings. These analyses pooled responses from meetings using the two DSS methods and analyzed the difference between pre- and post-survey responses for each learning outcome. The differences between knowledge of risk (Chapter IV) and risk-reduction options (Chapter V) prior to and following the meeting were calculated. In Chapter VI, differences between participants' intent to take action to reduce risk prior to and following the meeting were calculated. The differences were normally distributed, therefore t-tests could be used. The t-tests were performed using SAS 9.3 PROC TTEST Procedure (SAS 2012).

Cost analyses for the national geographic information systems (GIS) software and stakeholder-built computer-assisted decision support systems

The expense in time and money needed to train geographic information systems (GIS) technicians to perform the mapping in each of the two computer-assisted decision support system (DSS) methods was calculated and compared to determine if there was a difference between the two methods. The four technicians who completed comprehensive training kept work logs, updated daily, where each technician documented the number of hours they dedicated to training for the construction of maps in each DSS method. The total number of hours spent by all four technicians preparing for each community flood risk management meeting was calculated and recorded as the unit-effort per meeting (Data available upon request). The two-hour flood risk management meeting time was not included in the calculation of unit-effort training time. The meetings were entered in the data sheet in the order in which they occurred.

Ease of use survey for the national geographic information systems (GIS) software and stakeholder-built computer-assisted decision support systems

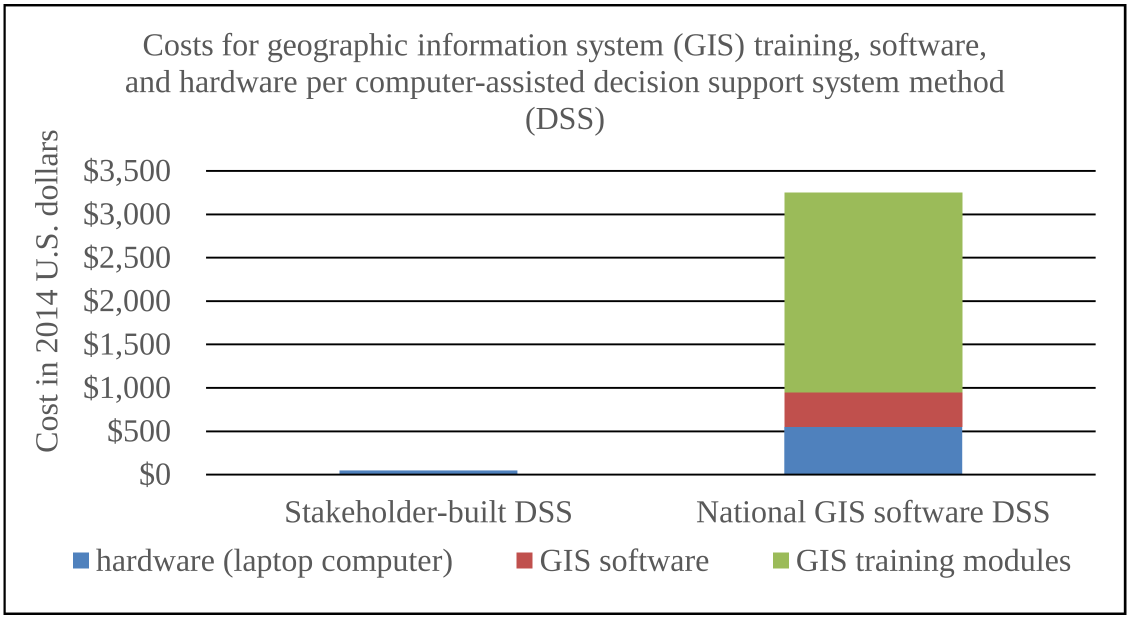
Once all flood risk management meetings were completed, the four geographic information systems (GIS) technicians and two members of the research team trained as meeting assistants were surveyed for their opinion of the learning curve required to master the use of each computer-assisted decision support system (DSS) and the ease of acquisition and use of hardware and software required for each DSS. The four GIS technicians were fully-trained in constructing maps using each of the DSS models. The two meeting assistants received some training in map construction using each DSS model. For these surveys, an online assessment tool was used (Olsen 2013a, Olsen 2013b).

Results

Cost analysis for the national geographic information systems (GIS) software and stakeholder-built computer-assisted decision support systems

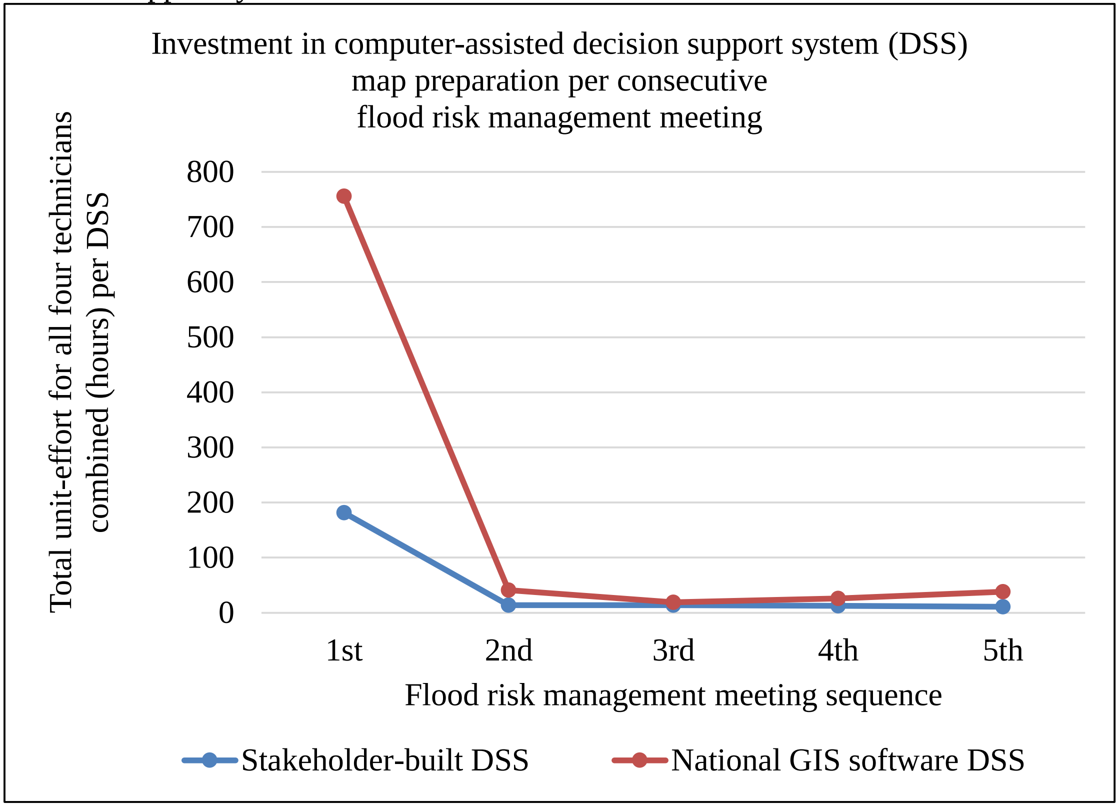
The cost of hardware, software, and training modules was approximately nineteen times more expensive for the national geographic information systems (GIS) software computer-assisted decision support system (DSS) (Figure 13) than was the stakeholder-built DSS. The stakeholder-built DSS training required minimal costs for hardware, a basic laptop or tablet computer with a Microsoft Windows^{TM} operating system, at a cost of less than $50 for a tablet (U.S. 2014 dollars) and no expenses for software or training modules.

Figure 13: Costs for geographic information system training modules, software, and hardware per computer-assisted decision support system method: the national GIS software and the stakeholder-built



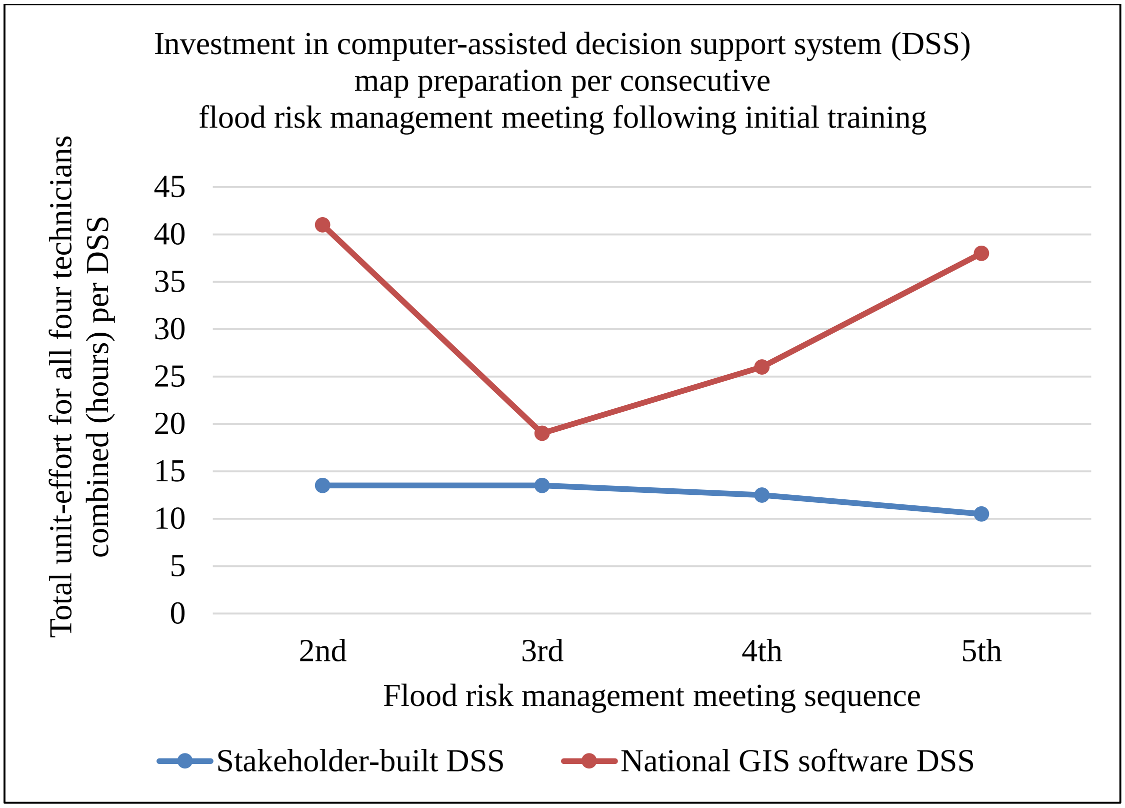
The national GIS software DSS method was found to require considerably more hours and, therefore, a much higher monetary investment than was required for the stakeholder-built method. The greatest investment was in the early training for both DSS methods with the national GIS software DSS requiring over six times the investment in time for initial training than the stakeholder-built method (Figure 14). In this study, the GIS technicians were undergraduate and graduate students. Three of the four had little or no previous training in the use of GIS models. One graduate student was experienced in the use of Environmental Science Research Institute (ESRI) ArcGIS^{TM} (ESRI 2012), but was new to the Multi-hazard Loss Estimation Methodology (HAZUS) program. All were familiar with Google Earth^{TM} (GoogleEarth™ 2013). None had previous experience using the Federal Emergency Management Agency National Flood Hazard Layer Keyhole Markup Language zipped file interface (FEMA and GoogleEarth™ 2011, FEMA and GoogleEarth™ 2013). They worked part-time, so the training spanned a four-month time period. The average time required for each GIS technician to complete initial training in the use of the national GIS software models was 151.13 hours. The research assistant with previous training in ESRI ArcGIS™ required less than the average amount of time for initial training, 148 hours total. The average time required for each GIS technician to complete initial training in the use of the stakeholder-built models was 36.25 hours. The research assistant with previous training in ESRI ArcGIS™ required less than the average amount of time for initial training, 22.5 hours total.

Figure 14: Unit-effort by geographic information system (GIS) technicians per consecutive flood risk management meeting map preparation for each computer-assisted decision support system method: the national GIS software and the stakeholder-built



Following the initial training, the unit-effort required to prepare the maps for each meeting was lower for the stakeholder-built models, with a mean unit-effort of 12.5 hours per meeting, as compared to the national GIS software model mean of 31 hours per meeting (Figure 15). The unit-effort calculated for each meeting included the total number of hours for all technicians working on the map preparation. This total was used because, after initial training, the mapping tasks were divided among the technicians. Each technician did not complete the entire set of maps needed per meeting. The unit-effort required for the stakeholder-built map preparation per meeting was more consistent from one community preparation to the next as compared to the national GIS software model. Map preparation using the stakeholder-built model varied 1.22 hours from one meeting to another. The national GIS software map preparation varied 20.14 hours in unit-effort from one meeting to another.

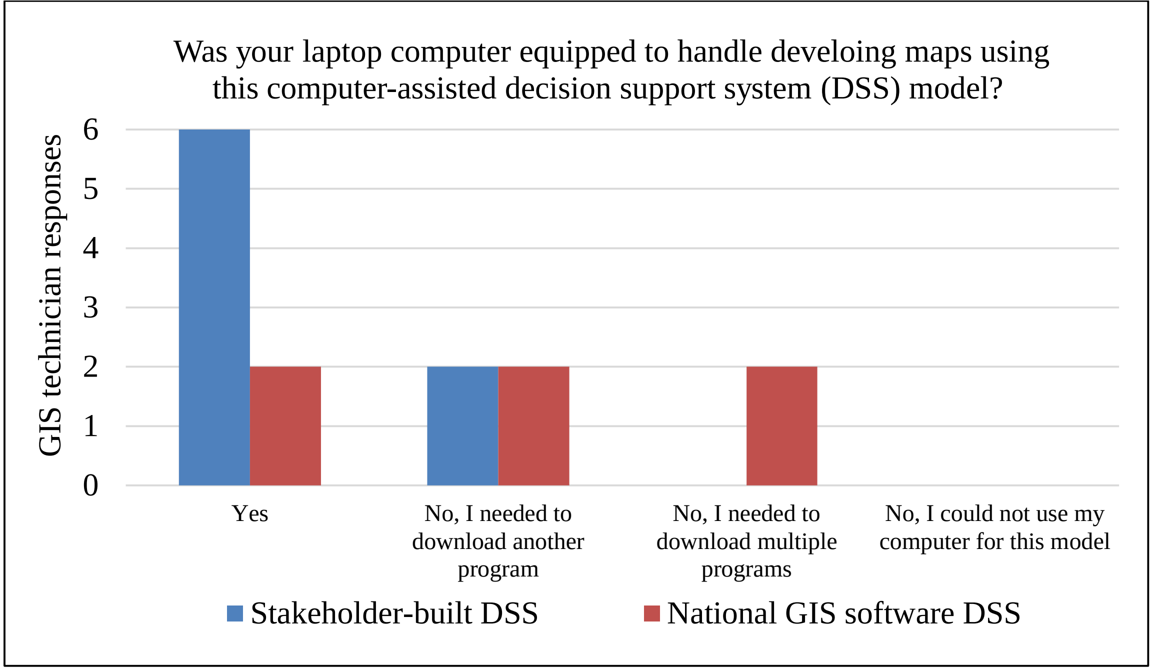
Figure 15: Unit-effort required per flood risk management meeting for map preparation following initial geographic information systems (GIS) technician training for each computer-assisted decision support system method: the national GIS software and the stakeholder-built



Survey of ease of use for computer-assisted decision support system methods

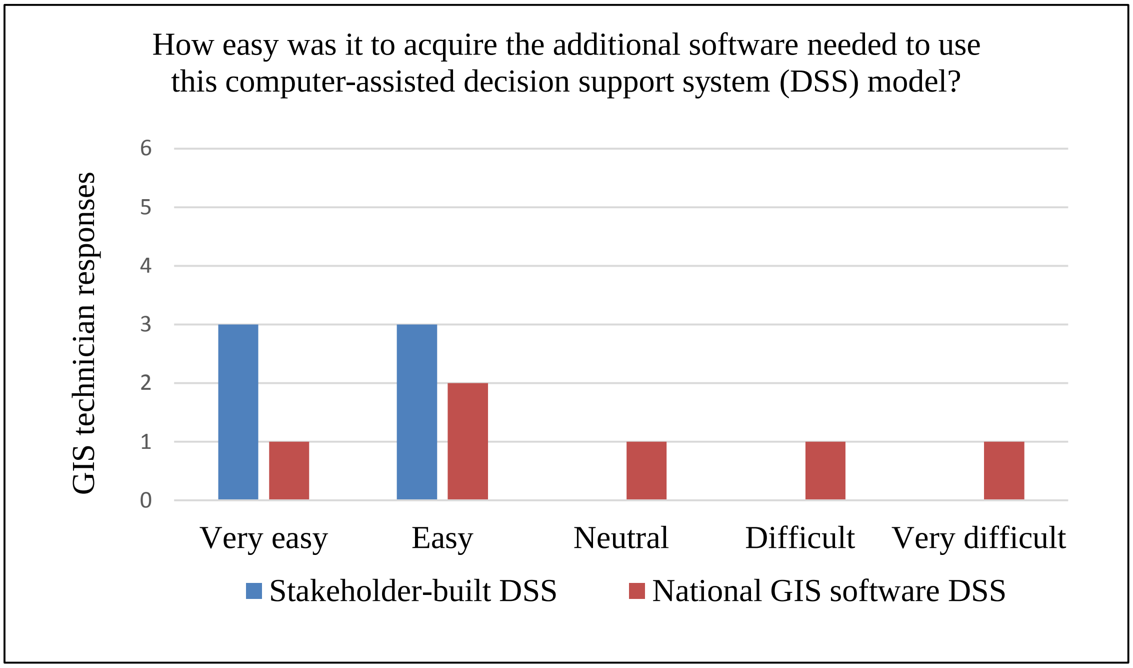
All six research assistants stated they were able to run the software required for both computer-assisted decision support system (DSS) models on their personal laptop computers (Figure 16).

Figure 16: Geographic information systems (GIS) technicians' survey responses to hardware and software requirements for the two computer-assisted decision support system models: the national GIS software and the stakeholder-built



Overall there was a greater need to install additional software in order to run the national GIS software DSS than was needed to run the stakeholder-built DSS (Figure 16). All found the software for the stakeholder-built model was easy to acquire (Figure 17).

Figure 17: Geographic information systems (GIS) technicians' survey responses to software availability for each computer-assisted decision support system model: the national GIS software and the stakeholder-built



The wide range in opinions as to the difficulty of acquiring the national GIS DSS software may be the result of the varying number of times each technician needed to perform a re-installation of the software before it was successful. Some were successful the first time. Others required multiple attempts before the program would run. The MicroSoft^{TM} operating system was much more compatible with the Multi-hazard Loss Estimation Methodology (HAZUS) software than was the operating system used in Apple^{TM} products. Practitioners experienced more error messages when working with the national GIS software program than with the stakeholder-built (Figure 18) and most found the stakeholder-built to be a more user-friendly program (Figure 19).

Figure 18: Geographic information systems (GIS) technicians' survey responses on the reliability of performance of the model-building program for each computer-assisted decision support system model: the national GIS software and the stakeholder-built

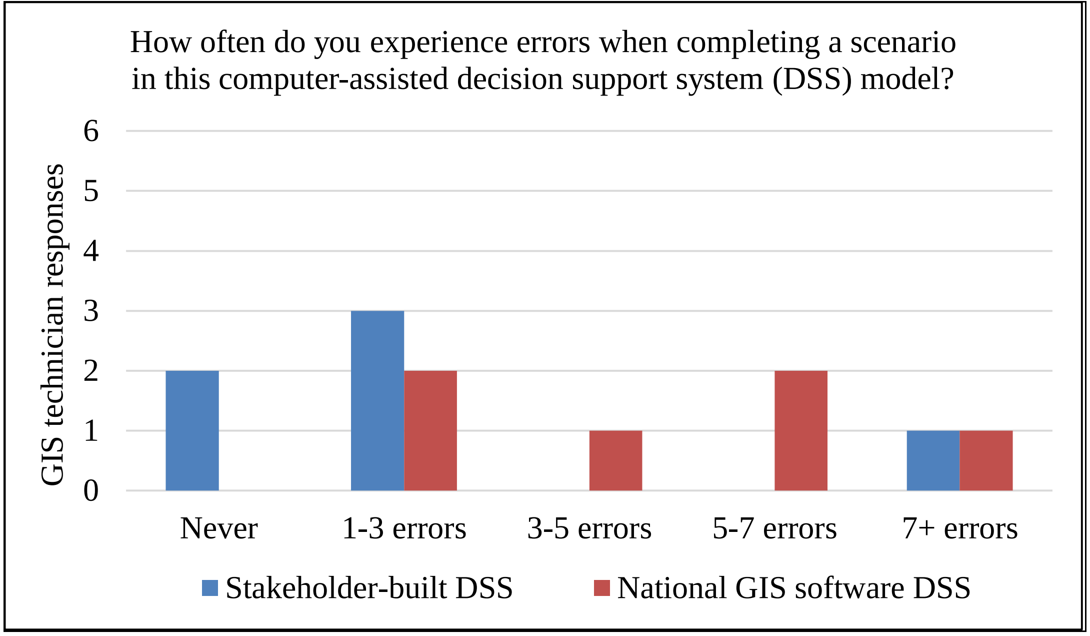
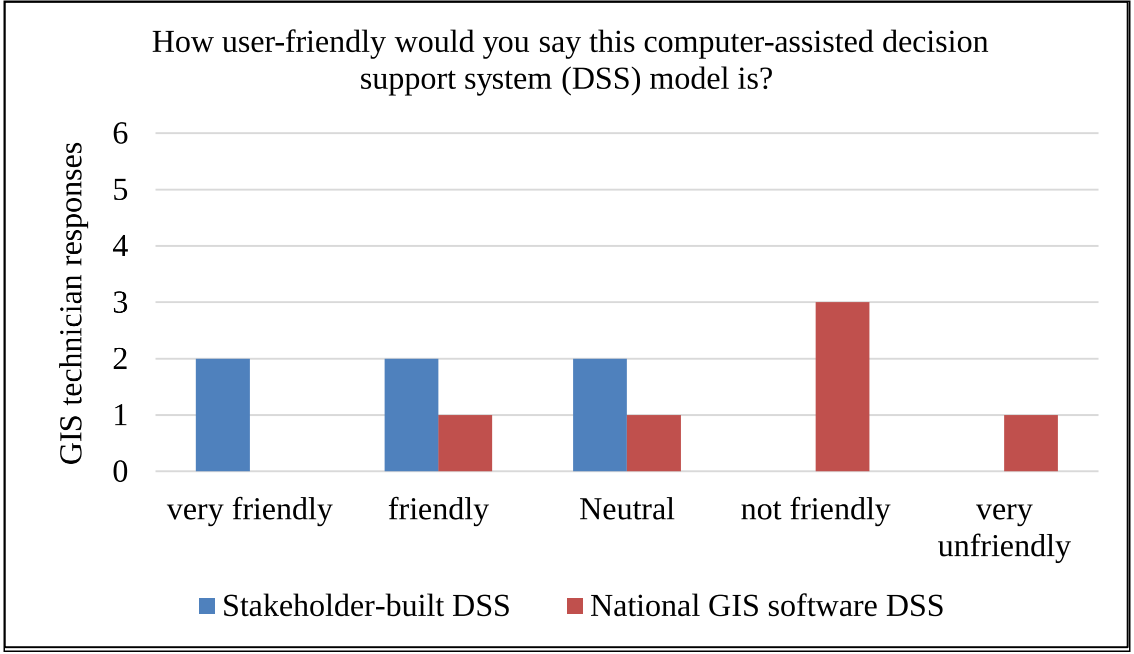
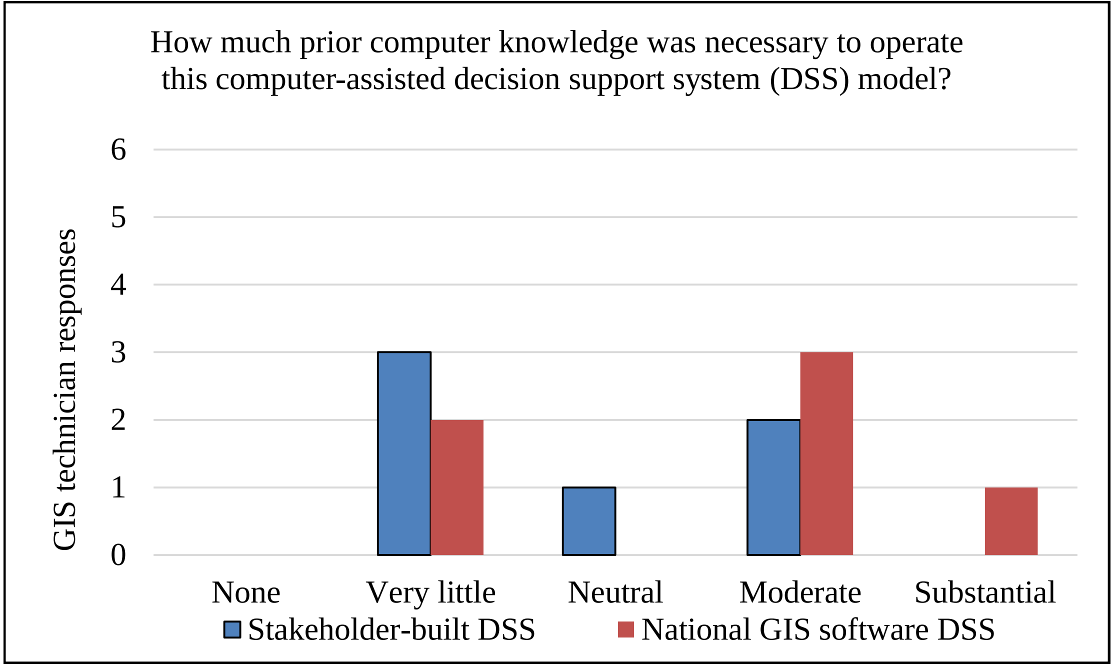


Figure 19: Geographic information systems (GIS) technicians' survey responses to the ease of use of the computer program for constructing each computer-assisted decision support system model: the national GIS software and the stakeholder-built



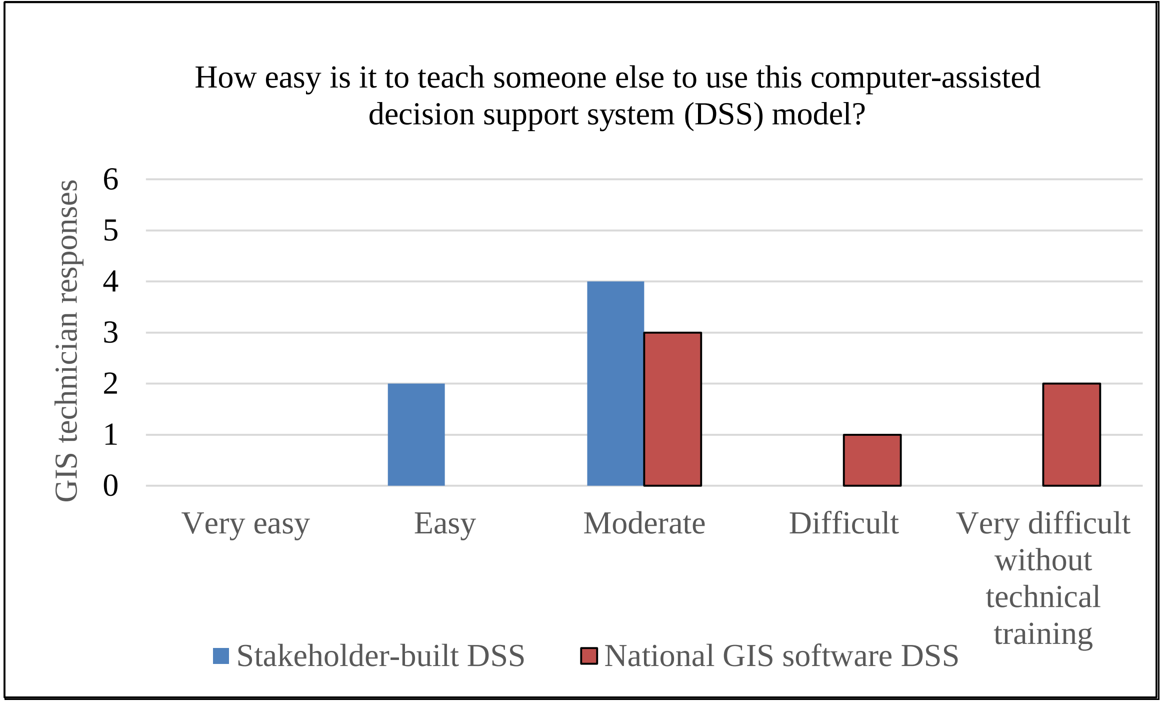
The amount of prior geographical information systems experience the technicians thought was needed to successfully work with each program varied. Overall, the stakeholder-built DSS model was considered to require less prior experience than the national GIS software DSS (Figure 20).

Figure 20: Geographic information systems (GIS) technicians' opinion of prior experience needed to successfully work with each computer-assisted decision support system model: the national GIS software and the stakeholder-built



The stakeholder-built DSS model was rated easy to moderate for teaching others to use. None of the technicians considered the national GIS software model to be easy to teach others. 50% of the technicians considered the national GIS software model to be difficult to teach to others. None held that opinion of the stakeholder-built model (Figure 21).

Figure 21: Geographic information systems (GIS) technicians' survey responses addressing the ease of teaching the use of each computer-assisted decision support system model: the national GIS software and the stakeholder-built



Interpretation of study results

The lower cost of investment in training geographic information systems technicians to run the stakeholder-built computer-assisted decision support system (DSS) as compared to the national GIS software DSS, the greater ease in the acquisition of software for the stakeholder-built DSS, and the user-friendly aspects of the stakeholder-built DSS give this method the advantage when utilized in flood risk management meetings designed to communicate flood risk information to end-users, the stakeholders in local communities.

Chapter III: Do all demographic sectors of the population have access to information through participation in community-level flood risk management meetings?

Introduction

When communicating flood risk information, the intent is to reach out to all sectors of the population at risk and include them in the community meetings. Past studies show that certain segments of the population may be underrepresented at these meetings. Factors that may influence individual participation rates include income, ethnicity, education, gender, age, and home ownership (Adger, Kelly et al. 2001, Bullinger, Ziegler et al. 2002, Cutter, Barnes et al. 2008, Ibarrarian and Ruth 2009, Patt, Daze et al. 2009, CFI_Group 2010, Cutter, Burton et al. 2010, Hvistendahl 2012, Miller 2012). Some communities choose not to participate in government insurance programs such as the national Flood Insurance Program because they either do not have the municipal funds to dedicate to complying with the required prerequisites or they do not trust programs sponsored by the Federal government. Non-participants are most often poor and/or minority communities (Ibarrarian and Ruth 2009). These communities have limited assets to dedicate to risk-reduction measures, limited access to credit markets from which to borrow the needed funds, and less access to government officials who could introduce them to the programs (Ibarrarian and Ruth 2009). Segregated minority communities are less likely to participate in government outreach programs (Ibarrarian and Ruth 2009). This may be due to a lack of trust based on past experience with government programs (Ibarrarian and Ruth 2009). In other cases, language barriers to receiving information about the programs in brochures, websites, meeting announcements, and other English-only communications may be a barrier to attendance (Ibarrarian and Ruth 2009, Cutter, Burton et al. 2010). Cultural norms that differ from that assumed in the design of government programs, such as multiple families living in one housing unit, may also pose barriers (Ibarrarian and Ruth 2009).

These barriers to community participation also exist for individual households living within participating communities (Ibarrarian and Ruth 2009). Those with low household income lack resources to purchase high quality, flood-protected land and the retrofits that make staying on flood-prone ground less hazardous (Adger, Kelly et al. 2001, Ibarrarian and Ruth 2009, Cutter, Burton et al. 2010). This lack of resources may lead to the perception that a meeting on risk reduction is irrelevant. Other barriers to attendance for low-income households may include the cost of childcare or eldercare (Cutter, Boruff et al. 2003, Ibarrarian and Ruth 2009) and the cost of transportation to the meeting (Ibarrarian and Ruth 2009, Cutter, Burton et al. 2010). Low wage-earners also tend to have jobs that are less flexible (Adger, Kelly et al. 2001, Ibarrarian and Ruth 2009) resulting in an inability to attend meetings scheduled during their work hours. A lack of education can result in less awareness of the program and associated meetings due to illiteracy (Ibarrarian and Ruth 2009, Patt, Daze et al. 2009, Cutter, Burton et al. 2010).

Gender has the potential to play the strongest role in meeting participation. Women are more likely to be poor, be less educated, have less flexibility in their work schedule, bare the greatest responsibility for child and eldercare, and lack social status, resulting in the denial of participation in decision-making (Cutter, Boruff et al. 2003, Ibarrarian and Ruth 2009, Patt, Daze et al. 2009). These factors can lead to male-dominated meeting attendance.

Individuals who perceive their social status to be different from other meeting participants may avoid attending because they predict the experience will be unpleasant. Household income, ethnicity, gender, and education can contribute to perceived differences in social status (Cutter, Boruff et al. 2003, Ibarrarian and Ruth 2009, Patt, Daze et al. 2009).

Whether an individual owns or rents their home may make a difference in participation (Cutter, Boruff et al. 2003, Cutter, Barnes et al. 2008, CFI_Group 2010, Cutter, Burton et al. 2010). Those renting may perceive the responsibility for reducing flood risk as belonging to the property owner and may therefore consider the meetings irrelevant.

Age can also be a factor (Cutter, Burton et al. 2010). The elderly are more likely to have health conditions that prevent attendance (Cutter, Boruff et al. 2003, Ibarrarian and Ruth 2009). Lack of personal contact and distrust of strangers decreases access to assistance. The elderly are more likely to perceive prevention programs as welfare (Ibarrarian and Ruth 2009) and avoid participation because they want to maintain their independence from ‘government handouts.’

Because these demographic factors may influence who receives information about flood risk, analyses of the characteristics of participants were conducted at the Federal Emergency Management Agency (FEMA)-endorsed flood risk management meetings (Bollinger 2013a) in the ten communities selected for this study within FEMA Region III (Figure 1) (FEMA 2010a). These analyses indicated whether or not meeting participants were a true representation of the population in FEMA Region III based on the characteristics surveyed.

Methods

At the start of each flood risk management meeting, participants were asked to complete a written survey that included self-reported demographic information on their gender, age, race, education, language, household income, and home ownership (Appendix 10). Each demographic category had at least two levels from which the participant was asked to choose. The number of levels and description of each matched those included in the U.S. Census Bureau (USCB) 2010 census (USCB 2010). The data from each participant were pooled within the community where the flood risk management meeting was held so that the proportions at each level of each demographic characteristic surveyed could be described for the community. In addition, the demographic information from all meeting participants in all ten communities were pooled into one group to identify the demographic proportions of all meeting participants combined and analyzed as if it were a sample taken from the Federal Emergency Management Agency (FEMA) Region III population. The data collected from the participant surveys is available upon request. The USCB 2010 census collected the total number of individuals self-reporting demographic information on their gender, age, race, education, language, household income, and home ownership at the state level. For the analyses in this study, the information for each state in FEMA Region III was combined to describe the Region III population. The totals were normalized by calculating the Region III proportions of the population at each level of each demographic characteristic surveyed (Appendix Table 1). The proportions at the community level and the Region III population level were then compared.

Univariate and multivariate statistical analyses were used to address whether participants in the flood risk management meetings were representative of all demographic sectors in the Region III population. The levels within each demographic characteristic surveyed were calculated as proportions of that characteristic based on the distribution of the demographics of participants within each community. The population demographic proportions were based on the USCB 2010 census (USCB 2010).

Univariate analyses

To find where the demographic differences between the Region III population and the communities participating in this study's flood risk management meetings were significant, the proportions at each level within each demographic characteristic for the ten-community aggregate were calculated. Then, for each demographic characteristics: gender, age, race, language spoken, educational attainment, household income, and home ownership, the 95% confidence interval (CI) was calculated. The CI was the range of values for the proportions for each demographic level that would be expected to contain the population value, given a population size of 29,829,606 and a sample size of 10 communities within which there were 98 participants. Details of the statistical analyses are located in Appendix 11. The population proportions for each level within each demographic characteristic calculated using the U.S. Census Bureau 2010 census (Appendix Table 1) were then identified as values within or outside the respective CI. If the population proportion was within the CI, it was determined that there was no significant difference between the demographic characteristic of the meeting participants in the ten communities and the general population in Region III. If the population proportion was outside the CI, the demographic characteristic of the meeting participants in the ten communities was considered significantly different from the general population in Region III. Where a significant difference was found, the population proportion was compared to the value for the combined ten communities to determine whether the community proportion was higher or lower than the population proportion.

Multivariate analyses

The univariate analyses described demographic comparisons between meeting participants and the Region III population by examining each level within each demographic characteristic independently. A multivariate analysis was performed to describe all levels of all seven demographic characteristics simultaneously for each of the ten communities in which a flood risk management meeting was conducted and for the population in Region III. A unit that represents the aggregate of all ten communities was included in the analysis. The multivariate analysis grouped these in clusters based on their overall demographic similarity. The Statistical Analysis System^{TM} (SAS) TREE Procedure: Ward's Minimum Variance Cluster Analysis (SAS 2012) was used for this multivariate analysis (see Appendix 11 for details of the analysis).

Principal Component Analysis was performed to address the interrelationships among the demographic characteristics. A multidimensional preference analysis based on the first two principal components was performed for the purpose of showing relationships between each of the ten communities, the Region III population, and vectors of each of the levels of the original demographic characteristics (see Appendix 11 for details of this analysis).

Results

Univariate analyses

The 95% confidence interval based on demographics of meeting participants in the ten communities for age, educational attainment, language spoken, household income, and home ownership had at least one level that did not include the related population proportions. The participants' demographic characteristics for gender and race included the population proportions at all levels (Table 5).

Table 5: Demographic differences between flood risk management meeting participants in ten communities and the Federal Emergency Management Agency (FEMA) Region III population

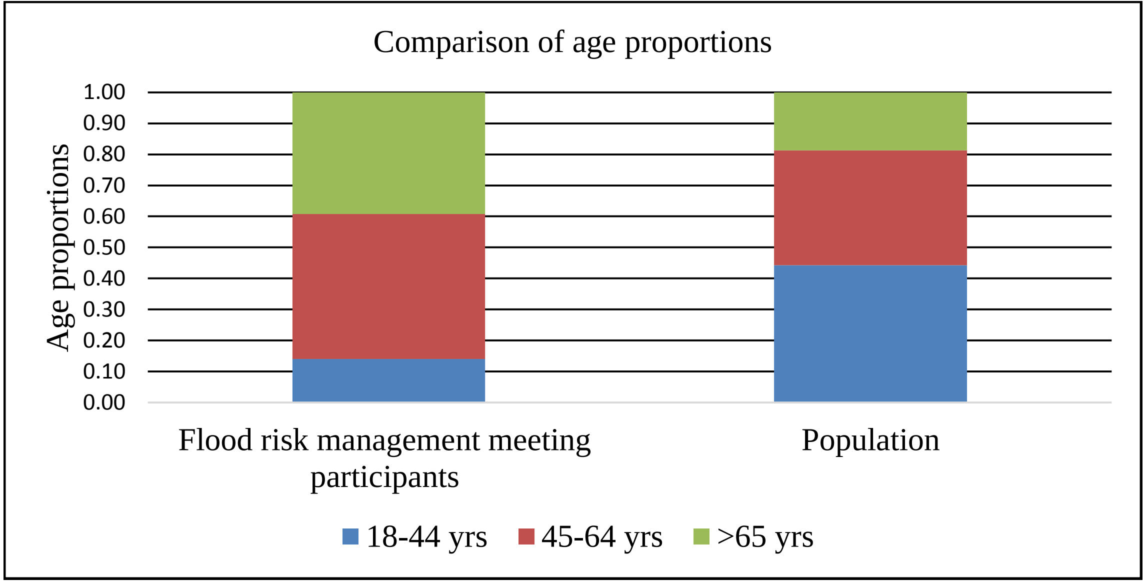
Demographic characteristic	A	B	C	D	Significant difference	E
Gender						
female	0.51	0.38	0.65	0.51	no	
male	0.49	0.35	0.62	0.49	no	
Age						
65 years of age or older	0.39	0.24	0.54	0.19	yes	higher
45-64 years	0.47	0.33	0.61	0.37	no	
18-44 years	0.14	0.03	0.25	0.44	yes	lower
Race						
Asian	0.02	0	0.05	0.04	no	
African American	0.18	0	0.39	0.17	no	
White	0.77	0.54	0.99	0.74	no	
multi-racial	0.04	0	0.08	0.02	no	
Education						
less than a high school diploma	0.01	0	0.03	0.13	yes	lower
high school diploma or equivalency credential	0.11	0.05	0.17	0.32	yes	lower
Associate degree	0.22	0.14	0.31	0.25	no	
Bachelor degree	0.28	0.19	0.37	0.18	yes	higher
graduate degree	0.36	0.26	0.45	0.13	yes	higher

No educational level provided	0.02	0	0.05	0.00	no	
Language spoken						
English only speakers	0.98	0.96	1	0.88	yes	higher
No language information provided	0.02	0	0.04	0.00	no	
Household yearly income						
< 35K (K=$1,000 U.S. dollars)	0.10	0.04	0.16	0.31	yes	lower
35K-50K	0.09	0.04	0.15	0.13	no	
50K-75K	0.14	0.07	0.21	0.18	no	
75K-100K	0.13	0.07	0.20	0.13	no	
100-150K	0.15	0.08	0.22	0.14	no	
150-200K	0.13	0.07	0.20	0.06	no	
>200K	0.08	0.03	0.14	0.06	no	
No income information provided	0.17	0.10	0.24	0.01	yes	higher
Home ownership						
own	0.86	0.75	0.97	0.68	yes	higher
rent	0.08	0	0.17	0.32	yes	lower
No ownership information provided	0.01	0	0.03	0.00	no	

Legend:
A = Demographic proportions for meeting participants in the ten communities
B = Minimum value within the 95% confidence interval (CI) for meeting participant proportions
C = Maximum value within the 95% CI for meeting participant proportions
D = FEMA Region III population proportions
E = Meeting participant proportions relative to FEMA Region III population proportions

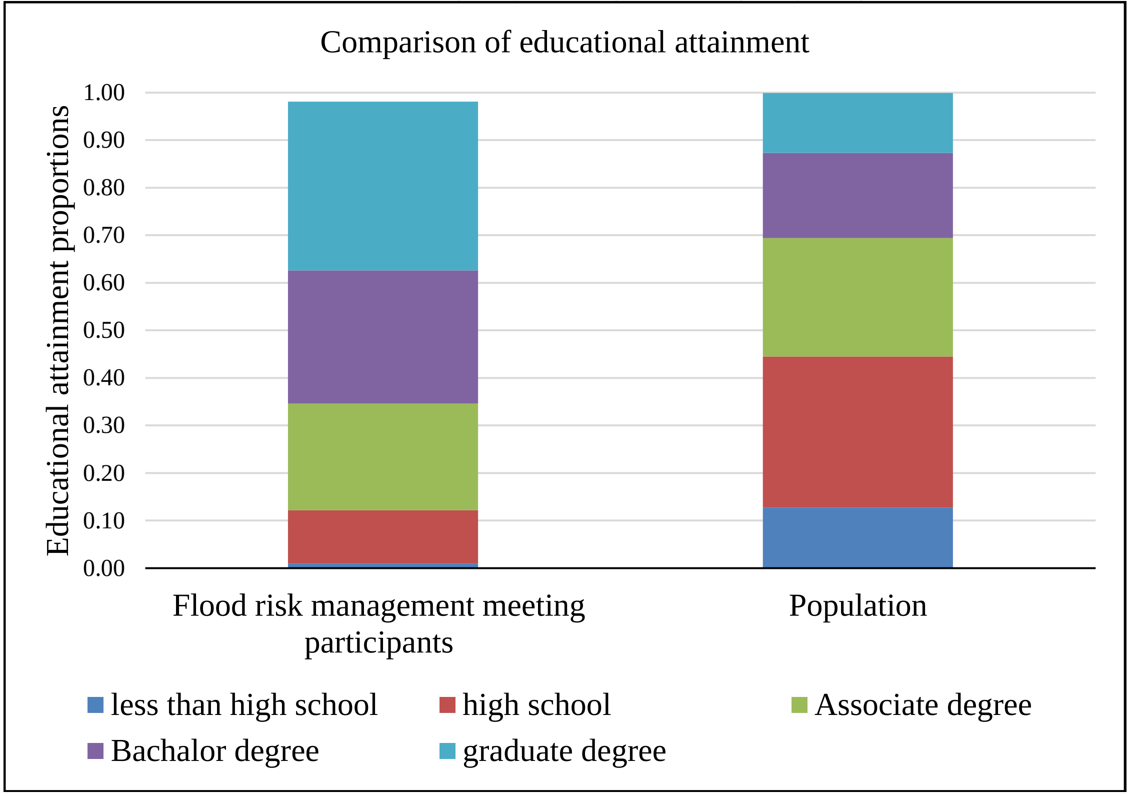
Representation in the oldest age level was significantly higher for the flood risk management meeting participants in the ten communities as compared to the population in Federal Emergency Management Agency (FEMA) Region III (Table 5 and Figure 22). Representation in the youngest age level was significantly lower for the flood risk management meeting participants as compared to the population for the youngest age level (Table 5 and Figure 22). Particularly noteworthy is that no flood risk management meeting participants in the ten communities were in the age category of 18-20 years. This was the youngest age group to whom the survey was available since the survey was given to adults only. The youngest participants are in the category of 21-44 years of age.

Figure 22: Comparison of age distributions for flood risk management meeting participants in ten communities and the Federal Emergency Management Agency Region III population



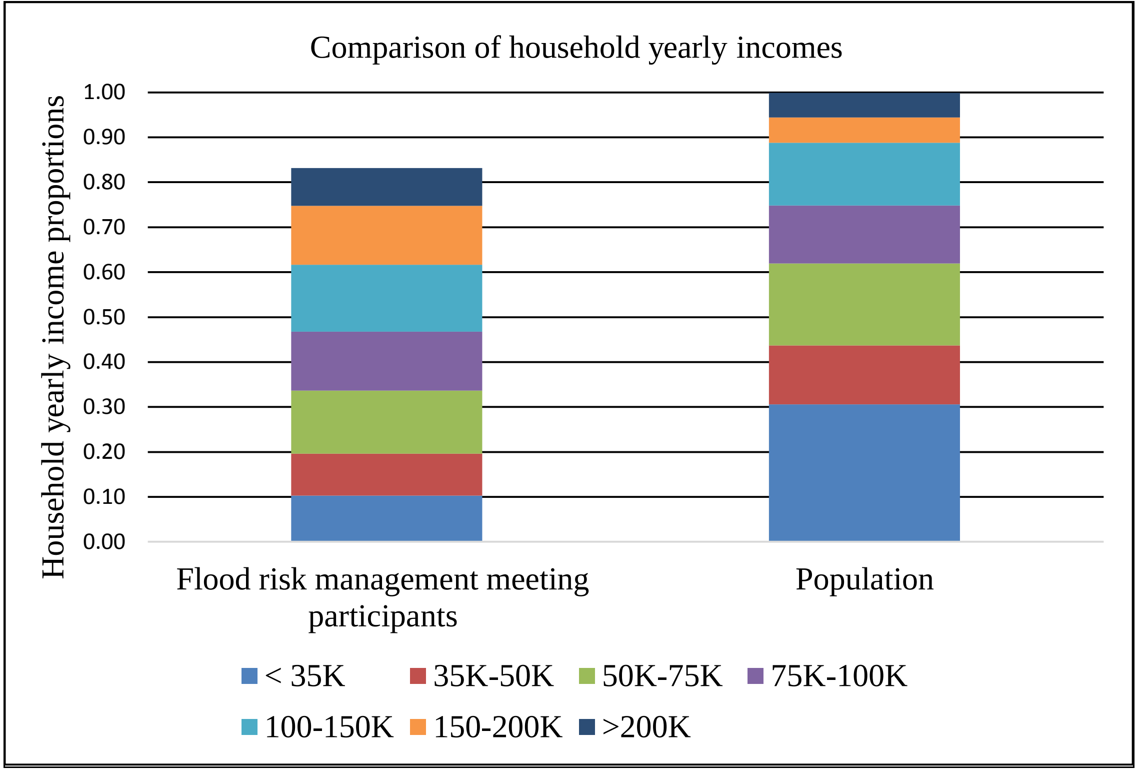
Flood risk management meeting participants in the ten communities are significantly better educated as compared to the population in FEMA Region III (Table 5 and Figure 23).

Figure 23: Comparison of educational attainment for meeting participants in ten communities and the Federal Emergency Management Agency Region III population



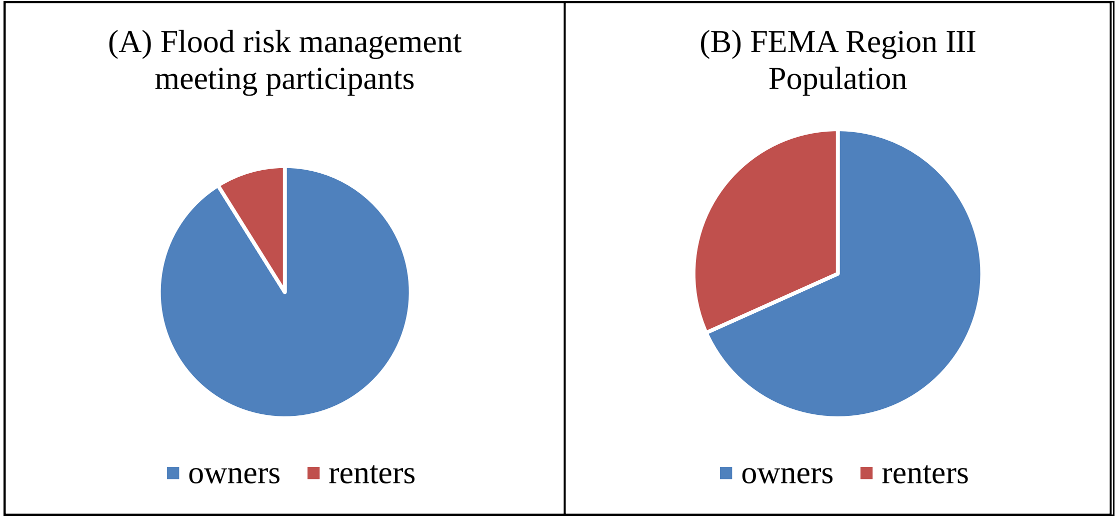
The flood risk management meeting participants (U.S. 2013 dollars) were not significantly different from the FEMA Region III population (U.S. 2010 dollars) in the distribution of yearly household incomes except in the lowest income level (Table 5 and Figure 24). The flood risk management meeting participants differed significantly in the lower proportion of yearly household incomes below $35,000. There were a significant number of participants that did not report their income on the survey. Since information on the income of those who chose not to report is unknown, it is possible that they are low-income households that did not wish to be identified as such. If this is the case, there would be no significant difference between the income of the meeting participants and the general population.

Figure 24: Comparison of household yearly incomes for meeting participants in ten communities (K = $1,000 in 2013 U.S. dollars) and the Federal Emergency Management Agency Region III population (K = $1,000 in 2010 U.S. dollars)



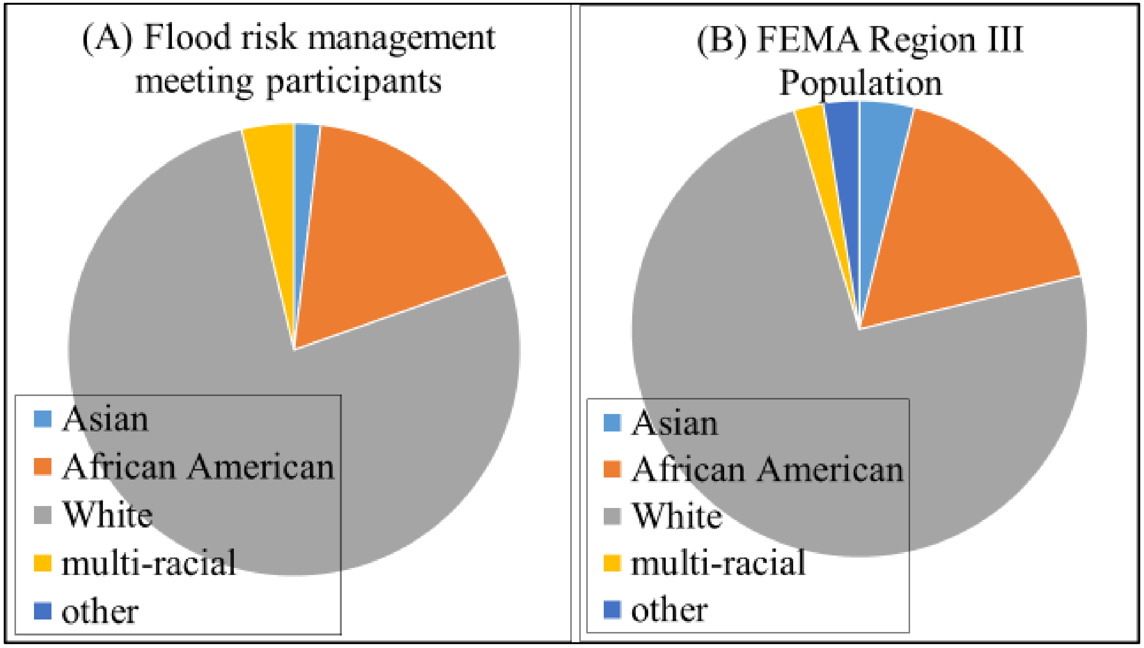
Those owning their property were significantly more likely to attend meetings than those renting (Table 5 and Figure 25A).

Figure 25: Comparison of home-ownership proportions for flood risk management meeting participants in ten communities and the Federal Emergency Management Agency (FEMA) Region III population



There was no evidence of significant differences in gender and race (Table 5 and Figure 26). Although statistically insignificant across all races, the "other" races category was not represented among the meeting participants (Figure 26A). This group comprised 2.54% of the U.S. Census Bureau data for the FEMA Region III population (USCB 2010) (Figure 26B). "Other" races included American Indian and Alaska Native, Native Hawaiian and other Pacific Islander, and "some other race" (Appendix Table 1).

Figure 26: Comparison of race distributions for the meeting participants in ten communities and the Federal Emergency Management Agency (FEMA) Region III population

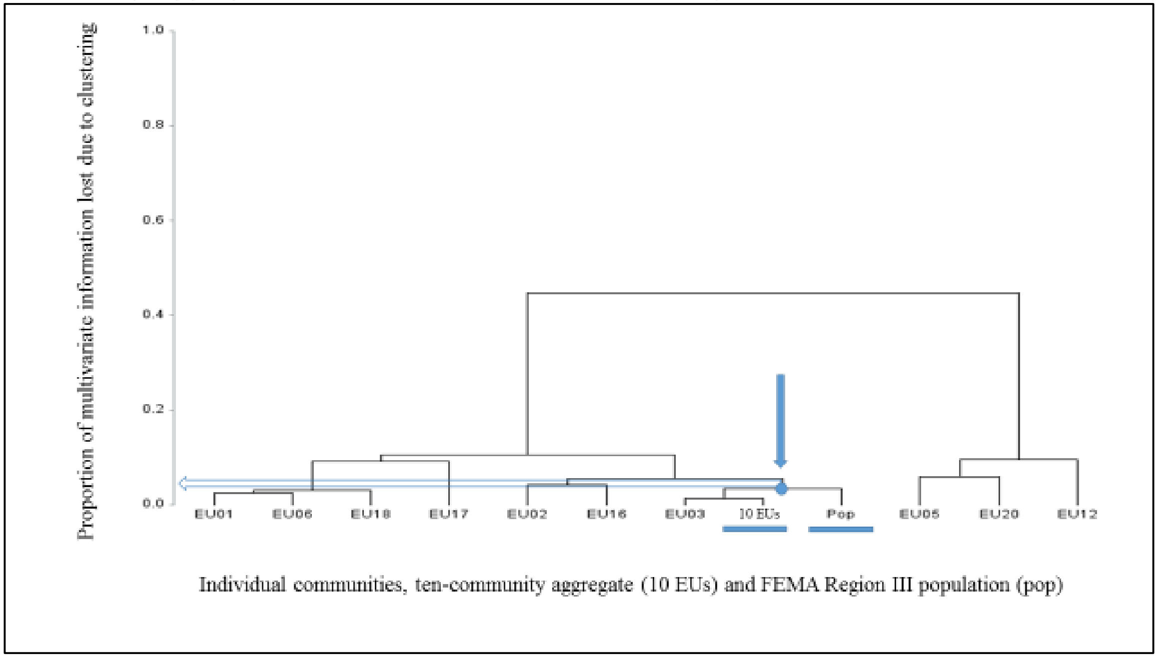


In summary, the univariate analyses indicated meeting participants were older, English-only speakers, better educated, from household incomes above $35,000 per year, and more likely to own a home than data indicated for the general population in FEMA Region III. There was no significant difference in gender or race.

<u>Multivariate analyses</u>

The univariate analyses in the section above described demographic comparisons between the flood risk management meeting participants and the Federal Emergency Management Agency (FEMA) Region III population by examining each level within each demographic characteristic independently. The multivariate cluster analysis compared all levels of all seven demographic characteristics simultaneously. Demographic similarities of the ten communities that participated in flood risk management meetings were compared with the data from the FEMA Region III population (Figure 27). A unit that represents the aggregate of all ten communities (Figure 27: “10 EUs”) was included in the analysis. The analysis formed clusters of units with similar overall demographic characteristics. Results showed on a scale of 0 to 1.0 (Y axis in Figure 27), the proportion of multivariate information lost in forming a cluster. The cluster that includes the unit representing the ten-community aggregate and the FEMA Region III population lost approximately 0.025 of the original information about each unit in order to describe the cluster (Figure 27). When the scale of 0 to 1.0 is converted to a scale of 0 to 100, the results can be interpreted as the percent difference between the demographics of the units within a cluster. This indicates only a 2.5% difference between the ten-community aggregate and the Region III population.

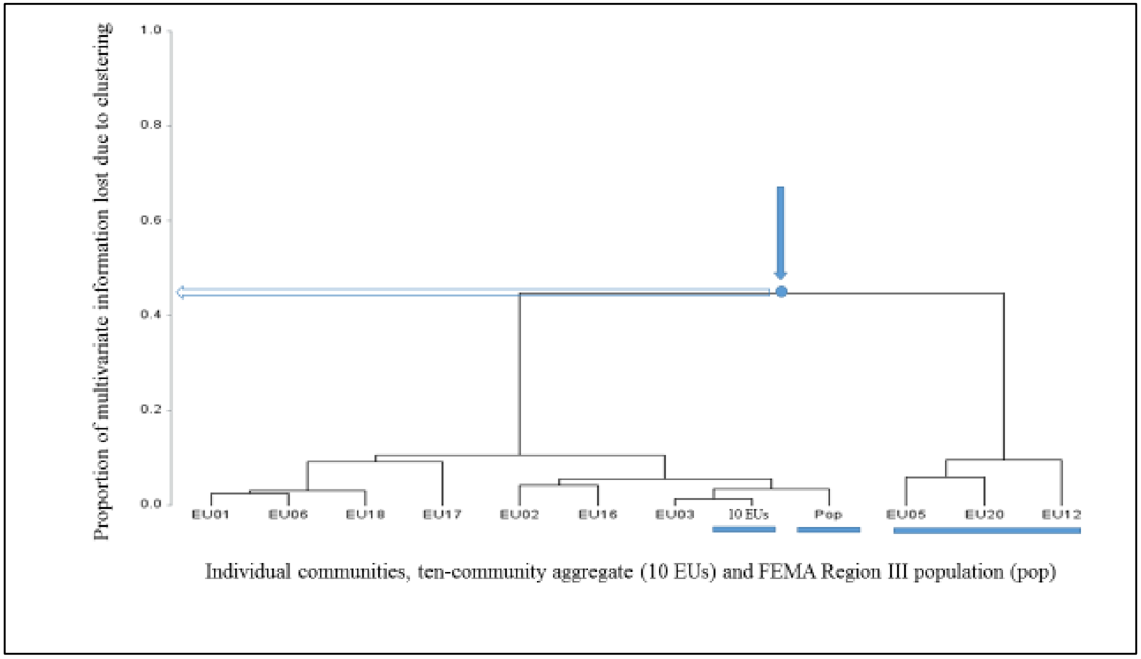
Figure 27: Demographic similarities of ten communities that participated in flood risk management meetings compared with the data from the Federal Emergency Management Agency (FEMA) Region III population. The vertical blue arrow points to the node of the cluster that contains the unit that represents the aggregate of all ten communities (10 EUs) and the Region III population (pop). The horizontal blue arrow points to the proportion of information that is lost in order to form the cluster describing the ten-community aggregate and the population (approximately 0.025 on the Y axis).



Legend:
EU(#) = demographic characteristics of participants at a single community flood risk management meeting
“10 EUs” = demographic characteristics of participants in all ten communities combined
“Pop” = demographic characteristics of the FEMA Region III population (USCB, 2010)

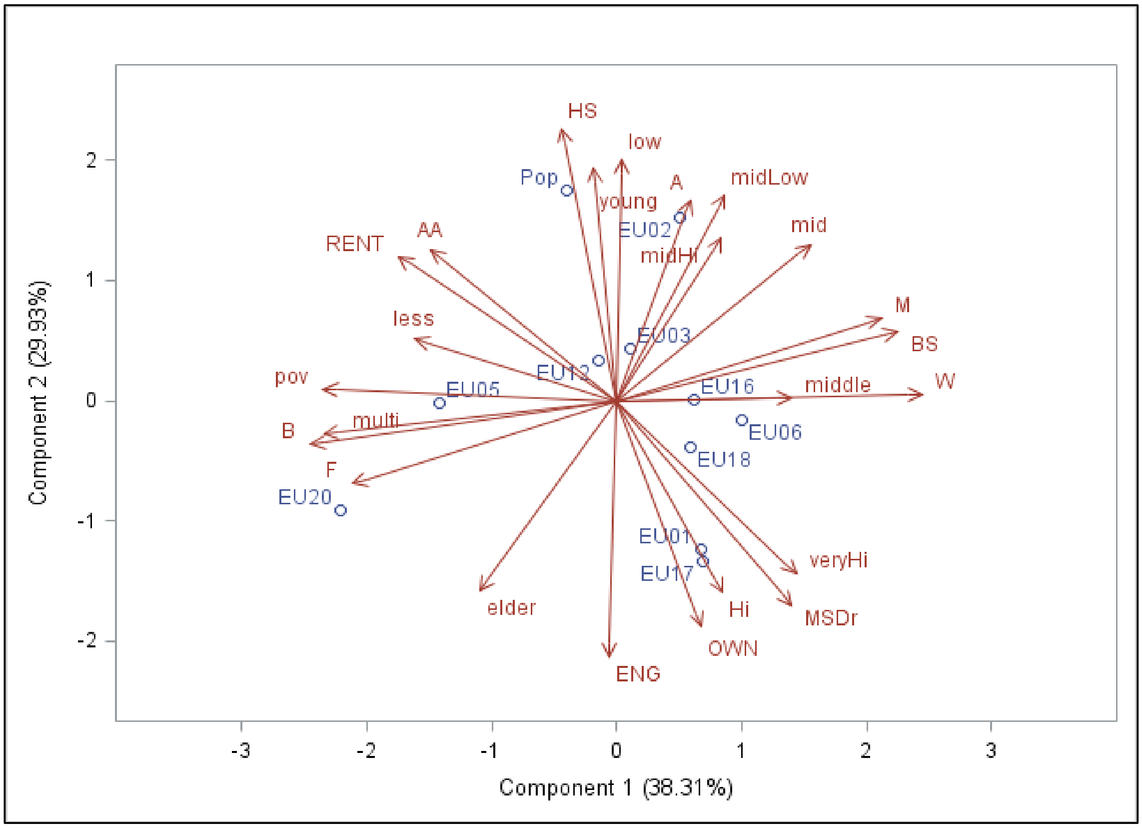
Upon examining demographic similarities between individual communities, one cluster, which included the flood risk management meeting communities labeled “EU05”, “EU20” and “EU12” (Figure 28 cluster on far right), shared approximately 55% of their overall demographic character with the other communities, the aggregate of the ten communities, and the population in FEMA Region III (Figure 28). The other communities were a much closer match to one another and the FEMA Region III population. To find which demographic characteristics explained the largest proportion of the difference between this distant three-community cluster and the others, a Principal Component Analysis (PCA) was performed (SAS 2013). In the PCA graphic (Figure 29), the ten communities receiving flood risk management meetings, the FEMA Region III population, and vectors representing the original demographic characteristics are displayed. Those that are most similar are located closest to one another. The three communities located in the most distant cluster in Figure 28, labeled “EU05”, “EU20” and “EU 12,” differ from the population, “pop,” in Figure 29, by gender: more female, “F,” participants; race: more Black/African American, “A,” and bi-racial, “multi,” participants; and yearly household income: more with incomes less than $35,000 (U.S. 2013 dollars) per year, “< $35K” (Figure 29). These three communities, by chance, were the first three surveyed. The aggregate of the ten communities showed no significant difference in race or gender between the participants and the population at large (Table 5). As the number of communities in the survey increased, their aggregate demographic similarity to the population increased.

Figure 28: Demographic similarities of ten communities that participated in flood risk management meetings compared with the data from the Federal Emergency Management Agency (FEMA) Region III population. The blue arrows indicate the point at which the most distant three-community cluster (“EU05” “EU20” “EU12”) diverges from the other communities and the FEMA Region III population (“pop”) in demographic similarity.



Legend:
EU(#) = demographic characteristics of participants at a single community flood risk management meeting
“10 EUs” = demographic characteristics of participants in all ten communities combined
“Pop” = demographic characteristics of FEMA Region III population (USCB, 2010)

Figure 29: Multidimensional preference analysis based on the first two principal components showing relationships between the communities participating in flood risk management meetings, the Federal Emergency Management Agency (FEMA) Region III population, and vectors representing the original demographic characteristics. The first and second principal components together explain 68.24% (38.31 and 29.93%, respectively) of the variation of the multiple responses used.



Legend:
“EU(#) ○” in blue text = demographic characteristics of participants at a single community flood risk management meeting
“Pop ○” in blue text = demographic characteristics of FEMA Region III population (USCB, 2010)
“Component (#)” labels on axes = combination of inter-dependent original variables that explains a percentage (shown in parentheses in axes labels) of the overall demographic character of participants in all ten communities combined
Original demographic characteristics = principal component analysis symbol in the third column below shown in the multidimensional preference analysis graphic with associated vector in red text:

Demographic characteristic	Level within each demographic characteristic	Principal component analysis symbol for each level within each demographic characteristic
Gender	female	F
	male	M
Age	65 years of age or older	elder
	45-64 years	middle
	18-44 years	young
Race	Asian	A
	African American	B
	White	W
	multi-racial	multi
Education	less than a high school diploma	less
	high school diploma or equivalency credential	HS
	Associate degree	AA
	Bachelor degree	BS
	graduate degree	MS/Dr
Language spoken	English only speakers	ENG
Household yearly income	< 35K (K = $1, 000 U.S. dollars)	pov
	35K-50K	low
	50K-75K	midLow
	75K-100K	mid
	100-150K	midHi
	150-200K	Hi
	>200K	veryHi
Home ownership	own	OWN
	rent	RENT

Interpretation of results

These results indicate that most demographic sectors of the Region III population are reached during flood risk management meetings. However, within the individual communities, there was often much less diversity. For example, some community meetings were represented primarily by low-income, African American females. Others were represented mainly by middle-aged, white males holding bachelor’s degrees. The message from these findings is that it is important for municipal flood risk managers to organize multiple community meetings in their jurisdiction so that they capture all of the demographically diverse sectors. While overall, the meeting participants were representative of the general population, there were some significant differences when each demographic characteristic was analyzed independently. These results showed the meeting participants were significantly older, English-only speakers, better educated, from households earning more than $35,000 (U.S. 2013 dollars) per year, and more likely to own a home than the U.S. Census Bureau (USCB) data indicate for the Region III population (Table 5, Figures 27, 28, 29 and 30). In contrast to the findings in some past studies, females were as likely to attend meetings as males, minorities were represented equal to their proportion of the population, and the elderly were well represented.

To disseminate flood risk information to those segments of the population that were under-represented, outreach methods need to be developed for young adults ages 18-44, speakers of languages other than English, those without a college education, those with incomes below $35,000, and home renters.

The low representation of participants ages 18-20 could be due to the high mobility of this age group. Many are in temporary housing while attending college and may show less interest in attending local flood risk management meetings (Cutter, Barnes et al. 2008). Since they do not plan to stay long in their present location, they may not consider it worth the investment of time and money to learn about flood risk and invest in reduction options. In college towns where this population is large, it may be advantageous for educational institutions to take the lead in expanding their flood preparedness to cover not only on-campus dormitories, but also off-campus housing where student resident density is high. Low interest in risk-reduction measures may also be due to the ‘invincible’ attitude attributed to this age group, thinking they can survive a flood without much prior preparation.

The significantly low participation rates for 18-44 year-olds may be associated with this group being of child-bearing age. Since there was no significant difference in gender attendance, if childcare is preventing this age group from participating, both parents are involved equally in the task of caring for young children. It is particularly important to reach this group since young children are highly vulnerable to morbidity and mortality during flood events (Suarez, Ribot et al. 2009). This age group is also more likely to be in the early stages of their careers where they may have less flexibility in scheduling their work time around community meetings than is the case for older individuals who are either at a more advanced stage in their career or are retired and, therefore, have more flexibility.

The elderly were well represented at the meetings, particularly by those living independently in homes they own. In the communities participating in flood risk management meetings, 95% of participants older than 64 years of age owned their homes. This is good news because this segment of the population is highly vulnerable to the effects of flooding events (Cutter, Mitchell et al. 2000).

The segment of the population for whom their primary language is not English was without representation among the participants in the community flood risk management meetings. According to the USCB, this is a growing sector in the United States (USCB 2010). The number and percentage of people in the United States who spoke a language other than English at home more than doubled between 1980 and 2000 (Shin and Bruno 2003). Spanish speakers grew by about 60% from 1980 to 2000 and

Spanish continued to be the non-English language most frequently spoken at home in the United States (Shin and Bruno 2003). The Chinese language, however, jumped from the fifth to the second most widely spoken non-English language, as the number of Chinese speakers rose from 1.2 to 2.0 million people (Shin and Bruno 2003). In 2000, most of these households reported they spoke English “very well” (Shin and Bruno 2003). Respondents who said they spoke English “very well” were considered to have no difficulty with English. In the United States, the ability to speak English plays a large role in how well people can perform daily activities. How well a person speaks English may indicate how well he or she communicates with public officials and other service providers. People who do not have a strong command of English and who do not have someone in their household to help them on a regular basis are defined by USCB as “linguistically isolated” (USCB 2010). In 2000, 4.4 million households encompassing 11.9 million people were linguistically isolated (Shin and Bruno 2003). These numbers were significantly higher than in 1990 (Shin and Bruno 2003). With this trend toward an increased number of households speaking English as a second language or speaking no English, the total absence of these groups in the community flood risk management meetings in this study indicates a need for more attention toward finding effective methods of communicating flood risk to those speaking languages other than English.

Meeting participants without a college education and those with yearly household incomes below $35,000 (U.S. 2013 dollars) were underrepresented in the community flood risk management meetings. These segments of the population are particularly vulnerable during floods (Cutter, Mitchell et al. 2000, Cutter, Barnes et al. 2008). Every effort needs to be made to successfully communicate risk information to them so that they have time to prepare for potential flood events.

Another segment of the population underrepresented in the community flood risk management meetings was those that rent their homes. Renters may think of flood insurance as a tool useful only to those who own their property. Flood insurance is available to cover the contents of a home and also to cover the cost of alternative housing (FEMA 2011a). Temporary alternative housing, such as hotel accommodations may be much more expensive than rent paid for regular housing, therefore both types of flood insurance could be useful to renters. In a U.S. nationwide survey conducted by FEMA in 2012, almost 31% of households believed that flood damage was covered by their homeowner's or renter's policy (FEMA 2013). Since most homeowner's and renter's insurance policies do not cover damage resulting from floods, many think they are insured when they are not (FEMA 2013). Adding to the communication problem, they are not discussing the issue with their insurance agents (FEMA 2013). The demographics in the community flood risk management meetings in FEMA Region III showed homeowners were receiving the information, but renters were not attending and therefore not receiving the information they need to make fact-based decisions on reducing their flood risk.

In summary, this study found that most demographic sectors of the Region III population are reached during flood risk management meetings. However, within the individual communities, there was often much less diversity. While overall, the meeting participants were representative of the general population, there were some significant differences when each demographic characteristic was analyzed independently. These results showed the meeting participants were significantly older, English-only speakers, better educated, from households earning more than $35,000 (U.S. 2013 dollars) per year, and more likely to own a home than the U.S. Census Bureau (USCB) data indicate for the Region III population (Table 5, Figures 27, 28, 29 and 30). In contrast to the findings in some past studies, females were as likely to attend meetings as males, minorities were represented equal to their proportion of the population, and the elderly were well represented.

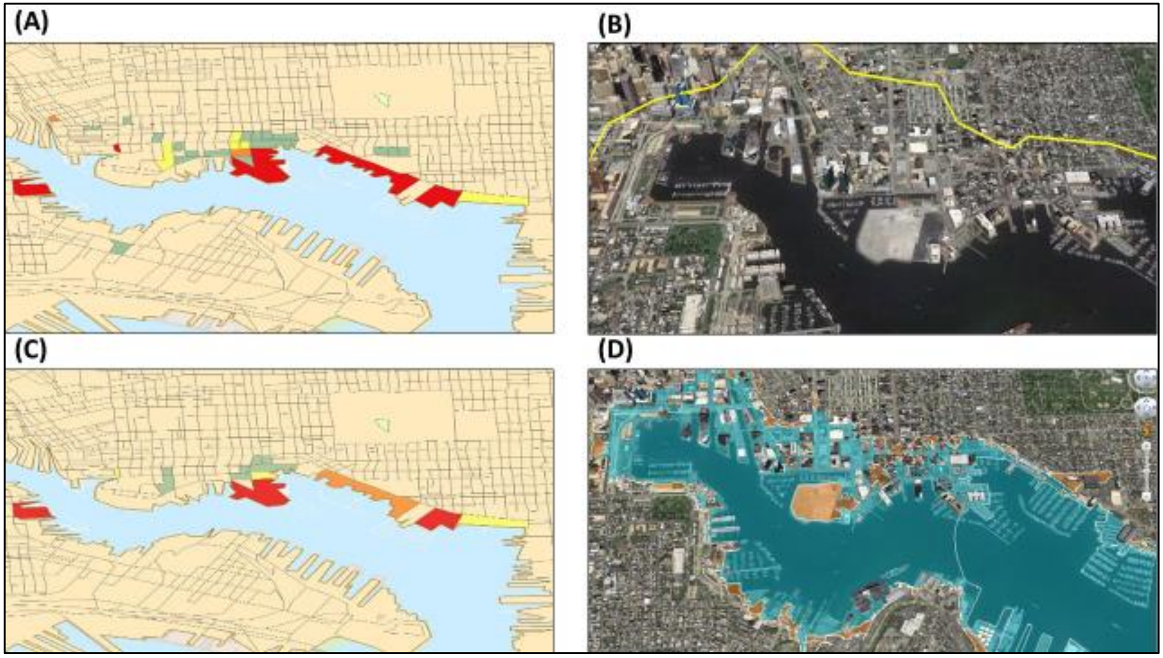
Chapter IV: Does realistic interactive visualization increase knowledge of flood risk communicated to stakeholders?

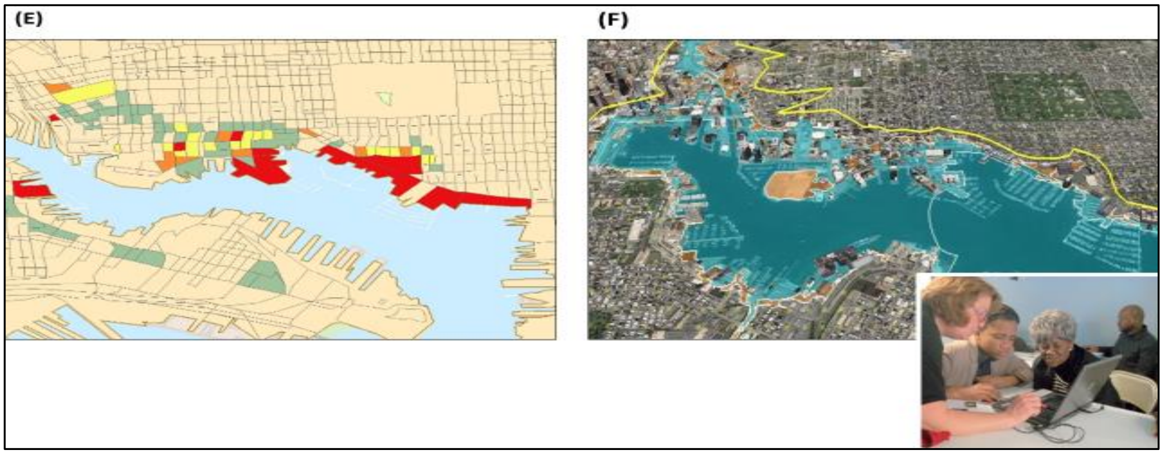
Introduction

Using probabilistic modeling techniques as a method of communicating potential flood risk is a challenge for those who prefer information that is “certain” to be true. Stakeholders, those affected by flooding events, want to be sure any actions they initiate to reduce risk will be necessary. Their time and money are limited. They do not want to spend time or money on actions that address flooding events that never materialize. This level of certainty can be achieved only when modeling past flood events. Once an event occurs, many sources of data are available to determine where the flooding occurred and which risk-reduction actions taken in advance were worth the effort and expense. The exact location and severity of damage associated with future flood events cannot be determined with the same level of certainty as past events. There are too many variables that need to be considered simultaneously when predicting where, when, and how severe the next flood will be. Probabilistic modeling, an iterative process that considers multiple scenarios showing varying “best guesses” based on the available data, is used to anticipate future flood events. The further out in time the predictions are made, the wider the range of possible flood scenarios. Assisting stakeholders in understanding probabilistic modeling with its inherent uncertainty is not an easy task.

In this study, community flood risk management meetings began with models of past flood risk (Figures 30A and 30B). The meetings then progressed to probabilistic modeling of present (Figures 30C and 30D) and anticipated future flood risk (Figures 30E and 30F). The study measured the effectiveness of communicating flood risk to stakeholders using this series of models with the assistance of two different computer-assisted decision support systems (DSS), the stakeholder-built DSS method and the national geographic information systems (GIS) software DSS method presently used by the Federal Emergency Management Agency. The stakeholder-built DSS method made use of realistic visualization when illustrating past (Figure 30B) and present (Figure 30D) flood scenarios. These scenarios were pre-constructed using Google Earth^{TM} realistic images of stakeholders' properties. The stakeholder-built DSS method made use of realistic interactive visualization when modeling the anticipated future flood risk (Figure 30F). For this scenario, the stakeholders built their own model during the meeting. The national GIS software DSS method presented all three of the model scenarios as pre-constructed maps illustrated using polygons and lines typical of most geographic information system formats (Figures 30A, 30B and 30E).

Figure 30: Model output illustrating an historic (past) flooding scenario using (A) the national GIS software computer-assisted decision support system (DSS) method and (B) the stakeholder-built DSS method. Model output illustrating present flood risk using (C) the national GIS software DSS method and (D) the stakeholder-built DSS method. Model output illustrating scenarios for anticipated future flood risk projected over the next 50 years using (E) the national GIS software DSS method and (F) the stakeholder-built DSS method. In (A), (C) and (E), red indicated greatest damage resulting from the flood scenario. Orange, yellow and green indicated decreasing levels of damage in that order. Tan indicated areas where data were not available. The stakeholder-built DSS method shows (B) historic (past) and (D) present flood risk using Google Earth™ images that are pre-constructed and presented to meeting participants. In (B), the yellow line represented the estimated upper limit of flood waters during the historic storm event. The area between the yellow line and the image of water (black area) represented the area flooded during the historic event. In (D), present flood risk was illustrated in the Google Earth™ image by the Federal Emergency Management Agency (FEMA) national Flood Hazard Layer (NFHL) 1% annual flood risk hazard area in blue (FEMA and GoogleEarth™ 2013). In (F), the Google Earth™ image shows the FEMA NFHL 1% annual flood risk hazard area as the blue layer (FEMA and GoogleEarth™ 2013). The yellow line was added by the stakeholder using the Google Earth™ drawing tool guided by Google Earth™ elevation data and represented anticipated flood risk within the next 50 years. The area below the yellow line represented property anticipated to experience flooding.





Methods

Surveys completed by participants in the community flood risk management meetings contained one multiple-choice question that evaluated combined knowledge of past and present flood risk (Appendix 3 Question #1) and one multiple-choice question that evaluated knowledge of anticipated future risk (Appendix 4 Question #1). Pre- and post-surveys were used to distinguish between the knowledge of flood risk gained during the meeting and the knowledge the participant possessed prior to the meeting.

After the meeting, the geographic information systems (GIS) technicians used the address on the Institutional Review Board consent form provided by each stakeholder (Appendix 9) to geo-locate the individual’s property on the maps generated by each computer-assisted decision support system (DSS) model used during the meeting. The property’s location with reference to past, present, and future flood risk was then linked to the stakeholder’s unique identification code and entered in the database. Answers to the survey questions were considered correct if they matched the position of the property with reference to flooding illustrated by the DSS models. For the analyses, each participant’s response was combined with others attending the same meeting and clustered within the community to define the characteristics of the community. To find where the differences were significant, an F-test was used for analysis of variance. In the analyses where there were no significant differences between the two DSS methods in their effect on learning outcomes, t-tests were performed to find where learning was significant as a result of participation in the community flood risk management meetings.

Statistical analyses were also performed to determine the effectiveness of each DSS method based on the GIS background of participants to determine if GIS experience had a significant effect on learning about flood risk.

Statistical analyses were performed to determine whether factors associated with the individual meetings significantly influenced learning outcomes. These included evaluating differences in the individuals serving as the GIS technician and meeting facilitator, the number of meeting assistants available during the meeting, whether or not a municipal planning department representative was available during the meeting to answer questions from participants about flood risk management issues, and the location and condition of the facilities in which the meetings were held.

Results

The results indicated that when realistic visualization was utilized independently (Appendix Table 4) and when it was combined with interactive visualization (Appendix Table 8) to illustrate flood risk in the stakeholder-built computer-assisted decision support system (DSS), both methods performed as well as the national geographic information systems (GIS) software DSS. All resulted in significant learning outcomes: $P < 0.04$ for learning about past and present flood risk (Appendix Table 5) and $P < 0.01$ for learning about anticipated future flood risk (Appendix Table 9). Pre-survey knowledge was found to have a significant positive effect on the participants' knowledge of flood risk ($P < 0.01$) when analyzed as a covariate (Appendix Tables 4 and 8).

The geographic information systems background of meeting participants did not have a significant effect on learning about flood risk. Factors associated with the individual meetings did not significantly influence learning outcomes. Details of these results are located in Appendix 12.

Interpretation of study results

The stakeholder-built computer-assisted decision support system (DSS) method using realistic interactive visualization performed as well as the national geographic information systems (GIS) software DSS in communicating flood risk. Realistic interactive visualization was engaged when participating stakeholders constructed their own models of anticipated future flood risk.

When realistic visualization was utilized independent of interactive visualization to illustrate flood risk in the stakeholder-built DSS, the method performed as well as the national GIS software DSS. Realistic visualization was implemented when geographic information systems technicians produced pre-constructed models that were used to illustrate past and present flood scenarios during the flood risk management meetings.

In all flood risk management meetings, learning about flood risk increased significantly ($P < 0.04$ for learning about past and present flood risk and $P < 0.01$ for learning about anticipated future flood risk). However, pre-survey knowledge was found to have a significant positive effect on the participants' knowledge of flood risk ($P < 0.01$) when analyzed as a covariate. In other words, although the flood risk management meetings resulted in significant learning about flood risk, there was not a sufficient amount of flood risk information presented at the meeting to close the gap between those with prior knowledge and those learning the information for the first time during the meetings. The lesson learned from this is that more than one flood risk management meeting or other method of communicating flood risk to the stakeholder is needed to provide a more complete understanding of risk.

Chapter V: Does realistic interactive visualization increase knowledge of flood risk-reduction options communicated to stakeholders?

Introduction

Most research to date has focused on flood prediction as a method of reducing risk by supplying information to warn the population of the probability and the likely intensity of an event. Some researchers have argued that there may be an overemphasis on the understanding of earth and atmospheric systems in reducing vulnerability to extreme precipitation events at the expense of examining the human behavior that contributes to the creation of a disaster (Pulwarty and Riebsame 1997, Fleetwood 2006, UMCES 2006, Ibarrarian and Ruth 2009, IPET 2009, Malone and Brenkert 2009, Suarez, Ribot et al. 2009). A hurricane or other severe flooding event is a natural phenomenon. A natural disaster does not exist until people and property are placed in harm's way. At this point a natural process becomes a disaster (Berke and Beatley 1997, Ibarrarian and Ruth 2009). The factors that determine exposure to a natural disaster are, to a large extent, based on choices made by individuals. Exposure is the one factor over which each stakeholder has some control. A stakeholder is defined here as an individual or community at risk of flooding. Eliminating exposure is usually impractical. Reducing it is the key to reducing risk.

In addition to providing information about flood risk, an effective means of communicating options for reducing risk that can be implemented at the individual and community level is needed. Many people are not aware of how costly flooding can be.

Just a few inches of water can cause thousands of dollars in damage to property (Hayes 2011, FEMA 2011b, FEMA 2011c).

In the United States, the National Flood Insurance Program (NFIP) offers ways in which a community as a whole can reduce flood risk and provides community-wide insurance discounts based on the effort put forth by the community to exceed the Federal Emergency Management Agency (FEMA) minimum standard flood risk-reduction practices. Participating communities agree to adopt and enforce ordinances that meet or exceed FEMA requirements to reduce the risk of flooding (FEMA 2011c, Bollinger 2013b). Those in the NFIP Floodplain Management Program have experienced a 1.4 billion dollar per year reduction in flood damages, an 80% reduction in damage as compared to levels experienced before participating in the program (Hayes 2011).

Given these high economic incentives for stakeholders to participate in flood risk-reduction options, flood risk managers need effective methods for increasing awareness among community residents of these options and their benefits (Cutter, Mitchell et al. 2000). This study tested the effectiveness of two such methods, a national geographic information systems (GIS) software computer-assisted decision support system (DSS) method represented by the Multi-hazard Loss Estimation Methodology (HAZUS) presently used by FEMA and the stakeholder-built DSS method that uses realistic interactive visualization. These were tested at flood risk management meetings in communities that recently received updated FEMA digital Flood Insurance Rate Maps (DFIRM). Presently, FEMA conducts Community Coordination and Outreach meetings with flood risk managers at the city and county municipal level where updated DFIRM are presented and recommendations are made for reducing the jurisdiction's risk of flood

(Janowicz 2011, Bollinger 2013b). The municipal managers are asked to disseminate FEMA information to their local communities through flood risk management meetings. The meetings held for data-collection purposes in this study also served as a way to assist municipal managers in disseminating information about flood risk-reduction options to the local communities.

Methods

Surveys completed by participants attending the community flood risk management meetings contained an open-ended question (Bernard 2002) that evaluated knowledge of flood risk-reduction options (Appendix 3 Question #2). Pre- and post-surveys were used to distinguish between the knowledge of flood risk-reduction options gained during the meeting and the knowledge the participant possessed prior to the meeting. Each participant's response was combined with others attending the same meeting and clustered within the community to define the characteristics of the community.

To find where the differences were significant between the two computer-assisted decision support system (DSS) methods, an analysis of variance was performed. If there was no significant difference between the two DSS methods in their effect on learning outcomes, a t-test was performed to find where learning was significant as a result of participation in the community flood risk management meetings.

An analysis was also performed to determine the effectiveness of each DSS method based on the geographic information systems (GIS) background of participants to determine if GIS experience had a significant effect on learning about flood risk-reduction options.

Statistical analyses were performed to determine whether factors associated with the individual meetings significantly influenced learning outcomes. These included evaluating differences in the individuals serving as the GIS technician and meeting facilitator, the number of meeting assistants available during the meeting, whether or not a municipal planning department representative was available during the meeting to answer questions from participants about flood risk management issues, and the location and condition of the facilities in which the meetings were held.

Results

Flood risk management meetings had a significant positive effect on flood risk-reduction options learning outcomes ($p < 0.01$) (Appendix Table 25). The stakeholder-built computer-assisted decision support system (DSS) method engaging participants in realistic interactive visualization and the national geographic information systems (GIS) software DSS method were equally effective (Appendix Table 24). Pre-survey knowledge was found to have a significant positive effect ($P < 0.01$) on the participant's knowledge of flood risk-reduction options listed on the post-survey (Appendix Table 24).

The GIS background of meeting participants did not have a significant effect on learning about flood risk-reduction options.

The results show that the only factor associated with the individual meetings that had a significant effect ($P < 0.03$) on how well risk-reduction options were communicated was the presence of a county or city municipal planning department representative (Appendix Table 35). Factors associated with the individual meetings that did not significantly influence learning outcomes included the individuals serving as the GIS technician and meeting facilitator, the number of meeting assistants available during the meeting, and the location and condition of the facilities in which the meetings were held.

Details of these analyses are located in Appendix 13.

Interpretations of study results

When the effectiveness of the two computer-assisted decision support system (DSS) methods at communicating flood risk-reduction options were tested with the pre-survey as a covariate, both performed equally well and resulted in significant learning outcomes ($P < 0.01$). While these results indicated the flood risk management meetings using a DSS method were very effective at communicating flood risk-reduction options to stakeholders, neither DSS method could close the gap in knowledge between those entering the meeting with prior knowledge of risk-reduction options and those entering with little or no prior knowledge as shown by the significant effect ($P < 0.01$) of the pre-survey responses.

When the presence of municipal planning representatives at the meetings was analyzed as a covariate, the research indicated risk-reduction learning outcomes were significantly higher ($P < 0.03$) when municipal planning representatives were available during the flood risk management meetings to answer participants' questions about local flood risk-reduction options. With this covariate, results indicate both DSS methods benefitted from the presence of the municipal planning representatives.

Chapter VI: Does realistic interactive visualization increase stakeholders' intent to initiate flood risk-reduction actions?

Introduction

Stakeholders are vulnerable to flooding but often take no action to reduce their risk (Mullainathan and Thaler 2000, Burby 2001, IPET 2009, Ruth and Ibarrarian 2009). If flood preparedness of stakeholders remains the status quo, anticipated increases in future flooding events will lead to increased cost in lives and damage to infrastructure. Effective communication of information about risk and the risk-reduction options that are available to stakeholders are essential first steps in flood risk management (NSF 2007, Suarez, Ribot et al. 2009, Cutter, Burton et al. 2010). Once science-based information is received by the communities, they can make wise use of their time and funds to reduce their risk. In this study, in addition to measuring knowledge of risk and risk-reduction options, stakeholders' intent to initiate actions to reduce that risk was evaluated.

Methods

Experimental design

The stakeholder-built computer-assisted decision support system (DSS) that engaged stakeholders in realistic interactive visualization was tested to evaluate its effectiveness at increasing the intent of stakeholders to initiate action to reduce their flood risk. A DSS based on a nationally-recognized GIS software package was also tested to serve as a comparison. The Federal Emergency Management Agency (FEMA) Multi-hazard Loss Estimation Methodology (HASUS) DSS served in this capacity. The two DSS methods were tested in ten communities in FEMA Region III (Figure 1).

Analytical methods

Each meeting participant was given a survey before the meeting began and an identical post-survey following the close of the meeting (Appendices 3 and 4). Three to six participants at each meeting were randomly selected to receive follow-up interviews (Appendix 6). Three approaches were taken to test the effectiveness of the computer-assisted decision support system (DSS) methods in initiating intent to take flood risk-reduction actions among stakeholders. Statistical analyses were performed using responses to (1) an open-ended (Bernard 2002) survey question where participants were asked to write a list of risk-reduction actions they and/or their community already put in place or plan to put in place (Appendix 3), (2) the same open-ended question asked in a follow-up interview (Appendix 6) conducted within the week after the flood risk management meeting, and (3) a series of six multiple-choice (Bernard 2002) survey questions where one specific risk-reduction action was described in each question and participants were asked whether or not they had implemented the action or planned to do so in the future (Appendix 4). In the analysis, a participant's response to each multiple-choice question was recorded if the choice she/he made in response to the question was appropriate for the flood risk to their property as indicated by the model used during the meeting. Therefore, answering "yes" to every question, indicating they would initiate action in all situations, was not recorded as an appropriate risk-reduction action unless their property was shown to be at risk to flooding according to the model.

Using three different methods of collecting participant responses checked the reliability of the assessment tools (Bernard 2002). The written responses were given immediately following completion of the flood risk management meeting before participants left the meeting room. These responses measured participants' initial change in intent to take action as a result of the risk management meeting. In each community, three to six randomly-selected participants were asked about their intent to take risk-reduction actions in an interview question asked within the week following the meeting. Interview responses evaluated the intent to take action after the participants had some time to think about what they planned to do.

In all three analyses, written pre-survey responses to the questions asking about intent to initiate flood risk-reduction actions were used to distinguish between the intent to take action initiated by attending the meeting and the actions the participants intended to take prior to the meeting. Each participant's response was combined with others attending the same meeting and clustered within the community to define the characteristics of the community.

Statistical analyses were also performed to determine the effectiveness of each DSS method based on the geographic information systems (GIS) background of participants to determine if GIS experience had a significant effect on intent to take action.

Statistical analyses were performed to determine whether factors associated with the individual meetings significantly influenced learning outcomes. These included evaluating differences in the individuals serving as the GIS technician and meeting facilitator, the number of meeting assistants available during the meeting, whether or not a municipal planning department representative was available during the meeting to answer questions from participants about flood risk management issues, and the location and condition of the facilities in which the meetings were held.

Observations of human behavior

While the meeting facilitator conducted the flood risk management meeting and during informal interaction prior to the start and immediately following the meeting, one of the researchers functioned as a non-participant and recorded anthropological jottings continuously as the meeting progressed. When all researchers were needed to conduct the meeting, jottings were recorded immediately following the meeting. These jottings included observations of dynamics during the meetings, including patterns of strong synergistic and/or antagonistic relationships among stakeholders that may have influenced the responses received on the stakeholder surveys based on body language, tone of voice, amount of time spent expressing certain opinions, and number of participants sharing those opinions. These dynamics can interfere with or enhance the cognitive absorption of information.

Results

Flood risk-reduction actions meeting participants stated they intended to initiate

Participants in the flood risk management meetings listed a wide variety of actions they intended to take to reduce their risk. The range of actions was similar following meetings using either the national geographic information systems (GIS) software or the stakeholder-built computer-assisted decision support system (DSS) (Table 6).

Table 6: Flood risk management meeting participant responses to the statement: “Steps my community and/or I already put in place or plan to do that reduce flood risk include:” Similar responses are grouped together.

- Review the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps:

“flood mapping”
“look at maps prepared by FEMA”
“check how high my land is relative to the water”

“know the areas prone to flooding” “city and community review together the floodplains”
• Participate in the National Flood Insurance Program (NFIP): “participate in CRS [Community Rating System]/NFIP program”
• Purchase flood insurance for structures: “purchase flood insurance” “added flood insurance policy” “buy comprehensive loss protection” “ask neighbors to consider purchasing flood insurance” “have workshops that include insurance”
• Purchase flood insurance for temporary housing: “I appreciated the cost of temporary housing insurance idea - going to check my policy”
• Increase flood insurance coverage: “check that flood insurance is for full replacement value”
• Prepare for increases in flood insurance rates: “steel self for increase in flood insurance rate”
• Implement a community emergency alert system: “plan emergency alert system” “evacuation education information” “robust communication plan” “train-retrain on emergency plan/partnering with state and federal agencies to address plan” “evacuation strategies” “evacuation routes” “warning system” “emergency notification’ “evacuation planning for emergencies” “confirm exits/evacuation” “shelter plans for residents” “evacuation site” “awareness programs/educate citizens . . .”
• Enroll in a community emergency alert system: “join emergency alert system” “assure all residents are a part of "red Alert" Program-call, text, email, FB [sic]” “access to information about potential flood risk” “sign up for code red” “early notification/information to public via social media, website, etc.”

- Prepare to shelter in place:

“prepare to shelter in place”
“expand on infrastructure impact to area: access to roads, hospitals, groceries; power stations flooded out; no EMS [emergency medical service], fire; 72 hours you're on your own”

- Elevate road used as the community evacuation route:

“raise entrance road level”
“elevate evacuation road to the bridge”
“community: improve road at bridge”
“build up evacuation route”
“raise roads”
“work with county and state to fix the road at the bridge”
“raise the road to the bridge”
“building a good exit off area”
“raise causeway to provide a 2nd egress route from city”

- Designate an elevated parking area for use during floods:

“make out-of-the-floodplain parking”
“get vehicles out”
“remove vehicles, etc. (boats, campers, etc.) when flood expected”

- Solicit funds for elevating the community evacuation route:

“seek support from agencies to protect and make accessible evacuation route off island”

- Raise structures above FEMA base flood elevation (BFE):

“home elevation”
“raising the property”
“raise my home to a higher elevation”
“raised homes”
“look into possible elevation”
“raise critical infrastructure”
“house above BFE”
“elevate home”
“elevate”
“elevate residence structure”
“raise foundation in our new construction”
“elevate crawl space”
“move up 1 story”
“my house on pilings”
“build house above floodplain”
“lifted my house”
“build structure at or above FEMA Base Flood Elevation”
“elevated 1st level of our new house 2 ft”
“encourage owners to take steps to improve their safety (raise houses)”

“elevate property” “construct physical ways to elevate”
• Update building codes to include requirements to build above BFD: “building code requirements to elevate” “require all new houses and any that require major renovation (50% or above) to be constructed to new standards” “improve county building code to prevent home flooding” “freeboard requirements for new construction”
• Solicit funds to cover the cost of raising structures above BFD: “increase freeboard $”
• Relocate outside of a floodplain: “move” “home should not have been built on this marsh in the first place”
• Improve drainage by keeping ditches free from debris: “keep drainage open and clear” “keep ditches clean/drainage open” “improve drainage by keeping ditches free from debris” “city and community work together on stream cleanups and neighborhood street cleanings” “community clean ups” “storm drain clean ups” “cleaning storm drains” “keeping trash off of the streets” “clear storm drains” “ditches, creeks cleaned of debris and trash, etc.” “maintain drain fields and ditches to direct flooding away from roads and property” “maintain proper drainage on property” “we have dry wells around the property” “dry wells in yard”
• Advocate for better storm water management: “advocate for better storm water management” “storm water management systems”
• Improve drainage by grading land and installing/replacing drainage systems: “improved drainage” “grade my yard so water flows away from the house and toward ditches” “improve low lying ditch areas-depth & solidification” “prepare proper drainage on property” “call city if drains clogged” “clear drain pipes”

• Solicit municipal government to improve storm drainage system: “convince city to mediate sewer overflow issues” “cleaning of drainage systems (city's sewers)” “convince city to mediate storm drainage issues” “keep the city informed about storm drains that are full”
• Keep flood vents clear of debris: “clear flood vents”
• Keep gutters clear of debris: “clear gutters” “keep gutters clean”
• Install flood vents: “install flood vents” “flood vents”
• Install sump pump: “install a sump pump under my home” “subpumps in our basement”
• Purchase back-up generator: “get a back-up generator for my sump pump”
• Elevate back-up generator: “raise level of standby generator”
• Install sewage back up valve: “sewer valve” “add back flow valve” “install sewage back up units” •
• Flood-proof well head: “raise or seal well head”
• Flood-proof heating, ventilation, and air conditioning systems (HVAC): “floodproof HVAC” “raise HVAC units” “HVAC in attic”
• Elevate propane and-or butane tanks: “raise propane and-or butane tanks”
• Flood-proof electrical systems: “floodproof electrical”

“raise utilities above flood plain”
• Maintain existing erosion-control structures: “maintain breakwaters” “maintain present rock seawall” “erosion control-rock seawall” “shoreline erosion control” “maintain bulkhead”
• Reinforce existing erosion-control structures: “reinforce bulkhead” “harden critical infrastructure” “beef up the bulkhead” “entrance bulkhead-stone reinforcements” “a second layer of riprap” “bulkhead protected by riprap” “shoreline reinforcement” “stone reinforcement”
• Build new erosion-control structures: “build breakwaters” “stones on shoreline” “build a groin” “rip rap” “revetments” “build bulkhead” “seawalls to protect property from flooding” “levees” “add flood walls” “H_2O barriers: walls” “dams” “spillways” “free-floating barriers”
• Solicit funding for shoreline erosion control: “seek funding to protect shoreline from further erosion”
• Install temporary flood-control barriers: “sandbags” “work together to build physical barriers around houses (sandbags)” “temporary flood wall on exterior door” “contractor bags to fill with dirt” “H_2O barriers-sandbags” “get sandbags, compost, etc. delivered”
• Restore barrier island:

“an artificial barrier island replacing the natural peninsula , now submerged”
• Restore wetland: “fix the wetlands breach” “fix wetlands area” “the organization most relevant to protecting [name of community] is [name of utility company] since they own most of the marsh that contribute to [name of community] flooding”
• Maintain vegetative buffer zone: “maintain marsh buffer” “maintain a "green" buffer between tidal areas and homes”
• Plant vegetative riparian/marsh buffer zone: “plant trees to restrict erosion” “plant more area-appropriate trees” “tree line” “landscape” Plant shrub “planting shrubs to restrict erosion” “reforest trees that come down” “plant buffers” “tear down the bulkhead and install green buffer of grasses, trees, etc.” “plantings along the stream” “establish wetland buffers” “trees between us and water” “plant trees close to the water” “wetland establishment” “vegetative buffers”
• Limit impervious surfaces: “limit new pavement”
• Secure outdoor items: “pick up and secure outside lawn furniture, toys, other loose items” “make sure trash and other debris are not left out” “encourage owners to take steps to improve their safety (secure items)”
• Flood-proof chemical storage units: “store chemicals high”
• Move items to a location protected from flooding: “move valuables to safer place” “we normally move or elevate furniture and carpeting when a severe storm with a tidal surge is approaching” “move personal property to avoid storm damage” “store items in garage above flood prediction”

• Store electronic copies of important documents off-site: “backup records”
• Store electronic copies of important photos off-site: “back up photos” “I was intrigued by the photo preservation idea”
• Reduce sources of climate change: “work to fight climate change”

Effectiveness of realistic interactive visualization in initiating flood risk-reduction actions among stakeholders

The study showed that following participation in the flood risk management meetings, significant increases occurred in the participants’ intent to initiate actions to reduce risk ($P < 0.01$) (Appendix Tables 41, 44 and 47) . When pre-survey responses to questions about intent to initiate risk-reduction action were used as a covariate, the results indicated the stakeholder-built computer-assisted decision support system (DSS) method and the national geographic information systems (GIS) software DSS were equally effective (Appendix Tables 40, 43 and 46). The effect of pre-survey participant intent to initiate risk-reduction actions differed in its significance, depending on the method used to collect post-meeting responses. Intent to initiate action prior to the meeting had a significant positive effect on responses on the survey completed following the meeting ($P < 0.01$) (Appendix Table 40). However, when asked the same question in an interview during the week following the meeting, the pre-survey responses did not have a significant effect on follow-up interview responses ($P > 0.44$) (Appendix Table 43). On the written post-survey, participants listed fewer risk-reduction actions (mean increase of 0.9 actions from pre- to post-survey responses) than they did in the follow-up interviews (mean increase of 2.3 actions from pre-survey to follow-up interview responses). Details of the analyses are located in Appendix 14. In summary, with pre-survey responses analyzed as a covariate, the flood risk management meetings using both DSS methods performed significantly well at increasing the participants' intent to take action to reduce flood risk.

The quality of the flood risk management meeting facilities had a significant effect on the intent of stakeholders to take action to reduce their risk ($P < 0.02$). The higher the quality of the facilities, the greater the intent to initiate risk-reduction action on the part of participants. The type of facility in which the flood risk management meetings were conducted varied widely. Some were located within well-maintained buildings where air conditioning was comfortable, visibility of the presentation was good for all participants, and acoustics were good for projecting the voice of the meeting facilitator throughout the room. Others were held in facilities where the wireless Internet connection was intermittent, there was no air conditioning and/or poor circulation with temperatures at 85 – 98^o F, visibility of the presentation was poor for some or all participants, and the acoustics were poor for projecting the voice of the meeting facilitator throughout the room. When the quality of the facilities was analyzed as a covariate, there was a significant increase in the intent to take action to reduce flood risk following the meetings when the stakeholder-built DSS method was used ($P < 0.01$) and a significant difference between the DSS methods utilized during the meetings ($P < 0.03$). When the national GIS software DSS was used with the quality of the facilities analyzed as a covariate, the increase in intent to take action to reduce flood risk following the meetings was not significant ($P > 0.07$). There was no significant interaction between the DSS method and the room quality ($P > 0.14$), indicating the stakeholder-built DSS outperformed the national GIS software DSS in all three levels: high, medium and poor quality facilities. Details of these analyses are located in Appendix Table 60.

The other factors related to community flood risk management meetings did not have a significant effect on participants' intent to take action to reduce their risk. Details of these analyses are located in Appendix 14.

Interpretations of study results

These results indicate the best combination for maximizing intent to initiate risk-reduction action is to hold the meeting in a high quality facility using the stakeholder-built computer-assisted decision support system (DSS) method.

Those interviewed during the week following the meeting listed more actions they intended to implement to reduce their flood risk than they listed on the written survey they completed at the close of the meeting. This was the case for both DSS methods. There are two possible explanations for this difference: (1) the interview format was more effective at encouraging responses from participants than the written survey and/or (2) when participants were given a few days to process the information they gained from the flood risk management meeting, they added to the list of actions they planned to take.

Based on anthropological jottings recorded by the research team during and immediately following the community meetings, the flood risk management meetings seemed to help with decision-making for the participants. Participants in communities located in municipalities bordering waterfront, but elevated well above the flood hazard areas according to the DSS models, indicated relief in understanding more about their low risk. Prior to the flood risk management meeting, which focused on their local conditions, they had interpreted the regional-level information they received to mean they were at high risk. They indicated they would concentrate on implementing the relatively easy risk-reduction actions such as organizing regular community clean-ups of street drains and individually preparing emergency kits for sheltering in place during a storm with the understanding that access roads would likely be flooded, but not their homes. This reaction was observed in meetings using both DSS methods.

Several individuals living in areas the DSS models showed at high risk of flooding indicated that prior to the meeting, they planned to retire to their waterfront property. Some homes offered spectacular views of both sunrise on a bay and sunset on a river. Information communicated during the meetings showed an increased risk associated with this choice. After the meetings, some expressed concern about retiring in that location. Couples in two different high-risk communities, each receiving information from a different DSS model, who planned to build a home on property they recently purchased, decided to raise the base elevation level on their blueprints prior to construction based on information provided at the flood risk management meeting. These notes on plans for action further support the quantitative analysis of the effectiveness of the flood risk management meetings in initiating flood risk-reduction actions.

Chapter VII: Summary

Findings

The model using realistic interactive visualization performed as well as the national geographic information systems (GIS) software computer-assisted decision support system (DSS) in communicating flood risk to end-users, the stakeholders at risk of flooding. The results indicated that when realistic visualization was utilized independently and when it was combined with interactive visualization to illustrate flood risk in the stakeholder-built DSS, both methods performed as well as the national GIS software DSS. All resulted in significant learning outcomes ($P < 0.04$ for learning about past and present flood risk and $P < 0.01$ for learning about anticipated future flood risk). Realistic visualization was implemented when GIS technicians produced pre-constructed models that were used to illustrate past and present flood scenarios during the flood risk management meetings. Realistic interactive visualization was engaged when participating stakeholders constructed their own models of anticipated future flood risk. Pre-survey knowledge was found to have a significant positive effect on the participants' knowledge of flood risk ($P < 0.01$) when analyzed as a covariate. In other words, although the flood risk management meetings resulted in significant learning about flood risk, there was not a sufficient amount of flood risk information presented at the meetings to close the gap between those with prior knowledge and those learning the information for the first time during the meetings.

When the effectiveness of the two DSS methods at communicating flood risk-reduction options were tested with the pre-survey as a covariate, both performed equally well and resulted in significant learning outcomes ($P < 0.01$). However, as was the case for learning outcomes for flood risk, neither DSS method could close the gap in knowledge between those entering the meeting with prior knowledge of risk-reduction options and those entering with little or no prior knowledge as shown by the significant effect ($P < 0.01$) of the pre-survey responses.

When the presence of municipal planning representatives at the meetings was analyzed as a covariate, the research indicated risk-reduction learning outcomes were significantly higher ($P < 0.03$) when municipal planning representatives were available during the flood risk management meetings to answer participants' questions about local flood risk-reduction options. With this covariate, both DSS methods performed equally well.

The study showed that following participation in the flood risk management meetings, significant increases occurred in the participants' intent to initiate actions to reduce risk ($P < 0.01$). When pre-survey responses to questions about intent to initiate risk-reduction action were used as a covariate, the results indicated the stakeholder-built DSS method and the national GIS software DSS were equally effective. The effect of pre-survey participant intent to initiate risk-reduction actions differed in its significance, depending on the method used to collect post-meeting responses. Intent to initiate action prior to the meeting had a significant effect on responses on the survey completed following the meeting ($P < 0.01$). However, when asked the same question in an interview during the week following the meeting, the pre-survey responses did not have a significant effect on follow-up interview responses ($P > 0.44$). On the written post-survey, participants listed fewer risk-reduction actions (mean increase of 0.9 actions from pre- to post-survey responses) than they did in the follow-up interviews (mean increase of

2.3 actions from pre-survey to follow-up interview responses). There are two possible explanations for this difference: (1) the interview format may be more effective at encouraging responses from participants and/or (2) when participants were given a few days to process the information they gained from the flood risk management meeting, they added to the list of actions they planned to take. In summary, with pre-survey responses analyzed as a covariate, the flood risk management meetings using both DSS methods performed well, significantly increasing the participants' intent to take action to reduce flood risk.

The quality of the facilities had a significant effect on the intent of stakeholders to take action to reduce their risk following the flood risk management meeting ($P < 0.02$). The higher the quality of the facilities, the greater the intent to initiate risk-reduction action on the part of participants. The quality of the facility in which the flood risk management meetings were conducted varied widely. Some were located within well-maintained buildings where air conditioning was comfortable, visibility of the presentation was good for all participants, and acoustics were good for projecting the voice of the meeting facilitator throughout the room. Others were held in facilities where the wireless Internet connection was intermittent, there was no air conditioning and/or poor circulation with temperatures at 85 – 98^{o} F, visibility of the presentation was poor for some or all participants, and the acoustics were poor for projecting the voice of the meeting facilitator throughout the room. When the quality of the facilities was analyzed as a covariate, there was a significant increase in the intent to take action to reduce flood risk following the meetings when the stakeholder-built DSS method was used ($P < 0.01$) and a significant difference between the DSS methods utilized during the meetings (P <

0.03). When the national GIS software DSS was used with the quality of the facilities analyzed as a covariate, the increase in intent to take action to reduce flood risk following the meetings was not significant (P > 0.07). There was no significant interaction between the DSS method and the room quality (P > 0.14), indicating the stakeholder-built DSS outperformed the national GIS software DSS in all three levels: high, medium and poor quality rooms. These results indicate the best combination for maximizing intent to initiate risk-reduction action is to hold the meeting in a high quality room using the stakeholder-built DSS method.

When the expense in time and money needed to train GIS technicians to perform the mapping in each of the two DSS methods was calculated, the national GIS software DSS method was found to require considerably more hours of training and, therefore, a much higher monetary investment, than did the stakeholder-built method. The cost of hardware, software, and training modules also added to the cost of the national GIS software DSS training. The stakeholder-built DSS training required minimal costs for hardware and no expenses for software or training modules. The greatest investment was in the early training for both DSS methods, with the national GIS software DSS requiring over six times the investment in time for initial training than the stakeholder-built method.

The research assistants trained as GIS technicians for this project were surveyed for feedback on their impressions of the differences between the two DSS methods. When asked about the capacity of their hardware to handle the software needed, all stated they were able to run the software required for both DSS models on their computers, but there was a greater need to install additional software in order to run the national GIS software DSS than was needed to run the stakeholder-built DSS. Most technicians experienced more error messages when working with the national GIS software model than with the stakeholder-built and most found the stakeholder-built to be a more user-friendly program. Overall, the stakeholder-built DSS model was considered to require less prior GIS experience than the national GIS software DSS. Most technicians found both DSS models to be moderately difficult to teach others to use, with opinions leaning toward the stakeholder-built model as easier to teach. The lower cost of investment to run the stakeholder-built DSS as compared to the national GIS software DSS, and the user-friendly aspects of the stakeholder-built DSS, gave this method the advantage when communicating risk to end-users.

To address whether or not the flood risk management meeting participants were a true representation of the Federal Emergency Management Agency Region III population, the research compared U.S. Census Bureau (USCB) demographic data to self-reported demographics provided by meeting participants. The study found that most demographic sectors of the Region III population are reached during flood risk management meetings. However, within the individual communities, there was often much less diversity. The message from these findings is that it is important for municipal flood risk managers to organize multiple community meetings in their jurisdiction so that they capture all of the demographically diverse sectors. While overall, the meeting participants were representative of the general population, there were some significant differences when each demographic characteristic was analyzed independently. Those results showed the meeting participants were significantly older, English-only speakers, better educated, from households earning more than $35,000 (U.S. 2013 dollars) per year, and more likely to own a home than the USCB data indicate for the Region III population. In contrast to the findings in some past studies, females were as likely to attend meetings as males, minorities were represented equal to their proportion of the population, and the elderly were well represented. To disseminate flood risk information to segments of the population that were under-represented, outreach methods need to be developed for young adults ages 18-44, speakers of languages other than English, those without a college education, those with incomes below $35,000, and home renters.

Significance

Stakeholder-built computer-assisted decision support system serves as a complimentary system to a national geographic information systems software DSS

Results of this research show the proposed stakeholder-built computer-assisted decision support system (DSS) can serve as a complimentary system to a national geographic information systems (GIS) software DSS such as the Multi-hazard Loss Estimation Methodology (HAZUS). At the local community level, the simpler, stakeholder-built DSS performed as well as the national GIS software DSS when illustrating various flood scenarios to communicate information about flood risk and risk-reduction options to the end-users, those at risk of flooding. Results indicate the best method for maximizing the intent to initiate risk-reduction actions among these end-users is to utilize the stakeholder-built DSS in a high-quality meeting facility.

This opens doors for flood risk management planners across the USA. The lower cost of investment in training GIS technicians to run the stakeholder-built DSS as compared to the national GIS software DSS, and the greater ease in the acquisition and use of software for the stakeholder-built DSS, holds promise for this method as a tool for end-users. At one-sixth the cost in hours of initial training for use of the national GIS software DSS method and one-nineteenth the cost of hardware and software, the stakeholder-built DSS is likely to be within the budgets of many municipal flood risk management planners that are financially unable to make use of the national GIS software DSS.

The Stakeholder-built DSS can be used in situations where communication about flood risk is desired, but individuals with the GIS training are not readily available and the time and money needed to hire and/or train a technician would be impractical.

Use as a rapid assessment tool for evaluating flood risk

Assessing anticipated future flood risk and developing risk-reduction actions should ideally be approached using a process in which new data can be incorporated as information becomes available. The stakeholder-built model is ideal as a rapid assessment tool to quickly make initial decisions on areas that would benefit most from closer monitoring for future changes in flood patterns. If a geographic information systems technician is interested in seeing a basic visual outline of flood hazard zones but does not need a structural damage report or other economic losses, the stakeholder-built model would be quite suitable.

Examples of situations where this would be useful is in conservation biology, where it is important to monitor such changes as wildlife habitat and migration routes that may result from changes in flooding patterns in the landscape. Another potential application is in flood hazard emergency preparedness for handling of domestic products such as livestock. The stakeholder-built model can be used as a tool for locating potential emergency shelters and evacuation routes. These are a few examples of the broad array of possible applications for this model.

Potential expansion of the application of computer-assisted decision support systems

The stakeholder-built computer-assisted decision support system (DSS) method has the potential to spread in use beyond the formal flood risk management meetings. Once instructed on its use, meeting participants may decide to teach others in their community or beyond how to assess flood risk information, amplifying the spread of knowledge beyond the communities in this formal study.

This user-friendly, inexpensive DSS could offer an introduction to those new to geographic information systems (GIS). After this initial experience, individuals may gain the confidence to venture into more sophisticated GIS platforms. This may be particularly useful for students, from grade school through the first years of college. After learning basic reading and typing skills, students could begin using the stakeholder-built model to learn about local flood issues. The low cost reduces one of the barriers to technology experienced by many school districts. The students' familiarity with Google Earth^{TM} makes this an unintimidating method for introducing them to GIS technology.

Potential for application of this method in communities outside the USA

There is potential for designing modifications of the stakeholder-built computer-assisted decision support system (DSS) to accommodate flood-prone areas outside of the USA. The stakeholder-built DSS model in this study made use of the Federal Emergency Management Agency (FEMA) National Flood Hazard layer (NFHL), which is available only in the USA. However, Google Earth^{TM} and its elevation data are available worldwide. A method for measuring anticipated flood risk that relies on other sources, such as present sea level elevation combined with the Intergovernmental Panel on Climate Change anticipated sea level rise in each country or region, could be developed to replace the reliance of this model on the FEMA NFHL. This would open to vulnerable communities worldwide the field of effective communication of flood risk and flood risk-reduction options, and spur the initiation of action on the part of stakeholders to reduce their risk using an inexpensive, user-friendly DSS.

References Cited

Adger, W. N., P. M. Kelly and N. H. Ninh (2001). Environment, society and precipitous change. Living with Environmental Change: Social vulnerability, adaptation and resilience in Vietnam. W. N. Adger, P. M. Kelly and N. H. Ninh. London, Routledge**:** 3-18.

Allen, D. and K. Tanner (2005). "Infusing Active Learning into the Large-enrollment Biology Class: Seven Strategies, from the Simple to Complex." Cell Biol Educ **4**(4): 262-268.

Beall, A. (2007). Participatory Modeling for Environmental Problem Solving: Reports from the Field. unpublished Ph.D. Dissertation, Washington State University.

Bellomo, D. (2010). Federal Emergency Management Agency Risk Analysis Division Director. personal communication: Community flood risk knowledge. V. B. K. Olsen. Washington, D.C.

Berke, P. R. and T. Beatley (1997). After the Hurricane: Linking Recovery to Sustainable Development in the Caribbean. Baltimore and London, The Johns Hopkins Press.

Bernard, H. R. (2002). Research Methods in Anthropology: Qualitative and Quantitative Approaches. Walnut Creek, AltaMira Press.

Boesch, D. F., L. P. Atkinson, W. C. Boicourt, J. D. Boon, D. R. Cahoon, R. A. Dalrymple, T. Ezer, B. P. Horton, Z. P. Johnson, R. E. Kopp, M. Li, R. H. Moss, A. Parris and C. K. Sommerfield (2013). Updating Maryland's Sea-level Rise Projections. Special Report of the Scientific and Technical Working Group to the Maryland Climate Change Commission. Cambridge, Maryland, University of Maryland Center for Environmental Science.

Bollinger, D. (2013a). Federal Emergency Management Agency (FEMA) Region III Mitigation Outreach Coordinator. Email personal communication: FEMA endorsement of research project. V. B. K. Olsen, FEMA Region III Mitigation Outreach Coordination.

Bollinger, D. (2013b). Federal Emergency Management Agency (FEMA) Region III Mitigation Outreach Coordinator. Batimore City Planning Department oral presentation: National Flood Insurance Program updates. Baltimore, Maryland, FEMA Region III Mitigation Outreach Coordination.

Bullinger, H.-J., J. Ziegler and W. Bauer (2002). "Intuitive Human-Computer Interaction-Toward a User-Friendly Information Society." International Journal of Human-Computer Interaction **14**(1): 1 - 23.

Burby, R. J. (2001). "Flood insurance and floodplain management: the US experience." Environmental Hazards **3**: 111-122.

CFI_Group (2010). FEMA citizen questionnaire, PennWell Corporation.

Chandler, P. (2009). "Dynamic visualisations and hypermedia: Beyond the "Wow" factor." Computers in Human Behavior **25**(2): 389.

CITI (2012). Social & Behavioral Research - Basic/Refresher Curriculum. Collaborative Institutional Training Initiative (CITI) Human Subjects Research. CITI, University of Miami.

Clauzel, D., K. Sehaba and Y. Prié (2011). "Enhancing synchronous collaboration by using interactive visualisation of modelled traces." Simulation Modelling Practice and Theory **19**(1): 84-97.

Cockerill, K., H. Passell and V. C. Tidwell (2006). "Cooperative Modeling: Building Bridges Between Science and the Public." Journal of the American Water Resources Association **42**(2): 457-471.

Cockerill, K., V. C. Tidwell and H. Passell (2004). "Assessing Public Perceptions of Computer-Based Models." Environmental Management **34**(5): 609-619.

Cockerill, K., V. C. Tidwell, H. D. Passell and L. A. Malczynski (2007). "Cooperative Modeling Lessons for Environmental Management." Environmental Practice **9**(1): 28-41.

Costanza, R. and J. Greer (1995). The Chesapeake Bay and its watershed. Barriers and Bridges to the Renewal of Ecosystems and Institutions. L. H. Gunderson, C. S. Holling and S. S. Light. New York, Columbia University Press**:** 169-213.

Costanza, R. and M. Ruth (1998). "Using Dynamic Modeling to Scope Environmental Problems and Build Consensus." Environmental Management **22**(2): 183.

Cutter, S. L., L. Barnes, M. Berry, C. Burton, E. Evans, E. Tate and J. Webb (2008). "A place-based model for understanding community resilience to natural disasters." Global Environmental Change **18**(4): 598–606.

Cutter, S. L., B. J. Boruff and W. L. Shirley (2003). "Social Vulnerability to Environmental Hazards." Social Science Quarterly **84**(2).

Cutter, S. L., C. G. Burton and C. T. Emrich (2010). "Disaster Resilience Indicators for Benchmarking Baseline Conditions." Journal of Homeland Security and Emergency Management **7**(1).

Cutter, S. L., J. T. Mitchell and M. S. Scott (2000). "Revealing the Vulnerability of People and Places: A Case Study of Georgetown County, South Carolina." Annals of the Association of American Geographers **90**: 713-737.

D'Avanzo, C. (2003). "Research on learning: potential for improving college ecology teaching." Frontiers in Ecology and the Environment **1**(10): 533-540.

Davis, M. (1999). Ecology of Fear. New York, Vintage Books.

Devetak, I., M. Hajzeri, S. A. Glažar and J. Vogrinc (2010). "The Influence of Different Models on 15-years-old Students' Understanding of the Solid State of Matter." Acta chimica slovenica **57**(4): 904-911.

Dino, S. and B. Wayne (2007). Interactive visualization for the active learning classroom. Proceedings of the 38th SIGCSE technical symposium on Computer science education. Covington, Kentucky, USA, ACM.

ESRI (2012). ArcGIS 10. ArcGIS. Redlands, Environmental Systems Research Institute, Inc.

FEMA (1999). Protecting building utilities from flood damage: principles and practices for the design and construction of flood resistant building utility systems, Federal Emergency Management Agency (FEMA).

FEMA (2009). HAZUS: FEMA's Methodology for Estimating Potential Losses from Disasters, U.S. Department of Homeland Security Federal Emergency Management Agency (FEMA).

FEMA (2010a). FEMA Region III. Washington, D.C., Federal Emergency Management Agency (FEMA).

FEMA (2010b). The National Flood Insurance Program base flood elevation (BFE), Federal Emergency Management Agency (FEMA).

FEMA (2010c). Risk Mapping, Assessment, and Planning (Risk MAP). Washington, D.C., Federal Emergency Management Agency (FEMA).

FEMA (2011a). Answers to Questions about the National Flood Insurance Program, Federal Emergency Management Agency (FEMA) 56.

FEMA (2011b). Flooding and Flood Risk: The Cost of Flooding, Federal Emergency Management Agency (FEMA).

FEMA (2011c). FloodSmart.gov: The official site of the NFIP. National Flood Insurance Program (NFIP), Federal Emergency Mangement Agency (FEMA).

FEMA (2013). 2012 Public Survey Findings on Flood Risk. H. Security. Federal Emergency Management Agency (FEMA) online library.

FEMA. (2014a). "Coastal Analysis and Mapping Region II." Retrieved June 30, 2014, 2014, from http://www.region2coastal.com/additional-resources-1/glossary#TOC-S).

FEMA. (2014b). "Federal Emergency Management Agency Resource and Document Library." 2014, from http://www.fema.gov/resource-document-library.

FEMA (2014c). FEMA Regional Offices. http://www.fema.gov/regional-operations, Federal Emergency Management Agency (FEMA).

FEMA (2014d). Mapping Information Platform: GIS Web Services for the FEMA National Flood Hazard Layer (NFHL). H. Security. Washington, D.C., Federal Emergency Management Agency.

FEMA and GoogleEarth™ (2011). The Federal Emergency Management Agency (FEMA) National Flood Hazard Layer (NFHL) utility kml version 2.4.

FEMA and GoogleEarth™ (2013). The Federal Emergency Management Agency (FEMA) National Flood Hazard Layer (NFHL) utility kml version 3.0. The Federal Emergency Management Agency (FEMA) National Flood Hazard Layer (NFHL) utility kml

Finan, T. J. and D. R. Nelson (2009). Decentralized planning and climate adaptation: toward transparent governance. Adapting to Climate Change: Thresholds, Values, Governance. W. N. Adger, I. Lorenzoni and K. L. O'Brian. Cambridge, Cambridge University Press**:** 335-349.

Fleetwood, N. R. (2006). "Failing narratives, initiating technologies: Hurricane Katrina and the production of a weather media event." American Quarterly (American Studies Assn) **58**(3): 767.

Francis, G. R. and H. A. Regier (1995). Restoration of the Great Lakes Basin ecosystem. Barriers and Bridges to the Renewal of Ecosystems and Institutions. L. H. Gunderson, C. S. Holling and S. S. Light. New York, Columbia University Press**:** 239-291.

GoogleEarth™ (2013). Google Earth for Desktop. Google Earth. GoogleEarth™.

GoogleEarth™ and EuropaTechnologies™ (2011). Montgomery County 24031C0390D.

Goran, W. D., J. P. Holland, J. W. Barko and A. J. Bruzewicz (1999). Plans for the Land Management System (LMS) Initiative, US Army Corps of Engineers Engineer Research and Development Center.

Griffin, J. R., D. F. Boesch, J. Scheraga, F. Coale, C. Conn, Z. Johnson, A. Miller and G. Knaap (2010). Comprehensive Strategy for Reducing Maryland's Vulnerability to Climate Change, Phase II: Building societal, economic, and ecological resilience. Report of the Maryland Commission on Climate Change, Adaptation and Response and Scientific and Technical Working Groups. K. Boicourt and Z. P. Johnson. Annapolis, Maryland, University of Maryland Center for Environmental Science, Cambridge, Maryland.

Gunderson, L. H., C. S. Hollings and S. S. Light (1995). Barriers broken and bridges built: a synthesis. Barriers and bridges to the renewal of ecosystems and institutions. L. H. Gunderson, C. S. Hollings and S. S. Light. New York, Columbia University Press**:** 489-531.

Handelsman, J., D. Ebert-May, R. Beichner, P. Bruns, A. Chang, R. DeHaan, J. Gentile, S. Lauffer, J. Stewart, S. M. Tilghman and W. B. Wood (2004). "Scientific Teaching." Science **304**(5670): 521-522.

Hansen, S. R., N. H. Narayanan and D. Schrimpsher (2000). "Helping learners visualize and comprehend algorithms." Interactive Multimedia Electronic Journal of Computer-enhanced Learning **2**(1).

Hartman, H. J. (2001). Metacognition in Learning and Instruction: Theory, Research and Practice. Dordrecht, Kluwer Academic Publishers.

Hayes, T. (2011). Federal Emergency Management Agency Mitigation Division Actuary. personal communication: Flood risk perception. V. B. K. Olsen. Hyattsville, MD.

Hegarty, M. (2004). "Dynamic visualizations and learning: getting to the difficult questions." Learning and Instruction **14**(3): 343.

Holling, C. S. (1995). What barriers? What bridges? Barriers and bridges to the renewal of ecosystems and institutions. C. S. H. Lance H. Gunderson, Stephen S. Light. New York, Columbia University Press**:** 3-36.

Hundhausen, C. D., S. A. Douglas and J. T. Stasko (2002). "A Meta-Study of Algorithm Visualization Effectiveness." Journal of Visual Languages & Computing **13**(3): 259.

Hvistendahl, M. (2012). "Gender and Violence." Science **336**: 839-840.

Ibarrarian, M. E. and M. Ruth (2009). Climate change and natural disasters: economic and distributional impacts. Distributional Impacts of Climate Change and Disasters: Concepts and Cases. M. Ruth and M. E. Ibarrarian. Northampton, Edward Elgar**:** 46-66.

IPCC. (2007). "Climate Change 2007: Impacts, Adaptation and Vulnerability." 2009, from http://www.ipcc.ch/ipccreports/ar4-wg2.htm

IPCC (2013). Climate Change 2013: Impacts, Adaptation and Vulnerability, The Intergovernmental Panel on Climate Change (IPCC) Working Group II.

IPCC (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Working Group II Contribution to the IPCC 5th Assessment Report - Changes to the Underlying Scientific/Technical Assessment. Intergovernmental Panel on Climate Change (IPCC) Assessment Report.

IPET (2009). Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System, Final Report, Interagency Performance Evaluation Task Force (IPET). U. S. Army Corps of Engineers. **I-IX**.

IWR (2009). Shared Vision Planning Method, U.S. Army Corps of Engineers Institute of Water Resources (ACE IWR).

Janowicz, J. (2011). Federl Emergency Management Agency Risk Analysis Branch Chief. Email personal communication. Scheduling of FEMA Region III Community Corordination and Outreach meetings. V. B. K. Olsen. Washington, D.C., Federal Emergency Management Agency (FEMA).

Jansson, B. and H. Velner (1995). The Baltic: sea of surprises. Barriers and Bridges to the Renewal of Ecosystems and Institutions. L. H. Gunderson, C. S. Holling and S. S. Light. New York, Columbia University Press**:** 292-372.

Kearney, M. S. and P. B. Levine (2014). "Media Influences on Social Outcomes: The Impact of MTV's 16 and Pregnant on Teen Childbearing." National Bureau of Economic Research.

Keller, C., M. Siegrist and H. Gutscher (2006). "The Role of the Affect and Availability Heuristics in Risk Communication." Risk Analysis **26**(3).

Langsdale, S. M. (2007). Participatory Model Building for Exploring Water Management and Climate Change Futures in the Okanagan Basin, British Columbia, Canada. Ph.D. dissertation, University of British Columbia.

Lee, K. N. (1995). Sustainability in the Columbia River Basin. Barriers and Bridges to the Renewal of Ecosystems and Institutions. L. H. Gunderson, C. S. Holling and S. S. Light. New York, Columbia University Press**:** 214-238.

Lewis, J. L., S. R. J. Sheppard and K. Sutherland (2004). "Computer-based visualization of forest management: A primer for resource managers, communities,and educators." BC Journal of Ecosystems and Management **5**(2): 5-13.

Light, S. S., L. H. Gunderson and C. S. Holling (1995). The Everglades: evolution of management in a turbulent ecosystem. Barriers and Bridges to the Renewal of Ecosystems and Institutions. L. H. Gunderson, C. S. Holling and S. S. Light. New York, Columbia University Press**:** 103-168.

Malone, E. and A. Brenkert (2009). Vulnerability, sensitivity and coping/adapting capacity worldwide. Ditribution Impacts of Climate Change and Disasters: Concepts and Cases. M. Ruth and M. E. Ibarrarian. Northampton, Edward Elgar**:** 8-45.

Maskiewicz, A. C., Heather P. Griscom, Nicole T. Welch (2010). Using active-learning strategies to address student misunderstandings of global climate change. The Ecological Society of America 95th Annual Meeting, Pittsburgh, Pennsylvania, The Ecological Society of America.

Mayberry, M. R., M. W. Crocker and P. Knoeferle (2009). "Learning to Attend: A Connectionist Model of Situated Language Comprehension." Cognitive Science **33**(3): 449.

McClintock, W. and E. Poncelet (2011). MarineMap - An Innovative Collaborative Support Technology Improving Community Engagement. U.S. Environmental Protection Agency's (EPA) 2011 Community Involvement Training Conference, Community Involvement in the 21st Century: Embracing Diversity, Expanding Engagement, Utilizing Technology, Arlington, Virginia.

McCoy, C. (2013). Federal Emergency Management Agency (FEMA) Region III Risk Analyst. Email communication: Baltimore City inventory update and depth grid data. V. B. K. Olsen. Philidelphia, PA, FEMA Region III Mitigation Division.

Michael, D. N. (1995). Barriers and bridges to learning in a turbulent human ecology. Barriers and bridges to the renewal of ecosystems and institutions. L. H. Gunderson, C. S. Holling and S. S. Light. Nwe York, Columbia University Press**:** 461-488.

Microsoft (2007). Microsoft Office, Microsoft Corporation.

Miller, G. (2012). "Getting Minds Out of the Sewer." Science **337**: 679-680.

Moore, P., W. Bohn and S. Hubbard (2012). HAZUS Multi-hazards for floods. H. Security. Emergency Management Institute, Homeland Security Federal Emergency Management Agency.

Morehouse, B. J., S. O'Brien, G. Christopherson and P. Johnson (2010). "Integrating values and risk perceptions into a decision support system." International Journal of Wildland Fire **19**(1): 123-136.

Muggleton, S. H. (2006). "Exceeding Human Limits." Nature **440**: 409-410.

Mullainathan, S. and R. H. Thaler (2000). Behavioral Economics, National Bureau of Economic Research.

NOAA (2011). Coastal inundation toolkit. Digital Coast. N. C. S. Center, National Oceanographic and Atmospheric Administration (NOAA).

NOAA (2014). National Weather Service National Hurricane Center, National Oceanic and Atmospheric Administration (NOAA).

NSF (2007). Hurricane Warning: The Critical Need for a National Hurricane Research Initiative, National Science Foundation (NSF) National Science Board.

NSTC (2005). Grand Challenges for Disaster Reduction, Executive Office of the President National Science and Technology Council (NSTC) Subcommittee on Disaster Reduction.

Olsen, V. B. K. (2013a). Feedback on HAZUS-MH survey. https://www.surveymonkey.com/summary/G5AJueP73mueQKtaGwwomOx6zAMTG5QwGm6ivVHiwM4_3D, SurveyMonkey, Inc.

Olsen, V. B. K. (2013b). Feedback on Stakeholder-Built survey. https://www.surveymonkey.com/summary/mP00fQ8IEq81EV_2FTZpwsolnkNNCD_2Bghfs1rOkfDe5u0_3D, SurveyMonkey, Inc.

Paolisso, M. (2010). University of Maryland Professor of Anthropology. Lecture: personal communication. Participant observation and informal interviewing. V. B. K. Olsen. University of Maryland, College Park.

Patt, A. G., A. Daze and P. Suarez (2009). Gender and climate change vulnerability: what's the problem, what's the solution? Distributional Impacts of Climate Change and Disasters: Concepts and Cases. M. Ruth and M. E. Ibarrarian. Northampton, Edward Elgar**:** 82-102.

PCmag.com. (2011). "Definition of: tablet computer." PC Magazine Encyclopedia Retrieved 09-July-2011, from http://www.pcmag.com/encyclopedia_term/0,2542,t=tablet+computer&i=52520,00.asp.

Ploetzner, R., S. Lippitsch, M. Galmbacher, D. Heuer and S. Scherrer (2009). "Students' difficulties in learning from dynamic visualisations and how they may be overcome." Computers in Human Behavior **25**(1): 56.

Pulwarty, R. S. and W. E. Riebsame (1997). The Political Ecology of Vulnerability to Hurricane-Related Hazards. Hurricanes: Climate and Socioeconomic Impacts. H. F. Diaz and R. S. Pulwarty. Germany, Springer-Verlag.

Ruth, M. and M. E. Ibarrarian (2009). Introduction: distributional effects of climate change - social and economic implications Distributional Impacts of Climate Change and Disasters: Concepts and Cases. M. Ruth and M. E. Ibarrarian. Northampton, Edward Elgar**:** 3-7.

SAS (2012). SAS Proprietary Software 9.3. Statistic Analysis System Base SAS, SAS Institute, Inc.

Schwamborn, A., H. Thillmann, M. Opfermann and D. Leutner (2011). "Cognitive load and instructionally supported learning with provided and learner-generated visualizations." Computers in Human Behavior **27**(1): 89.

Seely, B., J. Nelson, R. Wells, B. Peter, M. Meitner, A. Anderson, H. Harshawd, S. Sheppard, F. L. Bunnell, H. Kimmins and D. Harrison (2004). "The application of a hierarchical, decision-support system to evaluate multi-objective forest management strategies: a case study in northeastern British Columbia, Canada." Forest Ecology and Management **199**: 283–305.

Selwy, N. (2005). "Reflexivity and technology in adult learning." Media, Technology & Lifelong Learning **1**(1).

Sheppard, S. R. J. (2005). "Landscape visualisation and climate change: the potential for influencing perceptions and behaviour." Environmental Science & Policy **8**: 637–654.

Sheppard, S. R. J. and P. Cizek (2009). "The ethics of Google Earth: Crossing thresholds from spatial data to landscape visualisation." Journal of Environmental Management **90**(6): 2102.

Sheppard, S. R. J. and M. Meitner (2005). "Using multi-criteria analysis and visualisation for sustainable forest management planning with stakeholder groups." Forest Ecology and Management **207**(1-2): 171-187.

Shin, H. B. and R. Bruno (2003). Language Use and English-Speaking Ability: 2000, U.S. Census Bureau (USCB).

Stave, K. (2010). " Participatory System Dynamics Modeling for Sustainable 7 Environmental Management: Observations from Four Cases." Sustainability **2**(1).

Stieff, M. and U. Wilensky (2003). "Connected Chemistry - Incorporating Interactive Simulations into the Chemistry Classroom." Journal of Science Education & Technology **12**(3): 285.

Suarez, P., J. C. Ribot and A. G. Patt (2009). Climate information, equity and vulnerability reduction. Distribution Impacts of Climate Change and Disasters: Concepts and Cases. M. Ruth and M. E. Ibarrarian. Northampton, Edward Elgar**:** 151-165.

Szalay, A. (2006). "Science in an Exponential World." Nature **440**(413-414).

Tanner, K. and D. Allen (2004). "Approaches to Biology Teaching and Learning: From Assays to Assessments--On Collecting Evidence in Science Teaching." Cell Biol Educ **3**(2): 69-74.

U.S._State_Department_Geographer, EuropaTechnologies™, GoogleEarth™ and M. T. Atlas™ (2011). Stay Dry kmz version 2.4. Stay Dry.

U.S._State_Department_Geographer, EuropaTechnologies™, GoogleEarth™ and M. T. Atlas™ (2013). Stay Dry kmz version 3.0. Stay Dry.

UMCES. (2006). "A New Framework for Planning the Future of Coastal Louisiana after the Hurricanes of 2005." University of Maryland Center for Environmental Science (UMCES) Working Group for Post-Hurricane Planning for the Louisiana Coast Retrieved 09-Sept-2009, 2009, from http://www.umces.edu/la-restore/

USCB (2010). U.S. Department of Commerce Census Bureau (USCB) American Fact Finder Community Facts.

USGS. (2013). "United States Geological Survey (USGS) Water Watch Google Earth streamgages KML files State streamflow KML files." 2013, from http://waterwatch.usgs.gov/index.php?id=stategage.

van den Belt, M. (2004). Mediated Modeling: A System Dynamics Approach to Environmental Consensus Building. Washington, Island Press.

van den Belt, M. J. (2000). Mediated modeling :   a collaborative approach for the development of shared understanding and evaluation of environmental policy scenarios, with case studies in the Fox River Basin, Wisconsin and the Ria Formosa, Portuga. Ph.D., University of Maryland.

Vinge, V. (2006). "The Creativity Machine." Nature **440**: 411.

Vogel, J. J., D. S. Vogel, J. A. N. Cannon-Bowers, C. A. Bowers, K. Muse and M. Wright (2006). "Computer gaming and interactive simulations for learning: a meta-analysis." Journal of Educational Computing Research **34**(3): 229.