Applied Geography 31 (2011) 53–63

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

Examining geographic visualization as a technique for individual risk assessment

William M. Bass [1], R. Denise Blanchard *

Department of Geography, James and Marilyn Lovell Center for Environmental Geography and Hazards Research, Texas State University, 601 University Drive, San Marcos, TX 78666-4616, United States

Keywords:
Geographic visualization-risk
Visualizing risk
Cartographic visualization-hazards
Individual risk assessment
Hazards risk perception

ABSTRACT

This research examined the extent to which geographic visualization might serve as a technique for assessing and understanding levels of personal risk. An exercise was created, consisting of a series of five animations, representing five historical flood events in flood-prone central Texas and displayed on an Internet site along with a survey questionnaire. Three questions guided this research: 1) To what extent can individuals correctly rank levels of intensities among five historical rainfall events, and, therefore levels of risk after viewing visualizations; 2) Does professional training and experience in a hazards-related field prove to be an advantage for correctly identifying and ranking levels of risk among the rainfall events after viewing visualizations; 3) Is prior experience with a flood, or any other hazard occurrence a factor in whether individuals can correctly assess levels of risk in visualizations depicting rainfall events? Our study demonstrated that computer-interested individuals are willing and able to access website information related to historical flood events, and interact with that website in viewing, interpreting and ranking computer animations of featured events; and, for the most part, regardless of prior experience, or workplace training, can, more or less, distinguish between levels of intensity of events. However, due to the fairly recent introduction of geographic visualization in hazards research, we call for more work in this area, and have offered an extensive list of research questions for assessing the viability of this technique for more accurate risk assessment and management at the individual level.

Introduction

Managing and communicating risks associated with natural and environmental hazards is crucial for the safety and preservation of lives and properties at all geographic scales. Computer visualization of risk through its numerous cognitive and communicative advantages provides an effective way to display various types and levels of risk for improved understanding and salience by individuals (Eppler & Aeschimann, 2008, 2009). Buckley, Gahegan, and Clarke (2000, p. 2) explain that, "The human visual system is the most powerful processing system known. By combining technologies such as image processing, computer graphics, animation, simulation, multimedia, and virtual reality, computers can help present information in a new way so that patterns can be found, greater understanding can be developed, and problems can be solved."

This research examined the extent to which geographic visualization might serve as a technique for assessing and understanding levels of personal risk. An exercise was created, consisting of a series of five animations, representing five historical flood events in central Texas. The exercise was displayed on an Internet site along with a survey questionnaire. After viewing animated computer images, participants were asked to rank the flood events by levels of intensity, indirectly representing levels of risk. In addition, participants were directed to a survey questionnaire for additional information such as direct and indirect experience with a disaster, perception of personal risk, and other pertinent information. Recognizing that workplace training in a hazards-related field might prove to be an advantage for interpretation and ranking of the visualizations, we stratified our sample into laypersons, students, and professionals, where the latter group would be involved in a hazards-related occupation.

Our study area, Texas Hill Country, discussed below in Section 2, is comprised of one of the most flood-prone areas of the state. Assuming that many of our participants were likely to be familiar with flooding in central Texas, we focused on prior experience to assess the degree to which this might affect participants' usage and understanding of the visualizations. Furthermore, "prior disaster

* Corresponding author. Texas State University, James and Marilyn Lovell Center for Environmental Geography and Hazards Research, 601 University Drive, San Marcos, TX 78666-4616, United States. Tel.: +1 512 245 3090/2170; fax: +1 512 245 8353.

E-mail addresses: william.bass@h-gac.com (W.M. Bass), rb06@txstate.edu (R. Denise Blanchard).

[1] Tel.: +1 512 245 2170; fax: +1 512 245 8353.

0143-6228/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apgeog.2010.03.011

experience" stands out from the hazards literature as a significant variable in attempting to understand factors that contribute to the formation of individual risk perception and as a motivator for protective response (Anderson, 1969; Blanchard-Boehm, 1998; Blanchard-Boehm & Cook, 2004; Burton & Kates, 1964; Burton, Kates, & White, 1978; Gruntfest, 1987, 1997; Hutton & Mileti, 1979; Kasperson, Kasperson, Pidgeon, & Slovic, 2003; Kates, 1970; Krimsky, 1992; Lindell, Prater, & Perry, 1997, p. 79; Mileti, 1975; Mileti & Fitzpatrick, 1991, 1993; Smith & Tobin, 1979; White & Haas, 1975; and others). Thus, we expected higher experience with extreme precipitation events, or any other hazard, to be a positive influence on the number of correct rankings.

This study was similar to prior risk perception studies where participants of different skill levels and experiences were asked to rank hazards on a variety of measures from "most" to "least" (Fischhoff, Slovic, Lichtenstein, Read, & Combs, 2000; Slovic, 2000; Slovic, Fischhoff, & Lichtenstein, 2000). However, prior studies primarily focused on a wide variety of hazards, whereas this study focused only on how participants perceived risk associated with different levels of severe precipitation events. Furthermore, because this study dealt with a purposeful sample of 90 participants, our objective was not to establish causality between performance in ranking precipitation events and measures of workplace training and/or prior hazard experience. Contributions and intentions of this research were to: introduce geographic visualization as a tool in hazards research; provide a general method for creating images and displays; and, examine the use of this technique at the individual or household level for risk assessment and decision making. Currently, financial and government institutions employ visualization techniques for hazards risk assessment and management though model usage such as the Insurance and Investment Risk Assessment System, or IRAS, which simulates specific events and determines the likely impact at each event (Mileti, 1999); however, there are few opportunities for individuals to use visualization methods, beyond access to weather reports by broadcast and electronic media. Further, our decision to create and test visualizations based on historical flooding is supported in the literature by researchers such as Wilson and Crouch (1994, p. 238) who write that…"Risks based on historical data are particularly easy to understand and are often perceived, reliability. It is therefore easy to illustrate a risk calculated from historical data to understand some characteristics of risk estimation…it becomes clear that it is impossible to calculate any risk without a model of some sort, even the simple one that tomorrow will be like today." Thus, with this in mind, our visualizations served as a "model" for risk, and the questions that guided our study were as follows: 1) To what extent can individuals correctly rank levels of intensities among five historical rainfall events, and, therefore levels of risk after viewing visualizations; 2) Does professional training and experience in a hazards-related field prove to be an advantage for correctly identifying and ranking levels of risk among the rainfall events after viewing visualizations; and, 3) Is prior experience with a flood, or any other hazard occurrence a factor in whether individuals can correctly assess levels of risk in visualizations depicting rainfall events?

Computer visualization: An emerging technology

Computer visualization—concepts, techniques, and applications—is a relatively recent phenomenon, rising to the forefront of scientific computing as a result of a 1987 National Science Foundation (NSF) report, entitled, *Visualization in Scientific Computing*, produced by the agency's Panel on Graphics, Image Processing and Workstations. The panel wrote, "ViSC [visualization in scientific computing] is emerging as a major computer-based field…As a tool for applying computers to science, it offers a way to see the unseen…[it] promises radical improvements in the human/computer interface" (NSF, 1987, p. 101).

Computer visualization is defined as, "the process of converting raw data to images or graphs so that the data are easier to comprehend and understand" (Reckelhoff-Dangel & Petersen, 2007, p. 19). In particular, visualization involves: 1) searching through enormous volumes of data; 2) exploring data to find unsuspected relationships; 3) communicating complex patterns; and, 4) providing a formal framework for data presentation (Gahegan, 2000, pp. 253–254). The skills that support visualization include: data analysis, visual design, and an understanding of human perception and cognition (Stone, 2008, p. 1).

Geographic visualization and hazards

In a White Paper on "Geographic Visualization," Buckley et al. (2000) observe that, though computer visualization is being developed in nearly all branches of science, geographers and spatial scientists are uniquely positioned to contribute to its further development. Clearly, early theoretical and conceptual researchers such as, Buttenfield (1996), DiBiase (1990), DiBiase, MacEachren, Krygier, and Reeves (1992), Gahegan (2000), Krygier (1994), MacEachren (1994, 2004), MacEachren, Buttenfield, Campbell, DiBiase, and Monmonier (1992), Taylor (1991), and others, provided a framework for *geographic* visualization within the spatial sciences for problem-solving (Buckley et al., 2000).

Geographic visualization is a relatively new research development in hazards geography as a possible tool and shows potential for communicating and influencing more accurate risk perception. A nascent study by Collins (1998) investigated the use of geographic visualization for improved risk perception assessment, especially by individuals with lower levels of experience with a prior hazard event. Though Collins (1998) primarily focused on risk perceptions associated with hurricanes, his research demonstrated that other natural hazards might also be studied to determine the extent to which geographic visualization might prove useful as a tool for communicating levels of risk.

More recent extensions of geographic visualization to hazards research and practice are mentioned in several reports by the National Research Council (NRC) that identify and encourage uses of information technology (IT), including methods such as visualization for disaster mitigation, preparedness, response, and recovery (NRC, 2007a, b). In a recent publication, the NRC's Committee on Using Information Technology to Enhance Disaster Management writes that, "…IT provides capabilities that can help people grasp the dynamic realities of a disaster more clearly and help them formulate better decisions more quickly," and concludes that, "…IT has as-yet-unrealized potential to improve how communities, the nation, and the global community handle disasters" (Rao et al., 2007, pp. 2–3). Thus, in all aspects of emergency management, the development of geospatial data and tools shows promise for saving lives, limiting damage, and reducing costs to society.

Possibilities for assessment of personal risk

A broadly accepted definition of *risk* is, "…A situation or an event where something of human value (including humans themselves) is at stake and where the outcome is uncertain" (Pidgeon, Kasperson, & Slovic, 2003, p. 56). Researchers and practitioners of disaster and emergency management have taken notice of the advantages of computer visualization for applying large data sets to create images for improved understanding of physical and societal risks from hazards, and include: Collins (1998); Giordano and Gelpke (2003); Huang (2003); Johnson (1992); Lundgren and McMakin (2009); Monmonier (1994, 1996, 1998); NRC (2007b); NSF (2000); and

Thorton (2009). Geographers and spatial scientists have readily facilitated the development of "geovisualization" for understanding risk in other areas pertinent to hazards research through their knowledge and usage of: 1) geospatial data such as vector and raster maps for generating new cartographic products for visualization over the Internet; 2) digital elevation models (DEMs), *orthomosaics* and 3-D animations that combine with, and/or supplement, traditional techniques for the display of geospatial information and geographical phenomena; and 3) presentations of rendered landscapes with animated *fly-throughs* for decision making in fields such as hazard identification, environmental protection, safety and security, and natural resource management (Dymon & Winter, 2007, p. 4).

Difficulty exists for individuals to accurately perceive risk associated with a natural or environmental hazard because of the difference between objective risk (scientific quantification) and perceived risk (personalized understanding of the degree of imminent danger felt by the individual) (Dymon & Winter, 2007, p. 4). The theoretical approach known as "Mental Models" is one most often associated with visualization for improving understanding levels of personal risk and closing the gap between objective and perceived risk (Dymon & Winter, 2007); (Lundgren & McMakin, 2009). Morgan, Fischhoff, Bostrom, and Atman (2002, p. 21) write that, "By definition, the audience for a [risk] communication lacks a complete understanding of its subject matter. Yet, for most risks, people have at least some relevant beliefs, which they will use in interpreting the communication. They may have heard some things about the risk in question. It may remind them of a related phenomenon. Its very name may evoke some associations. If they must make some inferences about the risk, such as how big it is, how it can be controlled, or who manages it, they will assemble their fragmentary beliefs into a mental model, which they will then use to reach their conclusions."

Mental models are the diagrams and maps that people have stored in their memories from past experiences and learning about how the world works. Thus, the process that most people apply when viewing a map adjusts their mental models, and thus affects their perceptions of risk (Dymon & Winter, 2007). Monmonier (1996) explains that location and mental mapping are key concepts in the perception of risk. Because most people possess minimal map reading skills using traditional products, a blanket approach to risk evolves, where an entire area is believed to be at risk; in reality, only a small area may be hazardous. Further, because risk is not quantitatively built into maps of hazardous sites, location becomes the key in which the map reader calls upon his/her mental map and simply calculates the distance from an identifiable hazard to the home or place of work as a measure of risk—closer facilities pose a higher risk, while those farther away are perceived as less of a risk (Monmonier, 1996). Thus, the advantage of geographic visualization is that it has the capability, not only to create visual maps illustrating levels of objective risk, but also provides display media for individuals to compare and adjust their own "mental maps" for more accurate information of location relative to actual risk.

Because visualization is an emerging technology, Eppler and Aeschimann (2008; 2009) believe that risk visualization is still in a stage where there are few proven applications and various experimental solutions that still need further refinement, especially in evaluating existing solutions and comparing them to one another. Buckley et al. (2000) call for further research into perceptual and cognitive aspects of communication through visualization as current research focuses on visual properties and impacts of the display, as well as new techniques for dealing with increasing amounts of data, while research addressing the effectiveness of visualization has lagged behind. Thus, the following presentation, analysis, and discussion of findings provide a degree of insight into the emerging field of geographic visualization for improved individual risk perception and assessment.

Study area

The setting for this research focused on south-central Texas in the region of the Balcones Escarpment (Fig. 1). The escarpment is a geologic fault zone several miles wide that separates the Edwards Plateau to the west from the Coastal Plains to the east. Elevations along the Balcones Escarpment range from 1000 to 2500 feet. From a meteorological perspective, the study area lies in a transition zone between humid and semiarid climates, and experiences both wet and dry years—droughts are often ended in Texas by flooding with relatively little variation in between (Elsberry, 2006). For instance, Jordan (1978) writes that in 1956, Fredericksberg in central Texas, recorded only 11 inches of precipitation for the year, but for the following year, received over 41 inches.

The major source of precipitation for Texas is provided by the Gulf of Mexico, however, the eastern Pacific Ocean, and land-recycled moisture also provide, to a lesser extent, sources of annual rainfall to the state (Fig. 1). Other geographic and atmospheric conditions that combine to form severe storms over the state, include: the jet stream that crosses the state from the Rocky Mountains; closeness to the unstable west Texas "dryline" separating the dry desert air from the moist Gulf air; and, violent cell storms that release heavy rainfall amounts caused by local convection processes (Elsberry, 2006).

Of significance for central Texas, though, is that the *majority of total rainfall* occurs *during storm events* when a large amount of precipitation falls over a short period of time (Carr, 1967; Larkin & Bomar, 1983; Schmidt, 2001; Slade & Patton, 2003). In the "Hill Country" of central Texas, elevation increases along the northwest side of the Balcones escarpment—the Edwards Plateau—assist in the uplifting of air masses and the formation of storms. Many of the largest thunderstorms in the state form along the escarpment where they stall and produce extreme precipitation depths during a few hours or a few days (Slade & Patton, 2003). The runoff from the plateau sends floodwaters racing downstream into tributaries, creeks and rivers where the limestone and thin soils have minimal absorption rates, thus, exacerbating the intensity and impact of flooding. It is no wonder that the study area bears the moniker, "Flash Flood Alley," one of the nation's three most flash flood-prone areas (Griffiths & Ainsworth, 1981; Bomar, 1995).

Study approach and process

The research design called for a mixed-methods approach—a two-phased, sequential "exploratory" design in which qualitative data (animations) was supplemented by quantitative data collection (survey questionnaire) (Creswell, 2009). Specifically, the phases included: 1) development of computer cartographic visualizations; and 2) development of an online survey for data collection—recording participants' rankings of visualizations, and data on variables, especially personal and workplace training, prior experience, and perception of risk. The phases of this study are illustrated in Fig. 2 and are discussed in more detail below.

This research required participation through the use of electronic media in order to facilitate reaching the audience in a manner that did not negatively impact their personal and professional responsibilities. For this reason, Internet-based maps and surveys were developed.

There were several assumptions underlying this design: 1) that those participating in the study were capable of using the required resources, which included a personal computer, Internet access, and ability to view multimedia content; 2) that participants in this study would have skills ranging from novice to expert users of

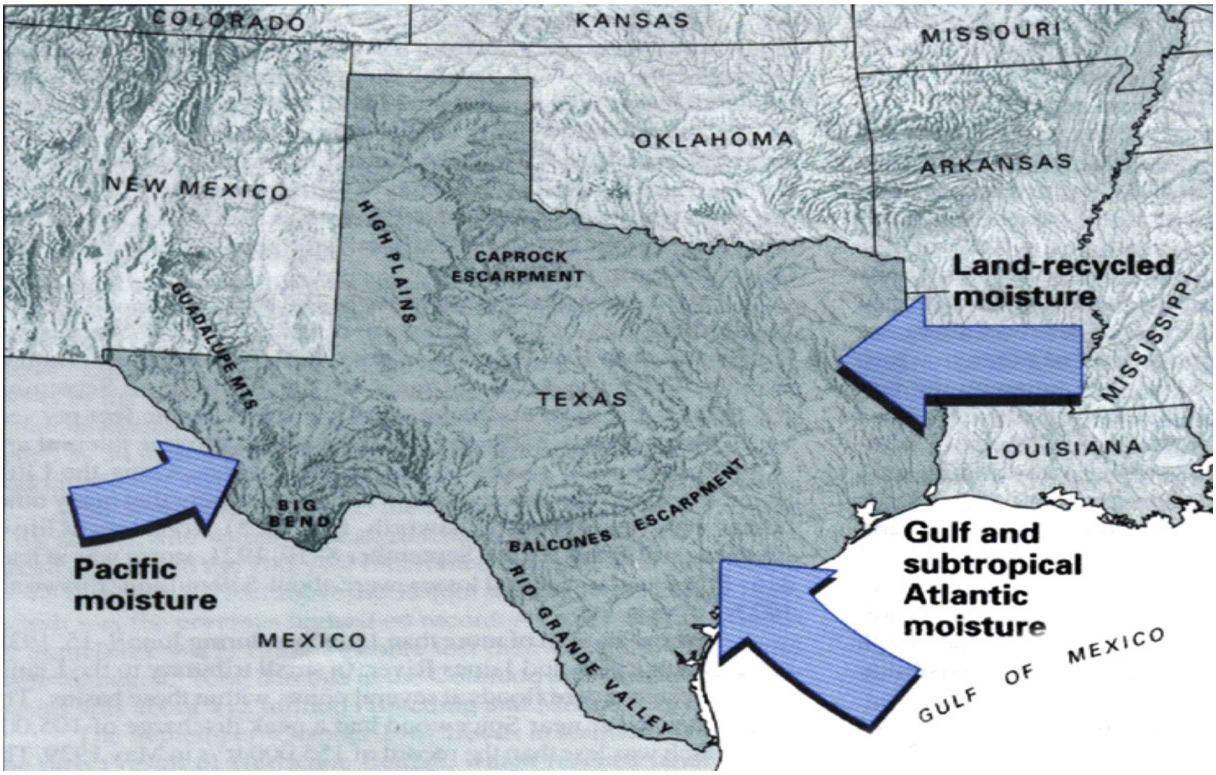

Fig. 1. Principal sources and patterns of delivery of moisture into Texas (Source: 2003, Slade and Patton).

personal computers, but would be able to access, view, and interpret the five cartographic visualizations on an Internet site; and, 3) that participants would adhere to instructions in a survey letter received beforehand as well as posted on the study website. Specifically, the letter emphasized to participants that they were to assess the risks of each event for the entire study area, and not rank events based upon risk to one particular place within the study area. Finally, participants were asked to use a Likert scale of 1 through 5 to rank the events, with 1 being the "most hazardous" and 5 being the "least hazardous." It was assumed that participants could correctly interpret and apply this scale. To assist their efforts, participants were given a precipitation legend, which cross-referenced the color scheme used to delineate precipitation amounts with their representation on the event visualization maps.

Development of computer cartographic visualizations and survey instrument implementation

Data acquisition

Data were obtained from the National Climatic Data Center (NCDC) to serve as the basis for producing five animated visualizations of previous flood events in central Texas of various magnitudes (i.e., levels of risk). Data were downloaded from the NCDC and imported into a GIS database for event identification and development of statistical maps used in the visualization exercises. The National Oceanic and Atmospheric Administration (NOAA) collects climate data on a daily basis from approximately 150 weather stations in the central Texas region (as of February 2004). These stations are managed by a network of volunteers and

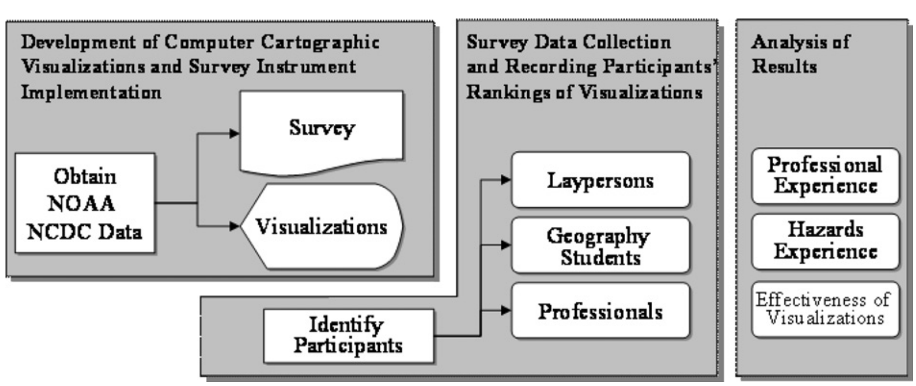

Fig. 2. Visual diagram of procedures: two-phase "explanatory" design.

National Weather Service (NWS) employees, and provide the data collected by NOAA for use by climate and hazards researchers. Data were available through the NCDC for each of the active stations, as well as stations no longer in service, but which included data in years past.

Study instruments

Two primary instruments, discussed above, were created to facilitate participant's rankings of risks associated with historical precipitation events. Cartographic animations, or geographic visualizations, consisted of a series of maps that represented cumulative rainfall for each day in the event sequence. Thus, each event animation consisted of seven frames, for a total duration of approximately 10 seconds. The animations were used to visually communicate the levels of precipitation for different events in the study area.

The process that this survey followed allowed for an efficient and effective manner in which to contact and disseminate the visualizations and survey to participants. The use of the online Internet-based survey allowed for various controls and data quality measures relating to the acquisition of survey responses. For instance, the web-based survey form permitted a respondent to only select one ranking across the five events, which ensured that no two events would be given the same ranking value. The survey form was also designed for ease in completion, meaning that instructions were clear and understandable for navigating through the questionnaire. This resulted in positive feedback from many participants regarding the effectiveness and efficiency in completing the questionnaire. For further ease in data collection, the methodology also limited the number of events for viewing and rating to five, so as to not extend the time for completing the process.

Selection of events for visualizations

Fig. 3 displays the precipitation events for testing, and are shown in order from the highest hazard (risk) due to cumulative precipitation to the lowest, as follows: (highest-most severe) 2002 June 30th to July 6th; 1998 October 15th to 21st; 1952 September 7th to 13th; 1978 July 30th to August 5th; and, 1985 November 21st to 27th (lowest-least severe). When selecting the events for this study, it was necessary to represent varying levels of flood hazards. For instance, to present extremes in events, two were included that represented significantly different amounts of cumulative rainfall. The 2002 situation represented one of the most widespread events with the largest amount of rainfall in the history of the region, whereas, the 1985 event represented a much lower level of rainfall for the region and was *not* considered to be especially hazardous. These, along with three additional events of intermediate severity and their seven-day sequences representing cumulative rainfall amounts, are illustrated below.

Detailed creation of cartographic visualization animations

The process for developing the visualization instruments first involved mapping precipitation data in a Geographic Information System (GIS). Each station was mapped within the GIS using the associated precipitation values for that station as the measurement value, representing the cumulative amount instead of the daily precipitation amount. For instance, for a seven-day event, the station's first day measurement value was the precipitation value for day 1, for day 2 the measurement value included day 2 plus the day 1 value, and for day 3, the measurement value included day 3 plus the cumulative amount used for day 2, and so forth. Therefore, the last day of the sequence, day 7, was the cumulative precipitation amount for all prior days in the sequence and represented the total precipitation for the seven-day period at a particular station. For each seven-day event, a series of daily cumulative precipitation *isarithmic* maps was created using *ArcGIS Geostatistical Analyst 8.3*. The individual maps that represented cumulative precipitation for each day in the date sequence were referred to as an event sequence. The *isarithmic* maps were developed using *kriging* (an interpolation technique) to estimate the precipitation amounts at un-sampled points using data collected at each gauging station.

Classification scale for cumulative precipitation

Different amounts of precipitation are represented by *isohyets*, lines connecting equal precipitation amounts, represented in a hypsometric tinting color gradient format (e.g. clear to dark red) as illustrated in Fig. 4.

Our trivariate choropleth map color scheme used shades of blue to represent lower amounts of cumulative precipitation, and more saturated, contrasting yellow to red shades to depict higher amounts of cumulative precipitation and thus, higher levels of intensity (Carr, 1993). Ware (2004, p. 125) writes that this schema is one often employed to counteract the effects of *deuteranopia*, or red/green color blindness. Ware further explains that the majority of people who are color blind cannot distinguish in a red-green direction, but can distinguish colors in a blue-yellow direction (2004, 125). Examples of this schema are often found in graphics produced by the National Hurricane Center (NHC) for visualizations produced from weather forecasting models of extreme precipitation events. In this research, the colors were chosen to widen the contrast between low-intensity and high-intensity cumulative rainfall amounts for greater ease in interpreting, comparing and ranking events against each other. In addition, events were chosen from the NOAA, NCDC data so that a range of hazard levels, from low/moderate to extreme danger, were represented in this exercise. All data that were used in the development of the precipitation maps were ratio-level data, and were presented in inches of precipitation.

Development of cartographic event animations

Once all daily precipitation maps were created, the animation of each day's cumulative precipitation values and spatial extent were developed. The animations of individual static maps were achieved through the use of *Macromedia Flash*, a multimedia authoring tool capable of combining static graphic images, and generating an animation to appear as if the data are being dynamically created. The use of animation was important to show the spatial extent of precipitation values for each event, and how the event evolved with time. The static *isarithmic* map for each day that comprised an event sequence was placed into a *Flash* template file. The individual maps were then animated and published in a format that was capable of being viewed using a standard Internet browser application, such as *Internet Explorer*. Each event animation was designed to allow the participant to perform the following: play an animation, stop the animation, step frame-by-frame forwards or backwards, and replay the animation. This final animation product was then posted to an Internet website where it was available for viewing by participants. A sample of the visualization product is illustrated below in Fig. 5. Each animation begins with the first day of the sequence; then, the participant is able to use the controls to view the animation.

Study website

Following the development of the event animations and the participant survey, a study website was created to provide participants with a single location on the Internet to access and

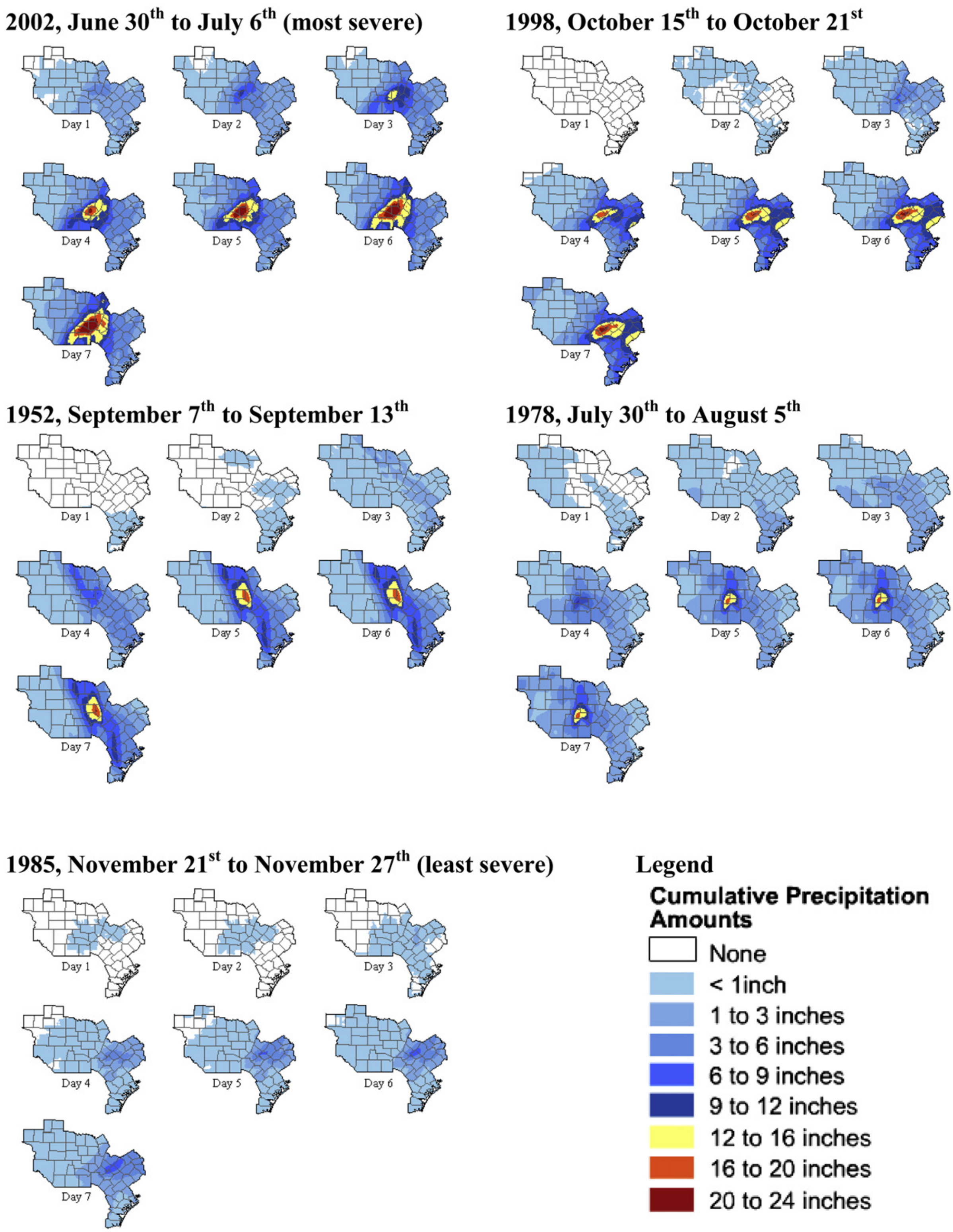

Fig. 3. Rainfall events in ascending order of intensity (severity).

view event visualizations, and to complete the survey. Participants were given a website URL to visit based on their classification as either layperson, geography student, or professional, so that survey data could be tracked separately for the three groups of participants. Fig. 6 illustrates the website which participants viewed to access the animations and submit their rankings and survey responses.

Survey data collection and recording participants' rankings of visualizations

Identifying participants

As mentioned earlier, participants were stratified into three groups, primarily based on their understanding and experience in

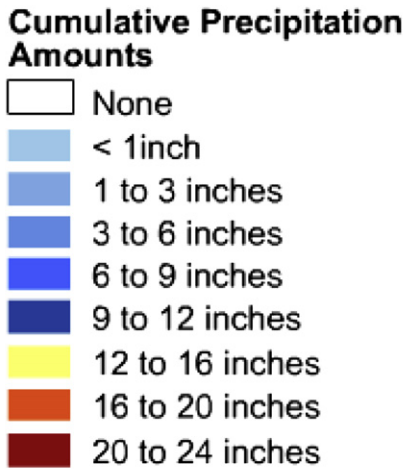

Fig. 4. Trivariate choropleth map color scheme for displaying precipitation amounts.

dealing with natural hazard events on a regular basis, with each group having at least 30 participants. The first group included professionals in the areas of environmental protection, emergency management/response, and climatology. The second group included geography graduate students (MA/MS and PhD). The third group included laypersons whose day-to-day professional work did not involve natural hazards or climate-related research. Each of the 90 participants was contacted either by phone and/or e-mail to request their participation in the study. An e-mail cover letter was submitted to participants that explained the purpose of the study, as well as procedures for viewing event visualizations via the Internet and completing the survey. All participants were at least 23 years of age, with the majority in each group being between 30 and 49 years of age. Furthermore, only participants who were at least 18 years of age or older were asked to participate in the study.

Results from the visualization exercise

Viewing of animations posted to the website was unlimited, and participants had the option to pause, step forward, step backward, or replay an event. Following the rankings, participants recorded responses for the remaining items on the survey questionnaire. Responses were downloaded into a *Microsoft Access* database for formal statistical testing. Several methods were used to summarize and analyze responses, including general descriptive statistics as well as non-parametric tests. Table 1 summarizes the number and percentage of participants who correctly ranked the five animated visualizations. Over half of the total number of participants (56 percent) ranked all five events correctly. Twenty-three percent missed just one; however, because of the nature of the ranking from 1 to 5, by default, there would have been two incorrect rankings, instead of one. The breakdown of groups by hazards-related workplace training and correct rankings was nearly even, with laypersons slightly ahead of the other two groups.

Analysis of workplace training and ranking performance

In this instance, the grouping variable was the participant's "professional classification" (layperson, geography student, professional), and the testing variable was the percentage of events correctly ranked. It was assumed that laypersons would have the least advantage, and therefore, score lower in rankings, while geography students and professionals in a hazards-related field would have greater workplace training and score higher.

Due to the non-random selection of respondents for this study, non-parametric statistical tests were the most appropriate means to test for group comparisons on "training" against "total score." To determine *which groups* were different with respect to average ranks, the Mann–Whitney *U*-test of two independent samples was employed for comparing two groups at a time, that is, Layperson to

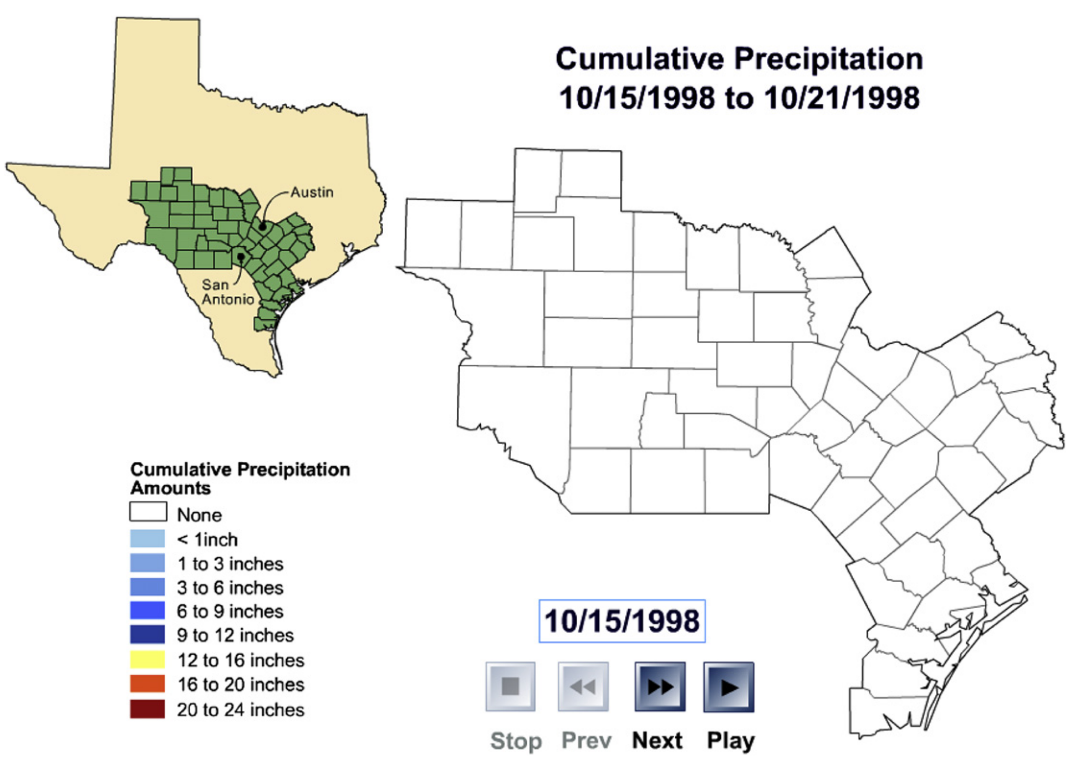

Fig. 5. Sample event animation page.

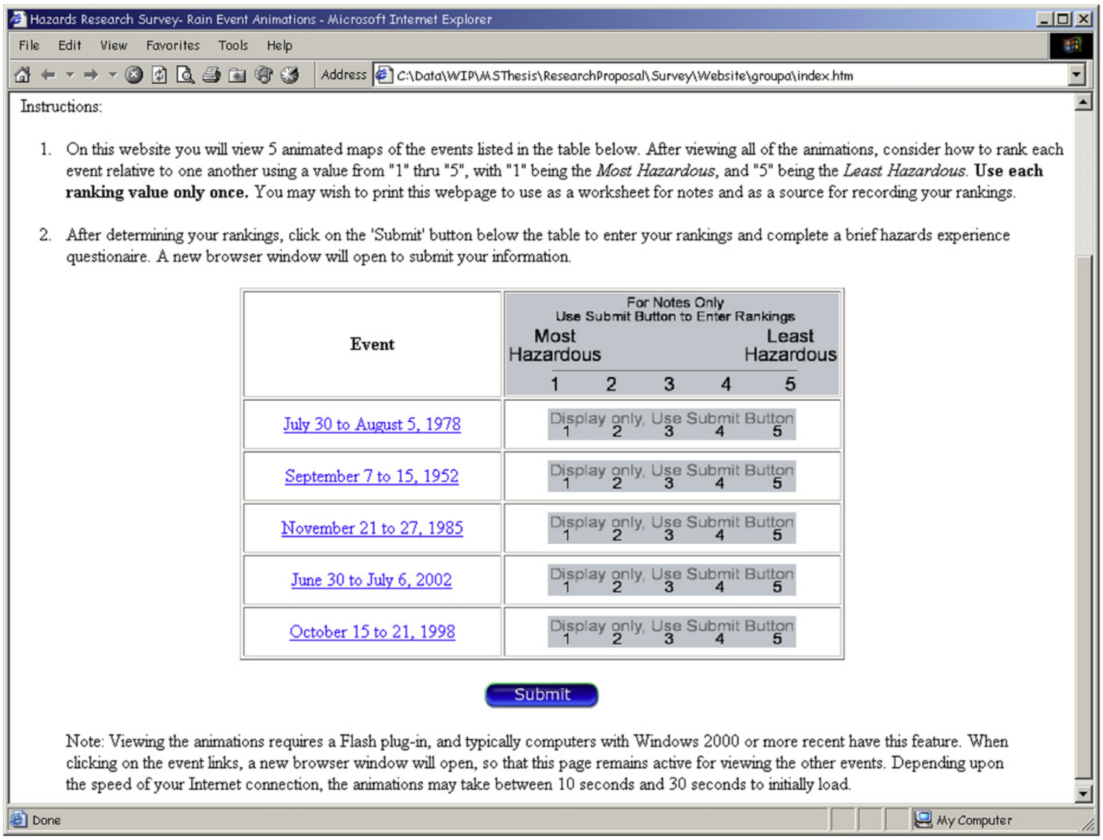

Fig. 6. Study website with link to event visualizations and survey.

Student; Layperson to Professional; and Student to Professional, in order to assess whether levels of professional training and experience were statistically significant factors in accurately ranking the visualizations (Lomax, 2001; Sorensen & Moore, 2003). Results are summarized below in Table 2, and indicate no statistically significant difference between the groups; that is, the assumed advantages with workplace training did not appear to have an influence on participants' rankings of events.

The role of prior experience

In this analysis, the Kruskal–Wallis one-factor analysis of variance test was performed to determine whether *prior experience* with a severe precipitation or weather event and ranking of events differentiated the three groups. Based on the frequency of flooding in our study area, as well as prior findings in the hazards research literature, it was expected that participants with prior "flood" experience would be able to rank events more correctly; however, as reported in Table 3, there was no statistically significant difference between the groups on experience with prior flood events, and his/her ability to correctly assess risk associated with historical rainfall events presented in the visualizations. The same test results were obtained for both the total "number of *all other* hazardous events," including tornadoes, ice storms, volcanic activity, and earthquakes, and "total exposure to hazards."

As a final note, we also tested to determine if there were any differences *within* each of the three training classifications of participants on prior experience with hazards and total scores from rankings, and, again, found no statistically significant differences between the groups. Because of this finding, we did not compile a table of data.

Discussion and summary

For the past two decades, scientific visualization techniques and methods have risen to the forefront of research and application in fields such as medicine, transportation, and the natural sciences.

Table 1
Summary of correct responses.

Correct rankings	Professionals		Students		Laypersons		All groups	
	N	Percentage	*N*	Percentage	*N*	Percentage	*N*	Percentage
All	16	53	16	53	18	60	50	56
Missed 1[a]	–	–	–	–	–	–	–	–
Missed 2	7	23	6	20	8	27	21	23
Missed 3	2	7	2	7	0	0	4	4
Missed 4	4	13	3	10	4	13	11	12
None	1	3	3	10	0	0	4	4
Total	30	100	30	100	30	100	90	100

[a] Because each rank (1 thru 5) could only be used once, it was not possible to incorrectly rank only a single event.

Table 2
Group comparisons of professional training.[a]

Group	L.P.	Student	L.P.	Prof.	Student	Prof.
N	30	30	30	30	30	30
Mean rank	32.23	28.77	31.90	29.10	30.08	30.92
Sum of ranks	967.00	863.00	957.00	873.00	902.50	927.50
U-statistic	398.00		408.00		437.50	
Z-score	−0.86		−0.69		−0.20	
Asymp. sig. (2-tailed)[a]	0.39		0.49		0.84	

[a] Mann–Whitney *U*-Test at the 0.05 level of significance and higher.

Table 3
Experience with prior events and correct rankings of levels of risk.

Events experienced	Floods		Other hazards		Total hazards	
	N	Mean rank	*N*	Mean rank	*N*	Mean rank
0	10	50.85	13	49.73	4	56.63
1	10	43.80	10	52.85	4	40.88
2	15	48.93	20	45.92	8	51.63
3	16	50.81	12	43.79	6	50.33
4	10	52.85	6	45.67	8	44.31
5	5	26.00	2	65.50	7	50.29
6 or more	24	39.29	27	39.67	53	43.08
Total	90		90		90	
H-statistic	7.76		4.56		2.70	
d.f.	6		6		6	
Asymp. Sig. (2-tailed)[a]	0.26		0.60		0.85	

[a] Kruskal–Wallis Test at the 0.05 level of significance and higher.

Visualization for displaying aspects of risk to aid managers in the finance and investment fields has increased, as well; however, the utilization of "geographic" visualization for spatial analysis and application for risk assessment and management, beyond usage of the geographic information system (GIS), has only recently been introduced in hazards research for assisting decision makers at all levels.

The aim of this research was to examine the extent to which geographic visualization might serve as a viable technique for individuals to use in discerning levels of risk. We first tested user ability to view and interpret levels of intensity, that is, risk, associated with five historical flood events in a flood-prone region of central Texas. Participants found it relatively easy to locate the Internet address, view and rank the animations, and navigate through to a survey questionnaire. For the ranking of events, fifty-six percent (50 out of 90 participants) ranked all five events correctly, while another 23 percent missed just one. The interpretation of this is ambiguous; while one may view the exercise in a positive way, given that three-fourths of participants correctly ranked all, or just missed one animation, another might view the results as inconclusive, given that only half of participants were one hundred percent accurate.

When we stratified our sample into laypersons, students, and professionals to identify any workplace or training advantages in using computer visualization, assuming that laypersons, especially, would be at a distinct disadvantage, and thus, not familiar with computer methods related to risk assessment, our expectations did not hold. Total scores of rankings did not differentiate the three groups whether they had a high level of hazards-related workplace training, or not.

Finally, we tested one of the most significant and consistently important variables in the hazards literature—prior experience with a hazard occurrence—against rankings/total scores for the participant group, as a whole, and found no statistically significant difference between prior experience with extreme precipitation events, or for any other hazardous events, for that matter. Additionally, the breakdown of the groups by levels of training, their prior experience, and ranking of events in the exercise, yielded no significant results, either. While early hazards research produced inconclusive and ambiguous findings regarding prior experience and its influence on risk perception and response behavior, as summarized in Sims and Baumann (1983), more recent hazards research points to this variable as having more influence on risk perception and response (Blanchard-Boehm, 1998; Mileti, 1999; Mileti & Fitzpatrick, 1991, 1993) whether for preparedness and mitigation, or in this study, response to correctly ranking animations. We expected to find high experience associated with high accuracy in ranking events, and, conversely, more incorrect rankings associated with lower levels of experience; however, this was not the case.

Our study demonstrates that computer-interested individuals are willing to access website information related to historical flood events, and interact with that website in viewing and interpreting computer animations of featured events, and, for the most part, regardless of prior experience, or workplace training, can distinguish between levels of intensity of events. However, the results of this study generate more questions, than answers regarding the viability of geographic visualization for assisting individuals in understanding and assessing their own personal risk from potential flood hazards. For instance, as a result of this study, we ask: "Did participants understand that, in ranking events, that they were also indirectly, ranking risk levels, or did they see the exercise as just performing a task as they might experience in navigating any website?" The concept of risk is complex. In discussing various concepts of risk, Tobin and Montz (1997) explain that in its simplest form, risk can be defined as the product of probability of occurrence and magnitude of an event; however, this technical measure of risk must be expanded to include society's views and perceptions of risk. Further, Tobin and Montz (1997, p. 289) write that, "one of the key issues in understanding risk and accomplishing risk assessment is the differing views people hold on the importance of various risks …it suffices to say that regardless of individuals' experience and training, it is not the scientific definition of risk on which they base decisions about which actions to take or to which hazards they will knowingly expose themselves." We, therefore, recommend further research to evaluate the assertion by many that the technique of geographical risk visualization holds great promise for more accurate risk assessment; and further, if this association is positive, will it result in motivating individuals to take actions of preparedness and mitigation against future potential flooding?

We also ask: What did the lack of differentiation between the groups signify? Green, Tunstall, and Fordham (1991), as discussed in Tobin and Montz (1997) find that engineers, emergency planners, and the public hold differing views of risk, with engineers interpreting risk as a measure of probability of occurrence of an event, emergency managers being more concerned with risks associated with public response to official actions, and the public holding a diversity of views toward risk. Green and colleagues further explain that views held by individuals are much more difficult to categorize because they vary based on experience, among other factors. Thus, the aspect of levels of professional training should be further explored to assess whether these differences among groups continue to hold, or have they shifted; and, as it applies to this research, could it be the case that familiarity with computer usage, in general, acts as a leveling factor among groups with or without hazards-related training?

And, finally, we ask: Is there a causal linkage between prior disaster experience and one's ability to distinguish levels of risk in visualizations, and, more importantly, to what extent might this association influence individual decision making in assessing personal risk? In other words, Would the availability and use of geographic visualization by individuals for personal risk assessment actually lead to response behavior in the way of preparing and mitigating against future natural disasters?

Further examination is called for, from this and other nascent research, before geographic visualization can be declared an acceptable and viable technique for decision making towards risk at the individual level. In addition to the questions outlined above that stemmed from this research, we suggest other avenues of research which include: 1) comparing geographic visualization products to traditional types of products, such as static maps, graphics, and illustrations; 2) assessing the ability and willingness of individuals to utilize geographic visualization for personal risk decision making; 3) examining the availability and reach of visualization products for a large populace; 4) investigating the cognitive aspects of viewing and interpreting geographic visualizations; and, 5) determining how visualization affects risk perception, especially with respect to how the cognitive aspects of visualization might combine with societal factors and, perhaps, even with particular locations. Thus, possibilities abound for development and usage of geographic visualization for risk assessment at the individual level; however, due to its relatively recent introduction, further research is necessary, and from a wide variety of perspectives, before claims can be made that this "new" technique is superior to traditional methods currently in place, and that its usage would result in more accurate risk assessment and management by the individual.

References

Anderson, W. A. (1969). Disaster warning and communication processes in two communities. *The Journal of Communication, 19*(2), 92–104.

Blanchard-Boehm, R. D. (1998). Understanding public response to increased risk from natural hazards: application of the hazards risk communication framework. *International Journal of Mass Emergencies and Disasters, 16*(3), 247–278.

Blanchard-Boehm, R. D., & Cook, M. J. (2004). Risk communication and public education in Edmonton, Alberta, Canada on the 10th anniversary of the "Black Friday" tornado. *International Research in Geographical and Environmental Education, 13*(1), 33–52.

Bomar, G. W. (1995). *Texas weather* (2nd ed.). Austin, TX: University of Texas Press.

Buckley, A., Gahegan, M., & Clarke, K. (2000). Geographic visualization. http://www.ucgis.org/priorities/research/research_white/2000%20papers/emerging/Geographicvisualization-edit.pdf.

Burton, I., & Kates, R. (1964). The perception of natural hazards in resources management. *Natural Resources Journal, 3*, 412–441.

Burton, I., Kates, R., & White, G. F. (1978). *The Environment as hazard*. New York, NY: Oxford University Press.

Buttenfield, B. (1996). Scientific visualization for environmental modeling: interactive and proactive graphics. In M. Goodchild, L. Steyaert, B. Parks, & C. Johnston (Eds.), *GIS and environmental modeling: Progress and research issues* (pp. 463–468). New Jersey: John Wiley and Sons.

Carr, D. (1993). Constructing legends for classed choropleth maps. Topics in scientific visualization. *Statistical computing and statistical graphics Newsletter*. http://mason.gmu.edu/~dcarr/lib/v4n3.pdf December 18.

Carr, J. T., Jr. (1967). *The climate and physiography of texas. Texas Water Development Board* report 53. Austin, TX: State of Texas.

Collins, R., Jr. (1998). *Risk visualization as a means for altering hazard cognition*. Unpublished dissertation, Department of Geography, University of South Carolina: Columbia.

Creswell, J. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches* (3rd ed.). Thousand Oaks, CA: Sage Publications.

DiBiase, D. (1990). Visualization in the earth sciences, earth and mineral sciences. *Bulletin of the College of Earth and Mineral Sciences, Pennsylvania State University, 59*(2), 13–18.

DiBiase, D., MacEachren, A., Krygier, J., & Reeves, C. (1992). Animation and the role of map design in scientific visualization. *Cartography and Geographic Information Systems, 19*(4), 201–214, 265–266.

Dymon, U., & Winter, N. (2007). *Hazard mapping and modeling. Session 5, Communicating risk*. Academic Emergency Management and Related Courses, Emergency Management Institute (EMI). Emmitsburg, MD: Federal Emergency Management Agency (FEMA). Higher Education Program.

Elsberry, R. (2006). Texas floods: why central Texas floods. http://www.news8austin.com.

Eppler, M., & Aeschimann, M. (2008). *Envisioning risk: A systematic framework for risk visualization in risk management and communication*. Institute for Corporate Communication (ICA) Working paper 5/2008. Lugano, Switzerland: Faculty of Communication Sciences, University of Lugano (USI). http://www.knowledge-communication.org/pdf/envisioning-risk.pdf.

Eppler, M., & Aeschimann, M. (2009). A systematic framework for risk visualization in risk management and communication. *Risk Management: An International Journal, 11*(2), 67–89.

Fischhoff, B., Slovic, P., Lichtenstein, S., Read, S., & Combs, B. (2000). How safe is safe enough? A psychometric study of attitudes toward technological risks and benefits. In P. Slovic (Ed.), *The perception of risk* (pp. 80–103). London, UK/Sterling, VA: Earthscan Publications Ltd.

Gahegan, M. (2000). Visualization as a computational tool. In S. Openshaw, & B. Abrahart (Eds.), *Geocomputation* (pp. 253–274). UK: Taylor and Francis.

Giordano, A., & Gelpke, R. (2003). Geographic information technologies and the history of a shoreline: the case of chapter 91 in New Bedford, Massachusetts. *The Professional Geographer, 55*(3), 329–342.

Green, C. H., Tunstall, S. M., & Fordham, M. H. (1991). The risks from flooding: which risks and whose perception? *Disasters, 15*(3), 227–236.

Griffiths, J. W., & Ainsworth, G. (1981). *One hundred years of Texas weather, 1880–1979*. College Station, TX: Texas A&M University Press.

Gruntfest, E. C. (1987). *What we have learned since the Big Thompson flood*. Special Publication No. 16. Boulder, CO: University of Colorado, Institute of Behavioral Science, Natural Hazards Research and Applications Information Center.

Gruntfest, E. C. (1997). *Twenty years later: What we have learned since the Big Thompson flood*. Special Publication No. 33. Boulder, CO: University of Colorado, Institute of Behavioral Science, Natural Hazards Research and Applications Information Center.

Huang, B. (2003). Web-based dynamic and interactive environmental visualization. *Computers, Environment and Urban Systems, 27*(6), 623–636.

Hutton, J., & Mileti, D. S. (1979). *Analysis of adoption and implementation of community land use regulations for floodplains*. San Francisco, CA: Woodward-Clyde Publishers.

Johnson, B. (1992). Advancing understanding of knowledge in lay risk perception. http://piercelaw.edu/risk/vol4/summer/johnson.htm#top.

Jordan, T. G. (1978). Perceptual regions in Texas. *Geographical Review, 68*(3), 293–307.

Kasperson, J. X., Kasperson, R. E., Pidgeon, N., & Slovic, P. (2003). The social amplification of risk: assessing fifteen years of research and theory. In N. Pidgeon, R. E. Kasperson, & P. Slovic (Eds.), *The Social amplification of risk*. UK: Cambridge University Press.

Kates, R. (1970). Human adjustment to earthquake hazard. In Committee on the Alaska Earthquakes of the National Research Council. (Ed.), *The great Alaska earthquake of 1964*. Washington, DC: National Academy of Science.

Krimsky, S. (1992). The role of theory in risk studies. In S. Krimsky, & D. Golding (Eds.), *Social theories of risk* (pp. 3–22). Westport, CT: Praeger Publishers.

Krygier, J. (1994). Sound and geographic visualization. In A. MacEachren, & D. Taylor (Eds.), *Visualization in modern cartography* (pp. 149–166). New York: Elsevier Science Ltd.

Larkin, T. J., & Bomar, G. W. (1983). *Climatic atlas of Texas: Texas Water Development Board limited publication 192*. Austin, TX: State of Texas.

Lindell, M. K., Prater, C., & Perry, R. W. (1997). *Introduction to emergency management*. New Jersey: John Wiley and Sons, Inc.

Lomax, R. G. (2001). *An Introduction to statistical concepts for education and behavioral sciences*. Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

Lundgren, R., & McMakin, A. (2009). *Risk communication: A handbook for communicating environmental, safety, and health risks*. New Jersey: Institute of Electrical and Electronics Engineers. New Jersey: John Wiley and Sons.

MacEachren, A. (1994). Visualization in modern cartography: setting the agenda. In A. MacEachren, & D. Taylor (Eds.), *Visualization in modern cartography* (pp. 1–12). New York: Elsevier Science Ltd.

MacEachren, A. (2004). *How maps work*. New York: Elsevier Science.

MacEachren, A., Buttenfield, B., Campbell, J., DiBiase, D., & Monmonier, M. (1992). Visualization. In R. Abler, M. Marcus, & J. Olson (Eds.), *Geography's inner worlds: Pervasive themes in contemporary American geography* (pp. 99–137). New Jersey: Rutgers University Press.

Mileti, D. S. (1975). *Natural hazard warning system in the United States*. Monograph 13. Boulder, CO: University of Colorado, Institute of Behavioral Science, Natural Hazards Research and Applications Information Center.

Mileti, D. S. (1999). *Disasters by design: A reassessment of natural hazards in the United States*. Washington, DC: Joseph Henry Press.

Mileti, D. S., & Fitzpatrick, C. (1991). Communication of public risk: its theory and its application. *Sociological Practice Review, 2*(1), 20–28.

Mileti, D. S., & Fitzpatrick, C. (1993). *The great earthquake experiment: Risk communication and public action*. Boulder, CO: Westview Press.

Monmonier, M. (1994). Graphic narratives for analyzing environmental risks. In A. MacEachren, & D. Taylor (Eds.), *Visualization in modern cartography* (pp. 201–214). New York: Elsevier Science.

Monmonier, M. (1996). *Drawing the line: Tales of maps and cartocontroversy*. New York: Henry Holt and Co.

Monmonier, M. (1998). Imagining vulnerability. In M. Monmonier (Ed.), *Cartographies of danger: Mapping hazards in America* (pp. 216–238). ILL: University of Chicago Press.

Morgan, M., Fischhoff, B., Bostrom, A., & Atman, C. (2002). *Risk communication: A mental models approach*. Cambridge, UK: Cambridge University Press.

National Research Council (NRC). (2007a). Committee on the Effective use of Data, Methodologies, and Technologies to Estimate Subnational Populations at Risk. *Tools and methods for estimating populations at risk from natural disasters and complex humanitarian crises* Washington, DC: National Academy Press.

National Research Council (NRC). (2007b). Committee on Planning for Catastrophe: a blueprint for improving geospatial data, tools, and infrastructure. *Successful response starts with a map: Improving geospatial support for disaster management* Washington, DC: National Academies Press.

National Science Foundation (NSF). (1987). Visualization in scientific computing. Referenced in (2000). Visualization: a way to see the unseen (on-line book) *NSF, America's investment in the future* (pp. 98–110). http://www.nsf.gov/about/history/nsf0050/pdf/aif.

National Science Foundation (NSF). (2000). Visualization: a way to see the unseen (on-line book) *NSF, America's investment in the future* (pp. 98–110). http://www.nsf.gov/about/history/nsf0050/pdf/aif.

National Research Council Committee on using Information Technology to Enhance Disaster Management. (2007). In R. Rao, J. Eisenberg, & T. Schmitt (Eds.), *Improving disaster management: The role of it in mitigation, preparedness, response, and recovery*. Washington, DC: National Academies Press.

Pidgeon, N., Kasperson, R., & Slovic, P. (2003). *The social amplification of risk*. Cambridge, UK: Cambridge University Press.

Reckelhoff-Dangel, C., & Petersen, D. (2007). *Risk communication in action: The risk communication workbook*. Cincinnati, OH: The United States Environmental Protection Agency (EPA), Office of Research and Development, National Risk Management Research Laboratory.

Schmidt, R. H. (2001). *The handbook of Texas, online*. Austin, TX: The General Libraries at the University of Texas at Austin and the Texas State Historical Association. http://www.tsha.utexas.edu/handbook/online/articles/TT/ryt2.html.

Sims, J. H., & Baumann, D. D. (1983). Educational programs and human response to natural hazards. *Environment and Behavior, 15*(2), 165–189.

Slade, R. M., Jr., & Patton, J. (2003). *Major and catastrophic storms and floods in Texas—215 major and 41 catastrophic events from 1853 to September 1, 2002: U.S. Geological Survey open-file report 03–193*. Water Resources Division, U.S. Geological Survey, U.S. Department of the Interior. http://pubs.usgs.gov/of/2003/ofr03-193/cd_files/USGS_Storms/index.html.

Slovic, P. (2000). Perception of risk. In P. Slovic (Ed.), *The perception of risk* (pp. 220–231). London, UK/Sterling, VA: Earthscan Publications Ltd.

Slovic, P., Fischhoff, B., & Lichtenstein, S. (2000). Rating the risks. In P. Slovic (Ed.), *The perception of risk* (pp. 104–120). London, UK/Sterling, VA: Earthscan Publications Ltd.

Smith, K., & Tobin, G. A. (1979). *Human adjustment to the flood hazard*. London, UK: Longman Group Ltd.

Sorensen, L., & Moore, D. (2003). *The basic practice of statistics SPSS manual*. New York, NY: W.H. Freeman.

Stone, M. (2008). Information visualization: challenge for the humanities. http://www.stonesc.com/CLIR/index.htm.

Taylor, D. (Ed.). (1991). *Geographic information systems: The microcomputer and modern cartography* (pp. 1–20). Oxford, UK: Pergamon.

Thorton, P. (2009). *Visualizing vulnerability and impacts of climate change*. The Communication Initiative Network. http://www.comminit.com/en/print/307370.

Tobin, G. A., & Montz, B. E. (1997). *Natural hazards: Explanation and integration*. New York, NY: The Guilford Press.

Ware, C. (2004). *Information visualization: Perception for design*. San Francisco, CA: Elsevier, Morgan Kaufmann Publishers.

White, G. F., & Haas, J. E. (1975). *Assessment of research on natural hazards*. Cambridge, MASS: MIT Press.

Wilson, R., & Crouch, E. A. C. (1994). Risk assessment and comparisons: an introduction. In S. Cutter (Ed.), *Environmental risks and hazards* (pp. 236–243). Englewood Cliffs, NJ: Prentice-Hall Publishers.