The impact of user expertise on geographic risk assessment under uncertain conditions

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ABSTRACT: This research addresses the impact that expertise has on the use of uncertain geographic information using the case study domain of floodplain mapping. An online survey was developed to collect initial insight into the possible differences between experts and novices. Fifty-six participants completed the survey in which they were required to assess the risk of an identified location in the landscape relative to three floodplain delineations, each carrying a different degree of certainty, and then report their perceived difficulty in making the assessment and their confidence in the assessment. The responses were examined across three realms of expertise (education/training, work experience, and self-reported) and for two definitions of expertise (domain and map use). Analysis found that user confidence is affected by expertise in both domain and map use expertise, but that it is domain expertise that most impacts the risk assessment itself and map use expertise that most impacts the perceived difficulty of the risk assessment.

KEYWORDS: geographic information uncertainty, expertise, risk assessment, decision making, user-centered design, floodplain mapping

INTRODUCTION

This research speaks to two current trends within GIScience. A first trend is the recent advance in geospatial technologies, particularly web-based applications and location-based services, which have improved the availability, affordability, and pervasiveness of geographic information. Such developments have empowered the general public with access to geographic information, and tools for representing and visualizing this information, once available only to professionals and domain experts

(Rød et al. 2001; Couclelis 2003; Wood 2003). As this trend continues to mature, it can be expected that the general public will become increasingly active in acquiring and utilizing geographic information to support risk assessment and decision making. A second trend is the growing consensus among GIScientists that uncertainty is inherent in all geospatial datasets and "not just a flaw to be excised" (Couclelis 2003, 166). Efforts concerning uncertainty are no longer focused solely upon reduction or elimination of uncertainties, but are rather investigating the nature of uncertainty throughout the analytical process, the forms in which it may be present in geospatial data and geographic information, and the ways in which cartographic representations and visualizations of uncertain information can be made both useful and usable for end users (Deitrick and Edsall 2008).

The overlap of these two trends in GIScience presents the potentially disastrous situation of an untrained, inexperienced novice using representations and visualizations of geographic information in support of risk assessment and decision making, each holding real-world consequences, without fully understanding the inherent uncertainty in the view. Further complicating this matter, the widespread availability of numerous data sources of the same geographic phenomenon produces a common condition of uncertainty due to lack of data agreement. While much work has been conducted to understand how uncertainty influences processes such as information assembly, risk assessment, and decision making, only a limited subset of these studies have taken into consideration the expertise level of the participant completing the task (e.g., Evans 1997; Kobus et al. 2001; Aerts et al. 2003; Hope and Hunter 2007). This research examines the differences between experts and novices in:

(1) geographic risk assessments completed under uncertain conditions,

(2) perceived assessment difficulty under uncertain conditions, and

(3) assessment confidence under uncertain conditions.

This paper is divided into six sections, with five more sections following this opening introduction. The next section summarizes several important studies investigating the impact of expertise on risk assessment under uncertain conditions. The case study domain of floodplain mapping is introduced in the third section and the map-based online survey methodology is described in the fourth section. The results of the survey are reported and discussed in the fifth section and closing remarks are offered in the final section.

LITERATURE REVIEW

Uncertainty is present in all geographic information, and therefore maps displaying this information, because of the inability to perfectly reconcile representations of the landscape with the actual reality of the landscape. This research defines *uncertainty* as "a measure of the user's understanding of the difference between the contents of a dataset, and the real [geographic] phenomena that the data are believed to represent" after Longley et al. (2005, 128); the often conflated terms ambiguity, error, quality, and reliability are assumed to be part of (although not synonymous with) this larger definition of uncertainty but are not addressed in further detail by this research. Defining uncertainty in this manner is perhaps controversial, as the user of the map plays an important role in its degree of certainty, suggesting that the certainty of the map is in part reliant upon external factors. However, when keeping in mind that the map is a tool that supports risk assessment, and decision making based upon these assessments, it is important to acknowledge the human component in the assessment or decision. Thus, a user-centered perspective of uncertainty is a “context-dependent concept, dependent on both the individual and the situation of the data’s creation and use” (Deitrick and Edsall 2008, 279). This research focuses upon a single aspect of the map user important to the interpretation and use of uncertain representations: his or her level of the expertise.

At least four studies have looked at the differences between experts and novices when using representations of uncertain geographic information, with contradicting results. Evans (1997) examined the utility of several different methods for representing the uncertainty of land use/land cover (LULC) data. Three methods were examined: (1) display of only certain pixels via map filtering, (2) integrated symbolization using hue for LULC class and saturation for certainty, and (3) animated flickering between the data and its certainty on a single map. Experts were defined as participants with either university-level training or professional experience in map use and interpretation. Forty-four experts and twenty-two novices completed a task-based experiment consisting of uncertainty assessment and area estimation tasks based on the aforementioned LULC representations. Evans (1997) discovered that, regardless of expertise level, a majority of map users understood the presented uncertainty information and found it helpful for completing the tasks. Further, there was no significant difference between experts and novices in response accuracy or the estimation of overall map certainty.

Aerts et al. (2003) examined several methods for visualizing the uncertainty of a 2050 urban growth projection for Santa Barbara, CA using the SLEUTH simulation. Two methods were considered: (1) side-by-side comparison of the data and its certainty on separate maps and (2) toggling between the data and its certainty on a single map. Participants were allowed to self-report expertise in urban planning, decision support, map visualization, or GIS; those that did not select one of these were considered novices. Thirty-seven experts and twenty-nine novices used the visualizations to estimate the rate of growth projected by the SLEUTH model and to make decisions about the growth in relation to the uncertainty of the model and other background information layers. Like Evans (1997), Aerts et al. (2003) concluded that a majority of the participants, regardless of expertise, could understand and use the uncertainty information and that inclusion of the information improved spatial decision making. Although some differences existed in preference of the two visualization methods, they were not significant. The only significant difference between groups was on the relative preference of a bivariate color scheme for representing uncertainty, as experts responded with higher affinity for a more complex bivariate scheme than did novices (although experts, like novices, still preferred the univariate scheme overall).

The findings of Kobus et al. (2001) and Hope and Hunter (2007) appear to sharply contrast those of Evans (1997) and Aerts et al. (2003). Kobus et al. (2001) recorded the impact of uncertainty representations on the speed and accuracy of tactical decisions made by military officers. Citing Klein's (1993) recognition-primed decision-making model, Kobus et al. (2001) asserts that expertise plays a fundamental role in military decision making, as an initial course of action (COA) is modified once features or patterns familiar from training and experience are identified. Experts were defined as participants with at least ninety days of command post work experience. Twenty-three expert and twenty-nine novice Marine Corps officers participated in a computer simulation designed to mimic a military scenario. Movements of troops were displayed on an interactive topographic map and additional information was provided via audio and onscreen text. Kobus et al. (2001) found that the experienced officers took significantly more time to develop situational awareness under uncertain conditions than novices, a finding also reported by Evans (1997). Further, experts were able to select and execute a COA significantly more accurately and quickly than their novice counterparts once situational awareness was established, suggesting that expertise level does in fact influence assessments or decisions predicated upon uncertain geographic information.

Hope and Hunter (2007) examined the presence of ambiguity aversion on an airport siting decision. Ambiguity aversion is defined as the tendency to focus upon certain rather than vague information during decision making, even if such focus eliminates potential decision outcomes that are highly advantageous or profitable (Ellsberg 2001). For the study, three levels of expertise were determined based on experience with GIS (novice = less than six months of experience with GIS, intermediate = six months to two years of experience of GIS, expert = more than two years of experience with GIS). Sixteen experts, thirty-seven intermediate users, and forty-seven novices were asked to identify the better of two potential zones or rank a set of six zones. Each zone was colored based on its suitability, with the certainty of the suitability measure represented by a cylindrical glyph atop each zone. Hope and Hunter (2007) found that experts were significantly more likely to choose less suitable, but more certain zones for the airport. Although the authors argue for the reduction of ambiguity aversion during decision making, their finding suggests that ambiguity aversion is possibly a positive trait that is learned through experience and reflects an enhanced reasoning ability that is able to incorporate the consequences of incorrect decisions into the decision making process itself.

THE CASE STUDY DOMAIN OF FLOODPLAIN MAPPING

The research reported here hopes to contribute to this debate in the literature using a case study domain of floodplain mapping. Floodplain maps typically represent a delineation of the *100-year* or *genetic floodplain*, the lowland areas adjacent to a river that have a 1% annual probability of flooding (Alexander and Marriott 1999). Floodplain maps are vital for assessing the flooding risk of sites in the landscape that already contain or may potentially contain structures, habitats, people, or other features that are vulnerable to extreme flooding.

The domain of floodplain mapping is particularly suited for examination of the impact of expertise on geographic risk assessment under uncertain conditions for at least three reasons. First, misuse of floodplain maps carries real world consequences. Inaccurate comprehension or inappropriate usage of floodplain maps, whether by the fault of the mapmaker or map reader, may result in an incorrect risk assessment, leading to an inappropriate flood control policy and, in extreme cases, the loss of billions of dollars and human lives. The Great Midwest Flood of 1993 is an example of such consequences, as uncertain data in part contributed to the underestimation of the worst-case flooding scenario in many locations along the Upper Mississippi River and its tributaries. Over one-thousand flood levees, designed for a much smaller maximum capacity, failed across the Midwest, producing an estimated 12 to 16 billion US dollars in damages, dislocating fifty-four thousand people from their homes, and taking the lives of fifty individuals (FEMA 2003). Second, floodplain maps are commonly used by both professionals and the general public alike for the purpose of risk assessment. These maps are commonly consulted by prospective buyers, untrained in map reading and floodplain mapping, prior to the purchase of land. Further, several efforts have been made to make floodplain maps more accessible through online viewers with a spatial resolution fine enough to view a potential site, such as a home, in relation to the floodplain delineation (e.g., the FEMA Map Service Center and the Southwest Florida Water Management Program). Improved online availability further increases the likelihood that several, possibly contradicting, delineations of the floodplain are utilized during a flood risk assessment, a situation already common when using static print maps (Lulloff 1994). Finally, floodplain maps are relatively simplistic, typically depicting only two categories on the map: inside and outside of the floodplain. Such simplicity reduces the learning curve associated with a complex map display.

Like any other geographic information, floodplain information inherently contains multiple types of uncertainty. Several authors have written on the multifaceted concept of uncertainty and its many subcomponents (e.g., MacEachren 1992; Buttenfield 1993; Zhu 2005; Deitrick and Edsall 2008). A typology of nine uncertainty categories first proposed by Thomson et al. (2005), and later extended by MacEachren et al. (2005), is particularly useful for explaining the many uncertainties in floodplain information; each of the nine categories of uncertainty is applicable in the domain of floodplain mapping. Table 1 summarizes the MacEachren et al. (2005) typology and provides examples of each type specific to floodplain information.

Uncertainty Category	*Definitions*	*Example of Uncertainty in Floodplain Mapping*
Accuracy/Error	The difference between observation and reality.	The dataset has an error margin of +/- 100m for the floodplain delineation.
Completeness	The extent to which information is comprehensive.	The dataset only covers 70% of the study region.
Consistency	The extent to which information components agree.	The dataset is a composite of three different commissions with little overlap, completed by different firms.
Credibility	The reliability of information source.	The dataset was commissioned by the realty firm trying to sell you property.
Currency	The time span from occurrence through information collection/processing to use.	The dataset was compiled twenty years ago.
Interrelatedness	The source independence from other information.	Two difference dataset show major disagreement in the position of the floodplain.
Lineage	The conduit through which information has passed.	It is unknown how the dataset was created.
Precision/ Resolution	The exactness of measurement/estimate.	The dataset was generated using a DEM with a spatial resolution of 1km.
Subjectivity	The extent to which human interpretation or judgment is involved in information construction.	The dataset was created by a person tracing a scanned contour map by hand.

Table 1: A summary of the MacEachren et al. (2005) typology and examples when applied to the domain of floodplain mapping. Definitions are abbreviated from those provided in MacEachren et al. (2005).

METHODOLOGY: A MAP-BASED ONLINE SURVEY

This research reports on a map-based survey developed in the Adobe Flash software and administered online in a similar manner as the Aerts et al. (2003) study. The survey required the participants to examine individually twelve map-legend pairs and answer a set of three questions relating to the bulleted set of research goals outlined in the introductory section. The primary drawback to conducting research online is that the participants are not tested in a controlled environment. This issue is especially a problem when attempting to measure time, as the participant can be interrupted midway (increasing response time), have his or her attention split on another website or activity (increasing response time), or be assisted by another person during the survey (decreasing response time); because of this limitation, response time was not gathered as it was in the Evans (1997) and Kobus et al. (2001) studies. However, like the Aerts et al. (2003) study, the use of an online survey was justified because of the desire to question a relatively large number of experts located across the United States. Most traditional methods of scientific inquiry would not allow for this to be completed in a manner that uses both time and resources efficiently.

The methodology section proceeds in six subsections. The following subsection details the background survey and initial survey training session; answers to the background survey were used to define the term *expertise*. The following three subsections describe the design and implementation of the three components of the main portion of the online survey: (1) a map displaying three delineations of the floodplain relative to a river along with a single marked site for reference by the questions (Figure 1A), (2) a legend describing the symbology on the maps (Figure 1B), and (3) a triplet of questions concerning the current map-legend pair (Figure 1C). The fifth subsection describes the implementation of the online survey and the final subsection details its administration.

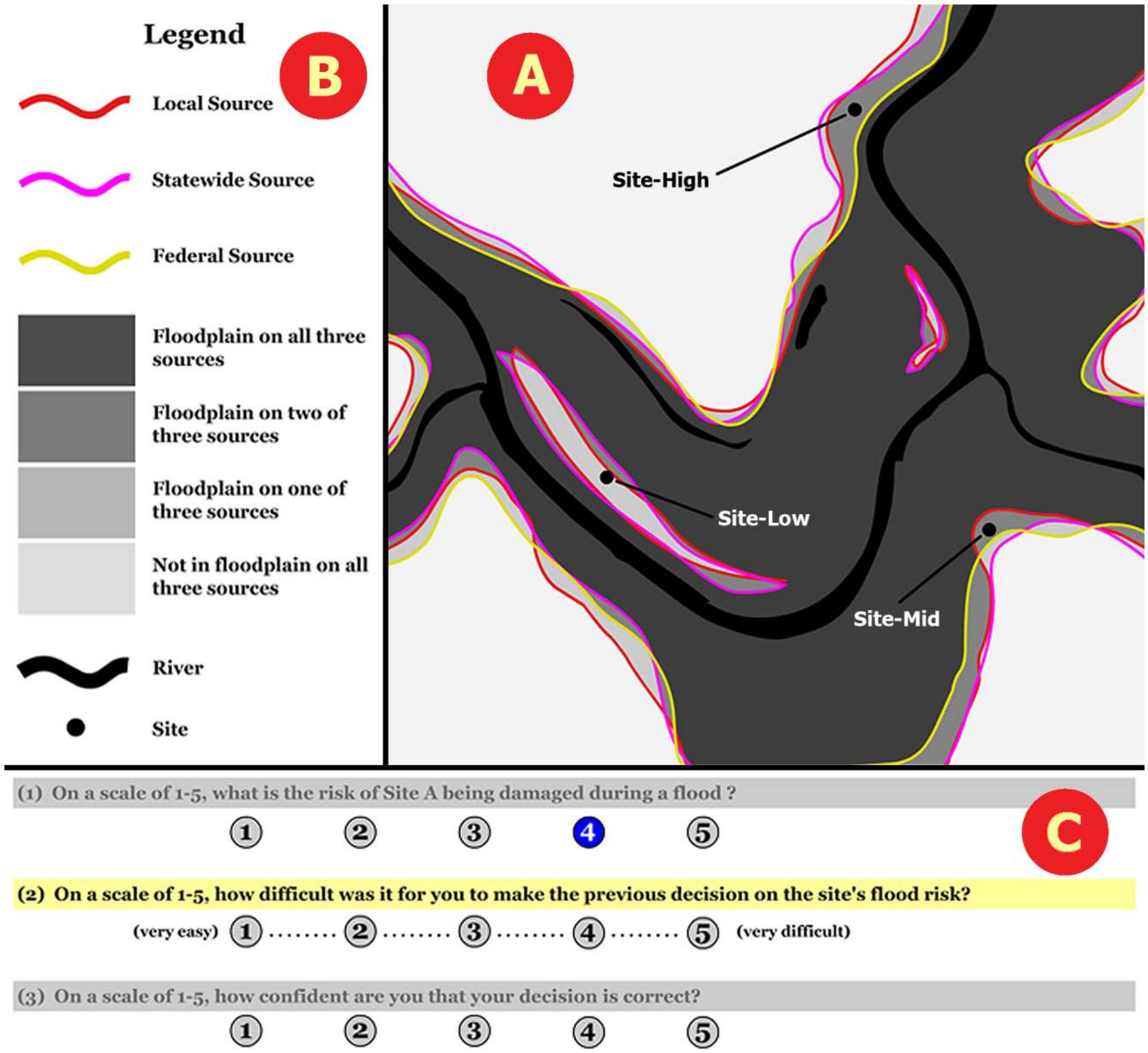

Figure 1: The layout for the main portion of the online survey. (A) The map component of the survey displayed three artificial delineations of the floodplain relative to a river network and one marked site for reference by the question component. The above example shows all three of the sites used in the survey for reference, but the actual survey displayed only a single site at a time. (B) The legend component of the survey described the symbology present on the maps. The upper portion of the legend suggested an ordinal difference in certainty of the floodplain delineations depicted in the map component. (C) The question component of the survey consisted of three questions using discrete visual analog scales (DVAS). Responses to these three questions defined the three variables: risk assessment, perceived assessment difficulty, and assessment confidence, respectively. The question component was the only interactive portion of the survey.

The Background Survey and Initial Training Session

Following digital completion of the consent form, participants were asked to complete a set of six background questions to establish each participant's level of expertise. The literature has described at least three realms of relevant expertise for geographic risk assessment under uncertain conditions: (1) the amount of formal education or training (e.g., Evans 1997), (2) the level of work experience (e.g., Evans 1997; Kobus et al. 2001; Hope and Hunter 2007), and (3) self-reporting of personal expertise (e.g., Aerts et al. 2003). Further, it is possible that expertise in the case study domain of floodplain mapping is fundamentally different than expertise in map use and interpretation in support of risk assessment and decision making (Aerts et al. 2003). The pairing of the three realms of expertise to the two definitions of expertise produces six categories of expertise for comparison. Six individual questions were included in the background survey to define participant expertise in each of the six categories. For background questions defining expertise by education/training and work experience, participants could select one of two levels of expertise (educated/trained versus uneducated/untrained, experienced versus inexperienced). For background questions defining expertise by self-reporting, participants could select one of three levels of expertise (expert, intermediate, or novice). The middle category 'intermediate' for the self-reporting realm was included because a pilot study revealed a tendency of participants to self-report themselves as an expert if the only other option available was novice; this tendency was not encountered in the other two realms during the pilot study, likely because these categories were based on specific credentials.

Once the background survey was complete, the participants were required to complete a brief training session demonstrating and explaining each of the three survey components. The training session consisted of nine unique slides, each showing a screen shot of the survey itself with several textual annotations. Participants were required to view all nine slides before continuing to the survey and they were given the option of stepping backwards to previous slides at any time prior to entering the survey. When finished with the training session, participants had the option of reviewing it again or continuing on to the survey itself.

Design of the Map Component of the Survey

Twelve different maps were loaded individually into the map component of the survey (Figure 1A). All maps displayed three delineations of the floodplain, relative to a central river network, and a single site of interest inside either one or two of these floodplain delineations. Provision of three separate floodplain delineations is a powerful and real-world map-use scenario for testing the influence of expertise on risk assessment, as both experts and novices often have access to several, possibly contradicting, delineations of the floodplain for assessing the flooding risk of a site (Lulloff 1994). Such a situation produces a condition of uncertainty for risk assessment and decision making due to lack of data agreement. The twelve maps viewed by participants varied by two aspects: (1) the uncertainty category displayed (four categories total) and (2) the type of site displayed (three variants total). Both aspects of map variation are described below.

The first aspect of map variation is the category of uncertainty exhibited by the floodplain delineations producing the condition of uncertainty. The survey used four of the nine types of uncertainty described in Table 1: (1) credibility, (2) currency, (3) precision/resolution, and (4) subjectivity. Inclusion of multiple categories of uncertainty matched the multifaceted nature of uncertainty and also ensured that survey responses reflect each participant's full comprehension of uncertainty rather than his or her familiarity with a single category of uncertainty. The survey did not employ all nine types of uncertainty for two reasons. First, several types of uncertainty are typically relevant to individual data items (e.g., accuracy/error), while others are typically relevant to the entire data capture as a whole (e.g., credibility). The former uncertainty categories require direct symbolization of uncertainty on the map (as each data item may contain a different degree of uncertainty), while the latter uncertainty categories only require a verbal statement of certainty in the legend or marginalia. Because floodplain maps rarely provide graphic uncertainty information in an integrated display, and because integrated uncertainty symbolization increases map complexity, it was decided to test several of the uncertainty categories relevant to the entire data capture. The second reason that only four types of uncertainty were tested was because testing of all nine would make the survey prohibitively lengthy; it was hoped that the survey could be completed in 15-20 minutes to avoid a decline in participant attention.

Three artificial delineations were created for each of the four categories of uncertainty to produce an ordinal decrease in certainty (i.e., high certainty, medium certainty, low certainty). The relative certainty of the colored delineations was explained by the legend component of the survey in a verbal statement (as shown in Table 2). Each floodplain delineation was symbolized by a unique hue on the map to allow for categorical discrimination. The qualitative color was used so that participants could not determine a delineation’s certainty without referencing the legend. This ensured that the participants considered both the category of uncertainty as well as the relative magnitude of uncertainty in their risk assessment. Each map displayed the three variants of a single uncertainty category (i.e., the twelve delineations were not mixed randomly but kept organized by associated uncertainty category).

Uncertainty Category	*Delineation #1* *(high certainty)*	*Delineation #2* *(intermediate certainty)*	*Delineation #3* *(low certainty)*
Credibility	federal source	statewide source	local source
Currency	data collected in 2005	data collected in 1995	data collected in 1985
Precision/ Resolution	high detail	intermediate detail	low detail
Subjectivity	floodplain defined by a simulated discharge level	floodplain defined by the historical record	floodplain defined by innermost terrace

Table 2: A description of the three delineations for each uncertainty category, as used in the legend component of the survey. The delineations were created to produce an ordinal decrease in certainty (i.e., high certainty, intermediate certainty, and low certainty).

The second aspect of map variation is the type of site marked on the map for risk assessment. Three sites within the map extent were chosen for flood risk assessment. The three sites varied in their location relative to the three floodplain delineations, and therefore in their amount of flood risk; for clarity, these sites are described as $\text{Site}^{\text{high}}$, Site^{mid}, and Site^{low} in Figure 1A according to their relative risk of flooding. Note that Figure 1A shows all three sites for illustrative purposes only; each map displayed only one site at a time and did not label them as High/Mid/Low. For all four uncertainty categories used in the survey, $\text{Site}^{\text{high}}$ and Site^{mid} were contained by two of the three floodplain delineations. However, $\text{Site}^{\text{high}}$ was contained by the two most certain floodplain delineations while Site^{mid} was contained by the two least certain floodplain delineations (and therefore had less flood risk because it was not within the most certain delineation). Site^{low} was contained by only one floodplain delineation, the least certain in each of the four uncertainty categories, and therefore had the lowest flooding risk.

The sites were symbolized using a large black dot and labeled using a large black font with white casing for reference in the survey questions. The background of the map was represented in varying shades of gray corresponding to the amount of overlap or agreement among the three floodplain depictions, reinforcing the condition of uncertainty to the participants. The river and surrounding oxbow lakes were symbolized in black to reflect the highest category in the grayscale representation of floodplain certainty.

Design of the Legend Component of the Survey

The legend component of the online survey described each symbol included in the map component. A new legend was loaded into the legend component each time a new map was loaded, producing twelve unique map-legend pairs. The top portion of the legend defined each floodplain delineation displayed in the map component using the verbal statements in Table 2. Beard and Mackaness (1993) contend that there are three uncertainty assessment tasks of increasing difficulty: (1) notification (presence of uncertainty), (2) identification (what kind of uncertainty is present and its relative amount), and (3) quantification (the magnitude of uncertainty). To avoid blending quantification assessments with identification assessments in the survey, categories commonly reported at the ratio level (e.g., precision/resolution) were worded in the legend to match uncertainty categories commonly reported at the ordinal level (e.g., credibility). The verbal statements explaining each floodplain delineation were the only aspect that changed from legend to legend. The middle portion of the legend explained the grey-scale shading used for the amount of overlap or agreement among the three floodplain delineations. The bottom portion of the legend explained the symbology used for the river itself and the site of interest.

Design of the Question Component of the Survey

The final component of the survey was a set of three questions. Each question was presented as a discrete visual analog scale (DVAS). A DVAS is similar to the more commonly known Likert scale and was first introduced as a method for patients to report their levels of pain or discomfort (DeVellis 2003). The DVAS and Likert scale both rely upon a horizontally-aligned visual scale of evenly-spaced integers to produce quantifiable metrics; once presented with a question or statement, the subject selects the integer along this scale that best matches his or her assessment, attitude, or opinion. Unlike the Likert scale, which technically must diverge from a central or neutral response and label the meaning of each individual integer, the more generic DVAS allows for sequential steps along a continuum with no middle-point and requires labeling of only the poles of the continuum.

Participants were required to answer three DVAS questions for each of the twelve map-legend pairs. The first question required the participant to assess the flood risk of the site on a five-level DVAS (‘1’ being safely located and ‘5’ being insecurely located). The variable *risk assessment* was defined as the response to this first DVAS question. Although there is never a predetermined ‘correct’ answer when responding to a DVAS, the average risk assessment response by participants with expertise in both the domain and map use is used as a correctness proxy for risk assessment accuracy comparison between experts and novices. In a flooding risk scenario, inaccuracy due to underestimation (i.e., not expecting flooding when it is likely to occur) carries greater consequences than inaccuracy due to overestimation (i.e., expecting flooding when it is not likely to occur), although they are both concerns.

The second and third questions for each map-pair were follow-up questions for the initial risk assessment. The second question asked the participant to rank the difficulty of the risk assessment on a five-level DVAS ('1' being an easy siting decision and '5' being a difficult siting decision). The variable *perceived assessment difficulty* was defined as the response to this second question. The perceived assessment variable is useful for understanding risk assessment efficiency. The third question asked the participant to rank his or her confidence in the risk assessment on a five-level DVAS ('1' being least confident that the decision was correct and '5' being most confident that the decision was correct). The variable *assessment confidence* was defined as the response to this third question (after Evans 1997). The assessment confidence variable is important for estimating the potential consequences of risk underestimation, as experts and novices alike that are not confident in their risk assessments are likely to seek further expert consultation, likely avoiding risk underestimation. However, people that underestimate risk but are incorrectly confident in their assessment are likely to base decisions on their estimation without further expert consultation. Figure 1C illustrates each DVAS for these three variables.

Implementation of the Online Survey

Following completion of the training session, one of the twelve map-legend pairs was loaded into the map and legend components and the DVAS triplet was loaded into the question component with the first DVAS question highlighted and labeled to prompt the participant to begin with the risk assessment. Once a risk assessment was selected, the selection was highlighted in blue with all other unselected responses removed from the display (e.g., a response of ‘4’ to the risk assessment DVAS in Figure 1C) and the next DVAS question was then highlighted (e.g., the perceived assessment difficulty in Figure 1C). Once the assessment confidence DVAS question was completed, a new map-legend pair was loaded into the map and legend components and the question component was reset so that all responses to the previous triplet were cleared and the first DVAS question was enabled and highlighted. To reduce the effect of learning during the survey, each newly loaded map was randomly rotated around its center. The order of maps was also randomized for each participant following Leitner and Buttenfield (2000), making it unlikely that two participants saw the same order of maps.

Because understanding the legend is vital to understanding the map, and therefore correctly assessing the flooding risk of a location in the landscape, several precautions were taken to ensure that the legend was read before interpreting the map and responding to the survey questions. First, the importance of the legend was stressed in the initial training session and the participants were instructed to first analyze the newly loaded legend before examining the map. Secondly, as a result of a pilot survey, the legend was placed at the top, left corner of the screen. Eye-movement studies have shown that Western readers tend to process a page from the top, left corner to the bottom, right corner, similar to the way text is read in a book (Slocum et al. 2005). Placing the legend at the top, left corner put it in the highest priority location on the screen and ensured that the participant did not need to scroll the browser to view it. Similarly, the most important information, the verbal statements explaining the three delineation variants, was placed at the top of the legend component for immediate reading. Third, a loading transition was programmed to darken the screen before loading a new map-legend pair to signal that the legend required reference. Finally, the question component of the survey was disabled until each map-legend was fully loaded and visible, preventing response before the new legend was loaded and visible.

Administration of the Online Survey

A link to the online quantitative survey was emailed individually to 135 potential participants. Among those asked were University of Wisconsin-Madison faculty and graduate students studying GIScience or fluvial processes and private, state, and federal professionals working in GIScience and floodplain mapping. In total, 56 of the original 135 potential participants completed the survey, producing a surprising high survey response rate of 41.5%. Table 3 provides a breakdown of the 56 participants according to the six categories of expertise.

	Expertise Category	*Expert*	*Intermediate*	*Novice*
Domain	Education/Training	26	n/a	30
	Work Experience	21	n/a	35
	Self-Reporting	10	34	12
map use	Education/Training	47	n/a	9

Work Experience	42	n/a	14
Self-Reporting	40	14	2

Table 3: Survey participation between experts and novices. This study adopted three realms of expertise (education/training, work experience, and self-reporting) and identified two different definitions of relevant expertise (domain and map use).

RESULTS AND DISCUSSION

Nonparametric testing was required for statistical analysis of DVAS responses because (1) the random variable recorded by a DVAS is not continuous (i.e., measurement of the variable is on the ordinal level of measurement rather than interval/ratio) and (2) DVAS responses typically are not normally distributed (McGrew and Monroe 2000). Application of parametric testing under such conditions increases the likelihood that a significant finding is spurious, making nonparametric testing a more robust approach.

Two nonparametric statistics were applied to the survey responses: the Mann-Whitney U and the Kruskal-Wallis H. The Mann-Whitney and Kruskal-Wallis statistics differ from their parametric alternatives (two-sample Student t and multiple sample ANOVA tests, respectively) in that they are applied to the rankings of the data (i.e., analysis of the data at an ordinal level) within the total sample space rather than the raw data itself (i.e., analysis of the data at a ratio level). The purpose of the Mann-Whitney U statistic is to test if two independent samples are drawn from the same population (H_0) or if the samples differ enough to suggest that they are drawn from different populations (H_A). To calculate an ordinal ranking for each data entry, the two samples are pooled together and ordered from smallest to largest. A ranking from 1 to n is assigned to each data item with tied values resolved using the average of their ranks (after Hollander and

Wolfe 1999). Rankings are then divided back into the original two groups and the ranking summation for each group is compared to determine if the null hypothesis should be accepted or rejected. The Kruskal-Wallis H statistic is calculated in a similar manner, but modified to allow for comparison across three or more samples. Assuming each group is of sufficient size (n=10 for Mann-Whitney and n=5 for Kruskal-Wallis), a normal approximation (z) can be applied for hypothesis testing of the Mann-Whitney U statistic and a chi-square (X^2) approximation can be applied for hypothesis testing of the Kruskal-Wallis H statistic. Nonparametric testing using these approximations contains 95% of the explanatory power of their parametric counterparts (Aczel and Sounderpandian 2006).

There were three components to the statistical analysis: (1) the category of expertise, (2) the type of site displayed on the map (each exhibiting a different degree of risk), and (3) the variable measured by the DVAS. Statistical analysis was completed across each of the six categories of expertise. The Mann-Whitney test was applied for the education/training and work experience realms of expertise because the biographical questions allowed for differentiation between just two groups of expertise, while the Kruskal-Wallis test was applied for the self-reporting realm of expertise because the biographical questions allowed for three groupings of expertise. For each category of expertise, the analysis was applied four times: once pooling all responses in the survey together and once for the responses to each type of site individually (pooling maps showing the same site but different types of uncertainty together). Initial examination of all DVAS responses pooled together provided an overview of the interaction for a single category of expertise. However, it was also important to examine the responses for each site individually because the varying level of risk associated with each site type could possibly produce a clouded signal for the pooled hypothesis tests. Uncertainty category was not accounted for because each site had the same relative amount of certainty regardless of the category of uncertainty described in the legend (i.e., $Site^{high}$ exhibited the highest flooding risk on all four types of uncertainty) and examination at the individual question level (i.e., a specific site/uncertainty category combination) produced sample sizes too small for reliable analysis. Finally, the statistical analysis was applied to each of the three variables collected by the survey: (1) risk assessment, (2) perceived assessment difficulty, and (3) assessment confidence. The following discussion of the results is organized around these three variables. In sum, sixty-four hypothesis tests were conducted.

The Impact of Expertise on Risk Assessment

The first DVAS question analyzed was for risk assessment. Z-scores or X^2 values, depending on the applied nonparametric test, and p-values for each hypothesis test completed on the risk assessment variable are provided in Table 3. The p-values of hypothesis tests that reject the null at alpha=0.05 are bolded and italicized in the table. An important pattern uncovered by the survey responses was that experts or intermediates, regardless of the realm or definition of expertise, responded with higher risk assessments than their novice counterparts for all three sites (with the two exceptions of the map use work experience category for $Site^{low}$ and the map use self-reported category for $Site^{mid}$). Assuming that flooding risk assessments from experts are more accurate than those from novices, this pattern in risk assessment suggested a tendency for novices to underestimate the flooding risk of a site in the landscape.

One possible explanation of this tendency is that domain experts better comprehend the implications of the uncertain conditions than domain novices and increase their risk assessment accordingly. The tendency for novice underestimation of risk appeared especially strong when domain expertise was considered, as five of the six domain expertise hypothesis tests for $Site^{high}$ (the site at most risk) and $Site^{low}$ (the site at least risk) were significant with extremely low p-values, with the sixth showing significance at alpha=0.10.

It was possible that none of the hypothesis tests was significant for $Site^{mid}$ under domain expertise because of its medium amount of relative risk; some participants, regardless of expertise, appeared to interpret it as more similar to $Site^{high}$ while others interpreted it as more similar to $Site^{low}$, producing a mixed signal for both expert and novice groupings. It was likely that only one of the three hypothesis tests applied to domain expertise when all sites were pooled together was significant because of this mixed signal for $Site^{mid}$, although it is important to note that all three tests showed significance at alpha=0.10.

The connection between map use expertise and risk assessment was much weaker, as only one of the twelve hypothesis tests was significant at alpha=0.05 and only two at alpha=0.10. This suggested that it is a lack of expertise in the domain at hand, rather than in map use and interpretation, causing the underestimation of risk by novices. Map use expertise does not appear to affect risk assessment significantly.

	Category	*$Site^{high}$*		*$Site^{mid}$*		*$Site^{low}$*		***All Sites***	
		z/ X^2	***p-value***	***z/ X^2***	***p-value***	***z/ X^2***	***p-value***	***z/ X^2***	***p-value***
domain	Education/Training	11.1860	***0.0000***	0.5582	0.5767	1.7282	0.0894	1.6906	0.0909

	Work Experience	2.4096	***0.0160***	0.8593	0.3902	1.8676	***0.0182***	1.9564	0.0504
	Self-Reporting (X^2)	10.1220	***0.0063***	1.5298	0.4654	8.2244	***0.0164***	9.2882	***0.0096***
map use	Education/Training	0.8702	0.3842	2.1236	***0.0337***	0.7972	0.4253	1.7319	0.0833
	Work Experience	0.9869	0.3237	1.2286	0.2192	-0.7240	0.4691	1.0107	0.3122
	Self-Reporting (X^2)	0.7314	0.6937	1.6459	0.4391	1.3923	0.4985	0.7194	0.6979

Table 3: Analysis of the variable risk assessment. Overall, experts responded with higher assessments of risk than their novice counterparts. The difference between experts and novices appears especially strong when domain expertise is considered, suggesting that is expertise in the domain at hand, and not in map use and interpretation, that affects a user's ability to correctly assess the risk of a site in the landscape.

The Impact of Expertise on Perceived Assessment Difficulty

Responses to the DVAS question concerning perceived assessment difficulty were then analyzed; results of the hypothesis tests for the perceived assessment difficulty variable are provided in Table 4. Generally, intermediate and novice participants found the assessment tasks to be more difficult than their expert counterparts (explaining the negative z-scores), although this pattern is violated for all four hypothesis tests conducted on the education/training realm of domain expertise. The reasoning for this counterintuitive violation is unclear, but may be an artifact of recruiting a large number of current graduate students that are educated but do not have work experience. Similar to the risk assessment variable, there is no significant difference across expertise in perceived assessment difficulty of Site^{mid}; it is again suspected that this is due to its medium amount of flooding risk.

The most striking finding for the perceived assessment difficulty variable is that five of the six realms of expertise are significant when pooling all sites together. This suggested that expertise does play an important role in the perceived difficulty of completing an assessment task under uncertain conditions. Interestingly, when examining responses for Site^{high} and Site^{low}, the division between expert and novice is stronger for map use expertise (four of six tests for Site^{high} and Site^{low} returning significance) than domain expertise (only one of six tests for Site^{high} and Site^{low} returning significance). Thus, while domain expertise significantly influences the risk assessment under uncertain conditions, it is expertise in map use and interpretation that influences the perceived difficulty in completing the assessment. Such a finding provides initial evidence that domain and map use expertise are two separate characteristics of a potential map user and need to be accounted for separately.

	Category	*Site^{high}*		*Site^{mid}*		*Site^{low}*		***All Sites***	
		z/ X^2	***p-value***	**z/ X^2**	***p-value***	**z/ X^2**	***p-value***	**z/ X^2**	***p-value***
domain	Education/Training	0.4589	0.6463	1.6176	0.1057	1.6538	0.0982	2.2051	***0.0274***
	Work Experience	-1.1170	0.2640	-0.3590	0.7196	-0.3260	0.7444	-0.9851	0.3246
	Self-Reporting (X^2)	10.6270	***0.0049***	5.3699	0.0682	0.4079	0.8155	10.9560	***0.0042***
map use	Education/Training	-2.3020	***0.0213***	0.3355	0.7372	-1.5020	0.1331	-2.0016	***0.0453***

Work Experience	-2.1540	***0.0312***	-0.6750	0.4997	-3.5430	***0.0004***	-3.7026	***0.0002***
Self-Reporting (X^2)	3.6201	0.1636	0.8139	0.6657	10.6520	***0.0049***	10.4169	***0.0055***

Table 4: Analysis of the variable perceived assessment difficulty. Overall, experts responded with a lower perceived assessment difficulty than their novice counterparts. The difference between experts and novices appears especially strong when map use expertise is considered, suggesting that it is expertise in map use and interpretation, and not in the domain at hand, that affects a user's ability to correctly assess the risk of a site in the landscape.

The Impact of Expertise on Assessment Confidence

The DVAS question concerning assessment confidence was the last to be analyzed; results of the hypothesis tests for the assessment confidence variable are provided in Table 5. Of the three DVAS variables, assessment confidence exhibited the most significant differences between experts and novices in both quantity and magnitude. Experts felt much more confident about their risk assessments than their intermediate or novice counterparts (with the lone exception of the domain education/training category of expertise on the Site^{low} maps). This finding is intuitive, as experts are expected to be much more comfortable assessing risk under uncertain conditions, and therefore more confident in their assessments, than novices. Five of the six categories of expertise reported a significance difference when all sites were pooled together. Further, of the twenty-four hypothesis tests conducted, nineteen are significant at alpha=0.10, seventeen at alpha=0.05, and twelve at alpha=0.01.

Although the pattern holds for both domain and map use experts, it appears slightly stronger for map use experts. This minor difference is explained by a relative lack of confidence by experts in their assessment of Site^{low} (lowest risk), reporting confidence values close to those reported by novices. Such a lack of confidence in the assessment of the site in the lowest flooding risk is not immediately intuitive. However, follow-up questioning of several domain experts revealed that this is likely an artifact of placing Site^low on an island in the river. Domain experts assessed the risk of flooding according to the position and certainty of the floodplain delineations, but tempered their confidence in the assessment due to the domain knowledge that a river island may wash away completely during a flooding episode (i.e., although the risk is small, if a flood does occur it can be catastrophic to the site).

	Category	*Site^high*		*Site^mid*		*Site^low*		***All Sites***	
		z/ X^2	***p-value***	***z/ X^2***	***p-value***	***z/ X^2***	***p-value***	***z/ X^2***	***p-value***
domain	Education/Training	2.1138	***0.0345***	1.0336	0.3013	-0.8590	0.3903	1.3178	0.1876
	Work Experience	3.5032	***0.0005***	2.2520	***0.0243***	0.4632	0.6432	3.5959	***0.0003***
	Self-Reporting (X^2)	17.7920	***0.0001***	12.4640	***0.0020***	4.9002	0.0863	30.3764	***0.0001***
map use	Education/Training	2.7230	***0.0065***	1.8612	0.0627	2.8352	***0.0046***	4.3968	***0.0000***
	Work Experience	2.9298	***0.0034***	1.9226	***0.0545***	2.6536	***0.0080***	4.4029	***0.0000***
	Self-Reporting (X^2)	6.0243	***0.0492***	4.2550	0.1191	6.5678	***0.0375***	16.2600	***0.0003***

Table 5: Analysis of the variable assessment confidence. Overall, experts felt more confident in their risk assessments than their novice counterparts. This pattern appears for both domain and map use expertise.

The results of the study strongly suggest that user expertise plays a significant role in all three collected variables (risk assessment, perceived assessment difficulty, and assessment confidence), concurring with the findings from Kobus et al. (2001) and Hope and Hunter (2007). Perhaps the most important finding of the study was that the six categories of expertise did not impact the three variables equally. Hypothesis testing suggested that an accurate risk assessment under uncertain conditions was a result of domain expertise, but ease in making this assessment under uncertain conditions was a result of map use expertise. Therefore, the evidence shows that domain experts better comprehend the uncertain information and are better equipped to incorporate this information into their analysis of the sites, leading to appropriately higher assessments of risk. However, map use experts cognitively process the cartographic representations and complete the risk assessments more easily, regardless of whether their risk assessments are accurate. Assessment confidence was the only variable of the three measured by a DVAS to exhibit significant differences for both domain and map use expertise. Except for the unusual finding for the perceived assessment difficulty variable in the domain education/training category of expertise, the way that expertise was defined (e.g., education/training, work experience, or self-reported) did not appear to influence participant response.

There are several important implications of these findings, as summarized in Table-6. First, a user that is both a domain and map use novice will tend to underestimate the flooding risk of a site in the landscape under uncertain conditions. However, coming with this assessment is also a large perceived difficulty and a low amount of confidence. Therefore, it is likely that this user will seek the opinion of an expert if the consequences of the risk are severe, making a disaster possible but not probable. Second, the optimal risk analyst under uncertain conditions is a user who holds expertise in the domain at hand (so that an accurate risk assessment can be made) and in map use (so that the assessment is completed easily). Therefore, training programs should focus both on providing the domain knowledge necessary for making the risk assessment (i.e., coursework on fluvial process and risk management) as well as instruction in map use and interpretation to improve the efficiency of this risk assessment (i.e., coursework on the cartographic basics). Third, perhaps the most disastrous situation comes when a map use expert, but a domain novice, attempts to complete risk assessment tasks under uncertain conditions. This user will find the assessment task to be relatively easy, and will perhaps be confident in their assessment. However, because this user is a domain novice, the assessment likely will underestimate the risk of the site. Therefore, they may make the unfortunate mistake of using the site for some sort of activity without consulting an expert, possibly leading to damage of persons and property. A domain expert, but map use novice, may have difficulty in completing the assessment, but will assess the risk accurately, avoiding unintended consequences.

		Domain Expertise	
		expert	*novice*
Map Use Expertise	*expert*	***ideal situation:*** *accurate risk assessment *low perceived assessment difficulty *high assessment confidence	***potential disaster:*** *underestimated risk assessment *low perceived assessment difficulty *intermediate assessment confidence
	novice	***OK situation:*** *accurate risk assessment *high perceived assessment difficulty *intermediate assessment confidence	***OK situation:*** *underestimated risk assessment *high perceived assessment difficulty *low assessment confidence

Table 6: Implications of the research findings. It was initially expected that a novice in both the domain at hand and map use would be the worst-case scenario. However, this may not be the case, as their assessment confidence will be extremely low, causing them to consult an expert. Instead, an expert in map use, but a novice in the domain at hand, may make potentially disastrous decisions. They will underestimate the amount of risk, but have an easy time completing this assessment and have an intermediate amount of confidence in the assessment, making it likely that they do not consult a domain expert prior to making a decision.

CONCLUSION

In many ways, the disciplines of Cartography and GIScience are currently experiencing changes that are unprecedented in both speed and extensiveness. From a practical standpoint, the ever-increasing (and seemingly here to stay) usage of geospatial technologies by the general public is not only changing *who* is using this technology, but also perhaps *how* and *why* this technology is used. From a theoretical standpoint, the recent acceptance of uncertainty as an inherent trait of geographic information is not only challenging the underlying epistemological assumption of a knowable and recordable geographic phenomenon, but is also perhaps changing *how* and *when* geographic information, and their uncertainty recordings, are put to use in advanced reasoning and decision making. Nothing or no one is affected more by these two developments than the users of maps ad other geospatial technologies. It is therefore necessary to focus scientific inquiry on the end user if we hope to understand fully the implications of these two developments.

This study examined a single user characteristic possibly important for proper map use under uncertain conditions: user expertise. Prior research on the interplay between user expertise and geographic information uncertainty has produced contradictory results. However, this disagreement appears to be due to variation in the complexity of the tested map-based task. Expertise does not matter when the task is simply to retrieve facts from maps displaying uncertainty (e.g., Evans 1997) or to make qualitative judgments about which representation may work best (e.g., Aerts et al. 2003). However, when the task involves a complex and realistic risk assessment or decision that requires sophisticated human reasoning (e.g., Kobus et al. 2001; Hope and Hunter 2007), expertise may make a profound difference. The findings of the map-based online survey appear to confirm this division in expertise impact, at least in the domain of floodplain mapping, as expertise has a significant influence of risk assessment, perceived risk difficulty, and assessment confidence. However, an important discovery from this research is that all types of expertise cannot be treated equally, adding yet another dimension to proper understanding of how risk is assessed under uncertain conditions.

So what does this mean for practicing cartographers designing the representations and visualizations of uncertainty for support of risk assessment or decision making? The key to designing useful and usable representations and visualizations of uncertainty (or of anything else) is to know the end user. This means constant consultation with domain experts to better understand the geographic phenomenon and the tasks that the representation or visualization need to support. This also means testing prototypes with potential end users at all stages of preparation and iteratively adjusting the design accordingly. However, cartographers must be aware that their representations and visualizations will be used both for unintended purposes (e.g., basic map comprehension tasks versus sophisticated map-based reasoning and decision making) and by an unintended audience (e.g., expert versus novice users). This means, above all else, cartographers must be honest about the certainty of the representation by explicitly symbolizing it on the map so that end user can make fully informed risk assessments and decisions (or, in the case of novices, to know that they should defer to experts).

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