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Advancing Flood Risk Communication and Management through Collaboration and Public Participation

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Advancing Flood Risk Communication and Management through Collaboration and Public Participation

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Planning, Policy, and Design

by

Wing Ho Cheung

Dissertation Committee:
Professor David L. Feldman, Chair
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2017

DEDICATION

To

my family, friends, and colleagues

I am forever in your debt for your support, encouragement, and guidance

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ACKNOWLEDGMENTS

This dissertation covered a great deal of issues and questions that were jointly investigated by hydrological and social scientists on the National Science Foundation (NSF) funded Flood Resilient Infrastructure and Sustainable Environments (FloodRISE) research project. I was fortunate to receive tremendous support and encouragement from colleagues, friends, family members, and many others who are too numerous to acknowledge here. I want to especially thank my advisor, David Feldman, for his unwavering support of my dissertation and my research. Moreover, the recommendations and guidance offered by my current and past committee members, including Douglas Houston, Richard Matthew, Brett Sanders, and Jae Hong Kim are invaluable in sharpening my thinking and guiding the dissertation in ways that maximize its impact in the field. Moreover, by collaborating with faculty members, post-doctoral researchers, and colleagues at the University of California-Irvine, such as Jochen Schubert, Victoria Basolo, Kristen Goodrich, Adam Luke, Kimberly Serrano, Abby Reyes, Santina Contreras, Amir Aghakouchak, Hamed Moftakhari, and Beth Karlin, I was able to fully experience and appreciate the joy and rewards of interdisciplinary collaboration. I would like to express my appreciation to Daniel Sourbeer and my colleagues at Palomar College, who motivated me to begin and persist in this academic journey. Finally, I hope to dedicate this dissertation to my family, and especially my grandmother, who has always been supportive of my life decisions, wherever they may take me.

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1. Cheung, Wing, Douglas Houston, Jochen Schubert E., Victoria Basolo, David Feldman, Richard Matthew, Brett Sanders F., Beth Karlin, Kristen Goodrich A., Santina Contreras L., and Adam Luke. "Integrating Resident Digital Sketch Maps with Expert Knowledge to Assess Spatial Knowledge of Flood Risk: A Case Study of Participatory Mapping in Newport Beach, California." Applied Geography 74 (2016): 56-64. Web.

2. Feldman, David, Santina Contreras, Beth Karlin, Victoria Basolo, Richard Matthew, Brett Sanders, Douglas Houston, Wing Cheung, Kristen Goodrich, Abigail Reyes, Kimberly Serrano, Jochen Schubert, and Adam Luke. "Communicating Flood Risk: Looking Back and Forward at Traditional and Social Media Outlets." International Journal of Disaster Risk Reduction 15 (2016): 43-51. Web.

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4. Cheung Wing H., Douglas Houston, Jochen Schubert et al. Role of participatory mapping in citizen science: challenges and opportunities. Citizen Science Association 2015 Meeting. (poster)

5. Cheung, Wing H., Gabriel B. Senay, and Ashbindu Singh. "Trends and Spatial Distribution of Annual and Seasonal Rainfall in Ethiopia." International Journal of Climatology 28.13 (2008): 1723-734. Web.

ABSTRACT OF THE DISSERTATION

Advancing Flood Risk Communication and Management through Collaboration and Public Participation

By

Wing Ho Cheung

Doctor of Philosophy in Planning, Policy, and Design

University of California, Irvine, 2017

Professor David L. Feldman, Chair

Flooding has been a pressing problem for communities around the world. The problem is expected to worsen due to climate change and sea level rise. Despite decades of research on risk communication and management, the toll of flooding continues to mount. In order to advance flood management to minimize future damages, there is a need to foster collaboration among research communities, promote the genuine engagement of local stakeholders, and co-develop targeted risk communication and mitigation strategies between experts and non-experts.

This dissertation experimented with different participatory approaches, such as household surveys, cognitive mapping, and focus group discussions, in order to respectively (1) examine how one's spatial awareness of flood risk is influenced by the interactions between social, geographical, informational, and hydrological factors, (2) identify differences in expert and non-expert flood knowledge, and (3) integrate diverse stakeholder perspectives in the future development of flood visualizations. Our findings indicate that flood awareness varies significantly between social groups from different geographical regions with different personal characteristics, which point to the need for targeted risk communication and outreach activities in order to address the concern of risk variability. Moreover, we found that while details and realism in flood visualizations can have positive cognitive and affective impacts on users, it is crucial for experts to be cognizant of stakeholders' background and expertise as these factors may influence their visualization preferences.

Although flood risk awareness is one of the precursors to the adoption of mitigation and preparatory measures, and flood visualizations have the potential to positively impact one's awareness, we have demonstrated that one's response to flood visualizations can be influenced by the complex feedback of social, geographical, informational, and hydrological factors. Thus, rather than looking at the development of flood model or flood visualizations as an end in itself, we must look to more adaptive and "no-regret" strategies such as the development of targeted risk communication campaigns and the accumulation of social capital as means to promoting risk mitigation behaviors, which can ultimately increase community resilience in light of the growing problem of flooding.

Introduction

Flooding has always been a major hazard for the lives and properties of people in communities around the world. This condition is likely to worsen as the number of coastal inhabitants swells to over one billion, and as climate change and sea level rise are expected to increase flood levels worldwide (Di Baldassarre et al., 2015; Jongman et al., 2014; Moser et al., 2012). Hinkel et al. (2014) estimated that in the absence of coastal flood adaptation, 0.2-4.6% of global population is expected to be flooded annually with annual losses in the range of 0.3-9.3% of global gross domestic product by 2100. In California alone, sea level rise of 1-1.4 m along the coast is expected to put over $100 billion worth of critical infrastructure (e.g. roadways, railways, wastewater treatment plants) at risk (Gallien et al., 2011). As the cause of nearly 9,000 deaths in the 20th century, and nearly $2 billion in annual property damage, flooding is one of the most destructive and frequent natural disasters in the United Stated (Knocke & Kolivras, 2007; Perry, 2000; FEMA, 2016).

Despite decades of research on disaster risk management, and actual policies designed to abate the impacts and losses associated with flooding, the problems of flood vulnerability and flood losses have been worsening partly due to the low level of proactive collaboration among experts in different research communities, and between experts and decision-makers responsible for flood hazard management (Thomalla et al., 2006). For example, hydrological scientists tend to focus on flood hazard characteristics and exposure indicators such as frequency, flood stage, and velocity, while social scientists focused on sensitivity and adaptation indicators such as population density, economic losses, and risk perception (Grothmann & Reusswig, 2006; Di

Baldassarre et al., 2014). However, since flood vulnerability is a function of exposure, sensitivity, and adaptation in settings with context-specific hazards (IPCC, 2007; Hung & Chen, 2013), there is not only a need for greater collaboration between different research communities to devise optimal strategies to communicate and mitigate flood risk, but also a need to engage affected stakeholders and decision-makers. Past research on the social-cognitive preparation model (Paton, 2003) and the Protection Motivation Theory (Grothmann & Reusswig, 2006) have found that individuals' risk perception and adaptive capacity may ultimately determine the success of flood risk communication efforts and whether one adopts risk management measures aimed at preventing and mitigating damage (Hung & Chen, 2013; Kellens et al., 2011; Dransch et al., 2010). In light of this, socio-hydrology scholars have called for a more interdisciplinary research approach that addresses the social and hydrological drivers of flood risk, as these drivers can interact with each other to alter individual flood knowledge and mitigation behaviors.

This dissertation examines expert and non-expert knowledge of flooding in order to identify opportunities for improving flood risk communication and promoting participatory flood risk management by taking into account a variety of hydrological and social factors. For this study, we define flood knowledge to encompass flood risk perception and flood risk awareness. These two related concepts have been examined extensively in previous research, and have been shown to influence individual behaviors before, during, and after flood events (Kellens et al., 2011; Morrow et al., 2015; Slovic, 2000; Siegrist & Gutscher, 2008). The analysis of flood knowledge through traditional and modified means, including traditional surveys, cognitive mapping, and focus group discussions, demonstrated that flood knowledge has different spatial and nonspatial dimensions across different socio-demographic subgroups. By accounting for the different dimensions of flood knowledge, researchers and different stakeholders can co-develop targeted communication strategies and risk management plans to reduce flood vulnerability and increase community resilience.

The overarching thesis of this dissertation contends that there is a gap between expert knowledge of flood hazard and their management on the one hand, and community knowledge of the same hazard and mitigation strategies on the other. Closing this gap requires an understanding of how experts (scientists, engineers) and non-experts (decision-makers, community opinion leaders, practitioners) negotiate their knowledge of flooding, as well as an interdisciplinary examination of the roles of various hydrological and social factors in this complex process. First, we examined what we termed the "seawall effect," where we analyzed the feedback between hydrological (e.g. seawall and flood model estimates) and social drivers (e.g. trust in government, risk perception) of personal spatial awareness of flood risk. Second, in order to obtain a richer understanding of individuals' spatial awareness of flood risk, we complemented traditional surveys with the technique of cognitive mapping in order to identify discrepancies and gaps between expert and non-expert knowledge of flood hazard. Finally, once we have identified the knowledge gaps as well as the hydrological and social drivers of these gaps, we engaged key community stakeholders in the development of communication and participatory management strategies that are designed to close the knowledge gaps and build community resilience.

Chapter 1 focuses on how hydrological and social factors interact to influence one's flood knowledge. It is an extension of the existing research on the social amplification of risk framework (Kasperson, 2012; Kasperson, 1988) and the levee effect (White, 1945; Burton & Kates, 1964). Specifically, we collected and analyzed traditional survey data to assess the relationship between individuals' flood knowledge and their social, geographical, informational characteristics as well as their proximity to flood defenses (i.e. coastal seawalls). While previous studies suggest that flood defenses such as seawalls and levees may influence flood risk awareness, we found that social, geographical, and informational characteristics such as trust in government, place of residence, and exposure to detailed flood maps can mediate the impact that flood defenses have on spatial flood risk awareness.

Whereas Chapter 1 focuses on how self-rated spatial flood risk awareness is influenced by respondents' social, geographical, and informational characteristics, Chapter 2 provides further insights on the spatial dimension of personal flood risk awareness by asking respondents to locate and sketch areas they considered to be at risk of flooding. The use of sketch maps or cognitive maps to assess individuals' environmental perception in fields such as urban planning, public safety, and environmental planning dates back to the 1960s (Lynch, 1960; Appleyard, 1970; Lopez & Lukinbeal, 2010; Tung-Wen Sun, 2009). More recently, sketch maps have been used to analyze individuals' perception of natural hazards and vulnerable regions (Ruin et al., 2007; Leone & Lesales, 2009; O'Neill et al., 2015). In this dissertation, we utilized sketch maps to gauge respondents' awareness of where flooding can occur in their community. Individuals' sketches were then compared to different expert flood model estimates provided by the Federal Emergency Management Agency (FEMA) and the Flood Resilient Infrastructure and Sustainable Environments (FloodRISE) research group. This enabled us to see if individuals from particular socio-demographic subgroups or geographical areas have significantly higher agreement with expert flood estimates relative to the study area average. Our results show that respondents with particular educational, income, and home ownership characteristics are associated with higher than average agreement with experts over where flooding may occur.

In an effort to understand why different subgroups have varying levels of flood knowledge, as well as opportunities for preventing and mitigating flood damages through improved flood risk communication and management, we invited opinion leaders from key stakeholder groups (i.e. home and business owners, nonprofits and civil society, emergency and city planners) to participate in focus group discussions. As shown in Chapter 3, we not only learned about user-specific requirements for developing useful flood visualizations in our discussions, but also identified ways to increase the accessibility and resonance of flood risk information, which can ultimately motivate personal mitigation behaviors and advance the participatory management of flood risk (Fuchs et al., 2009; Dransch et al., 2010). By implementing Fiorino's (1990) democratic process criteria in the design of our focus groups, we were able to genuinely engage expert and non-experts in the design of future flood visualizations, which can ultimately enhance their relevance and utility for different stakeholders. This effort is particularly important for reducing the human and economic toll of flooding since "flood maps are increasingly regarded as important for mitigating the impacts of natural hazards" (Meyer et al., 2012, p. 1701).

Finally, Chapter 4 reflects upon the importance of public engagement and interdisciplinary collaboration in flood risk communication and management. Specifically, there has been growing recognition among decision-makers that "the public needs to be more engaged with flood risk, its geography and the wider set of measures that can be adopted to reduce exposure and vulnerability" (Lane et al., 2011, p. 20). In light of this need, we will consider the benefits and issues in furthering public engagement in flood risk management from a citizen science perspective. In addition, we will consider the future of socio-hydrology, and argue that interdisciplinary collaboration and convergence thinking hold the key to alleviating the persistent problem of flooding and building more resilient communities.

Aside from analyzing the social, geographical, and informational drivers of flood knowledge between different subgroups within our study area, this dissertation also identified the scale effect, a sub-problem of the Modifiable Areal Unit Problem (Openshaw & Taylor, 1979), as one of the key methodological issues that should be considered when analyzing public participation Geographic Information Systems (PPGIS) data or modeling the potential hydrologic impacts of flood defenses (Wong, 2009). A theory-based justification for an appropriate scale of analysis will help ensure that key patterns and trends in a given study area are not overlooked or misinterpreted. More importantly, this will inform how the geographical scale for future flood risk communication activities and flood hazard modeling exercises should be chosen, and address the concern of risk variability by ensuring that flood knowledge is equitably disseminated among different socio-demographic subgroups that may experience different levels of risk (Frewer, 2004).

The problem of flooding – as stated earlier – is only getting worst despite decades of research on the topic. While hydrological scientists have improved flood model estimates over the years, and social scientists have made significant progress in understanding flood risk perception, the mechanism in which more precise flood model estimates impact human flood risk perception and awareness is not clear. By studying how flood knowledge is negotiated between expert and non-experts, we hope to integrate hydrological scientists’ knowledge of the physical processes of flooding with social scientists’ understanding of flood risk perception to produce useful visualizations that can advance flood risk communication and management. This will enable decision-makers and flood risk managers to communicate flood knowledge to vulnerable stakeholders in an actionable form, motivate personal mitigation behavior, and hopefully reduce the impact of future flood events.

The issues and questions explored in this dissertation are the products of a collaboration between hydrological and social scientists on the National Science Foundation (NSF) funded Flood Resilient Infrastructure and Sustainable Environments (FloodRISE) research project. This collaboration has greatly further my understanding of the different dimensions embedded in the wicked problem of flooding. The support and guidance I received from my advisors and colleagues are invaluable in shaping my research, and exemplified the interdisciplinary collaboration needed to solve many of society’s complex problems. I especially want to thank my advisor, David Feldman, for his unwavering support of my dissertation and my research. Moreover, the ideas and advice offered by my current and past committee members, including Douglas Houston, Richard Matthew, Brett Sanders, and Jae Hong Kim are invaluable in guiding the dissertation in ways that maximize its contributions to the field. Additionally, I have also learned a great deal and benefited greatly from working with faculty members, post-doctoral researchers, and colleagues at the University of California-Irvine, such as Jochen Schubert, Victoria Basolo, Kristen Goodrich, Adam Luke, Kimberly Serrano, Abby Reyes, Santina Contreras, Amir Aghakouchak, Hamed Moftakhari, and Beth Karlin. The encouragement provided by Daniel Sourbeer and my colleagues at Palomar College undoubtedly motivated me to begin and persist in this academic journey. Finally, and most importantly, I hope to dedicate this dissertation to my family, and especially my grandmother, who has always been supportive of my life decisions, wherever they may take me.

Beyond the “levee effect”: Flood defenses, geographical, social and informational factors in spatial flood risk awareness

ABSTRACT

Previous research on the “levee effect” suggests levees or other flood defenses may instill a false sense of security among individuals, thus reducing flood risk awareness among local residents. We applied the “levee effect” to a coastal context, to see how flood defenses (i.e. seawalls) that are not federally certified impact individuals’ spatial flood risk awareness. We exposed local residents to two different estimates of flood hazard distribution and analyzed their personal characteristics, in order to understand how seawalls interact with geographical and social factors to impact spatial flood risk awareness. We found the effects that seawalls have on respondents’ spatial flood risk awareness is mediated by individual characteristics such as age and risk perception. However, after the two flood hazard maps were shown to respondents, factors such as trust in government, place of residence, and previous flood experience became significant predictors of risk awareness. Our findings suggest that exposure to flood hazard information (i.e. informational factor) can change the ways in which social and geographical factors interact with flood defenses to influence spatial flood risk awareness.

1. BACKGROUND

Flood hazard is a serious threat to society. Affecting at least 20 million people worldwide annually, flooding has been recognized as the third most damaging natural hazard globally (Loucks, 2015; Kellens 2013). As a result of climate change, the impacts of these events are expected to become much greater and costlier (Newell et al., 2015; Faulkner & Ball, 2007). Meanwhile, the number of lives at stake and vulnerable communities are expected to increase as development along coastal areas continues to intensify in the United States and elsewhere in the world (Morrow et al. 2015; Di Baldassarre et al. 2015). One example of these vulnerable communities is the City of Newport Beach located in Southern California, where past studies examining historic tidal range data (Flick et al., 2003) and the frequency of nuisance flooding (Moftakhari et al., 2015), as well as analyses of extreme events (Tebaldi et al., 2012) all suggest that the frequency of flooding is likely to increase in the region due to sea level rise. Consequently, high impact events that are of low probability at the moment, such as the so-called "century" extremes or the "100-year flood" (1% annual exceedance probability event or 1% AEP[1]), are expected to become annual occurrences by 2050 in Southern California (Tebaldi et al., 2012).

In this study, we define spatial flood risk awareness not only as one's "awareness of living in an at-risk area" (Burningham et al., 2008, p. 217), but also the knowledge of where flood hazards are relative to one's residence. Although levees and seawalls share the common goal of protecting residences and infrastructures from flooding, neither of these structures provide absolute protection against flooding as shown in seawall overtopping during the 2011 Tohoku earthquake and tsunami in Japan, and levee breaches during Hurricane Katrina in New Orleans (Kte'pi, 2013). While levees usually run parallel to the course of a river, seawalls have

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[1] 1% AEP is used to characterize a flood event that has a 1% chance of taking place in any given year.

been regarded as the coastal analog of riverine levees, and their construction usually entails destroying existing beaches and wetlands (Kte'pi, 2013; Burton & Kates, 1964). This case study of the coastal community of Newport Beach will focus on how seawalls interact with various social, geographical, and informational components in the socio-hydrological system to influence residents' spatial flood risk awareness.

1.1. The Levee Effect

In response to the threat of flooding, the nearly one billion people that currently live in floodplains (Di Baldassarre et al., 2013) have come to rely on a range of nonstructural and structural adjustments to protect themselves against floods. Examples of nonstructural adjustments include flood abatement (e.g. revegetation of riverbank), land use zoning and regulation, and insurance (White, 1945), but they are beyond the scope of this chapter. In examining structural adjustments to floods such as flood defense structures, White (1945) coined the term "levee-effect" to suggest that structures which are intended to reduce the frequency of flooding may change local hydrological conditions and instill a false sense of security among floodplain inhabitants, which may in turn reduce inhabitants' awareness of flood risk and encourage human settlements in vulnerable areas that are still subjected to the residual risk of flooding. Burton and Kates (1964) extended White's thesis beyond the riverine context, and argued that a coastal analog of the levee effect can be seen in the extensive developments on the sea slope or flood prone areas protected by barrier dunes, seawalls, or other types of coastal flood defenses. Based on the logic of the levee effect, we introduce the term "seawall effect" in this study to test the impacts that aging, locally maintained coastal flood defenses have on residents' flood awareness.

As Di Baldassarre et al. (2013) pointed out, there has been a long tradition of studies that examined how humans adjusted to floods (White, 1945; Kates, 1971; Parker & Harding, 1979; Paul, 1984; Wong & Zhao, 2001; Grothmann & Reusswig, 2006), and how flood hazard characteristics (e.g. velocity, flood stage, tidal amplitudes) can be changed by flood defenses (White, 1945; Matthingly et al. 1993; Gergel et al., 2002; Heine & Pinter, 2012; Byun et al., 2004; Kang, 1999). However, many of these studies tend to narrowly focus on the economic losses or the hydrological impacts of flooding, rather than offer an integrated examination of the feedbacks between economic and hydrological drivers within the human water systems (Di Baldassarre et al., 2013). Consequently, flood issues with clear social and physical dimensions such as the “levee effect” became “a prime example of how an incomplete understanding of the role of structural and nonstructural measures in flood mitigation limits what can be authoritatively said with respect to the flood problem” (Pielke, 1999, p. 420). In fact, empirical studies on the interaction or feedback between how flood control structures influence regional hydrology, human settlement decisions, and flood awareness remained largely underexplored until the introduction of the science of socio-hydrology by Sivapalan et al. (2012).

Through the use of surveys and computer models, researchers have studied the “dynamic interactions between the hydrological and social dimensions of floods” as a coupled human-water system (Di Baldassarre et al., 2013, p. 3239). Examples of which included the use of computer simulations to examine changes in human settlement pattern, flood stage, and flood awareness in the presence of levees (Di Baldassarre et al., 2013), the use of computer models to analyze the influence that collective memory, risk taking attitude, and trust in protective measures have on the wealth and size of floodplain communities (Viglione et al., 2014), the use of census data and satellite imagery to study the change in population in flooded areas over time

(Collenteur et al. 2015), and the use of survey data to examine the flood awareness of residents within levee-protected lands (Ludy & Kondolf, 2012). While these studies found that flood awareness of individuals living within levee-protected areas tends to be low as predicted by the "levee effect", the levees examined by these studies tend to be ones that are certified as protecting against the 100-year flood (Ludy & Kondolf, 2012), or hypothetical levees that may be constructed or raised in response to hypothetical flood events (Di Baldassarre et al., 2013; Viglione et al., 2014). On the whole, there seems to be a shortage of empirical studies that directly assess the impacts that levees or other types of flood defenses have on personal spatial flood risk awareness outside of the studies mentioned here.

Although the total length of flood defenses in the United States is not clear (Heine and Pinter, 2012), Tobin (1995) reported that there are over 25,000 miles of levees, seawalls, embankments, and dikes offering flood protection in the United States. However, only 5.5 percent of floodplain communities are protected by levees which are certified against the 100-year flood event, while "the remaining levees, many of which do not meet official standards, provide different levels of protection to farmland and small communities" (Tobin, 1995, p. 360). A case in point is the Mississippi River basin, which has approximately 8,000 miles of levees of different age, ownership, size, and quality, but only 42 of the 8,000 miles are maintained by the federal government. This shows that a majority of existing levees and other forms of flood protection structures in the United States do not meet federal standards, are of various age and conditions, and offer varying level of protection. Since a majority of floodplain communities in the United States are not protected by federally certified flood defenses, this case study will examine the extent in which these defenses influence residents' spatial flood risk awareness.

Specifically, we will empirically assess if locally maintained seawalls that are not federally certified instill the same false sense of security as predicted by the “levee effect”.

A number of studies have shown that levee and seawall construction can impact regional hydrological regime. In the case of levees, the reduction in the area for flood water storage and reduction in the width of floodplain can exacerbate flood problems elsewhere in the floodplain (Heine & Pinter, 2012; Tobin, 1995; White, 1945). In the case of seawalls, it has been shown that such structures can lead to elevated high water level (Kang et al., 2009), significant changes in tidal amplitudes (Byun et al., 2004; Kang, 1999), as well as changes in sediment budget and beach erosion (Lee et al., 1999; Morton, 1988). Given that previous studies have already demonstrated the hydrological impacts of flood defense construction, we will focus on how various geographical, social, and informational factors (i.e. exposure to scientific information such as flood hazard maps) interact with flood defenses to shape individuals’ flood awareness. This study will contribute to the field of socio-hydrology and disasters studies by examining how spatial flood risk awareness may be influenced by the presence of flood defenses (i.e. seawalls) that are not federally sanctioned against the 100-year flood. Specifically, we hypothesized that since flood defenses which are not federally certified have a higher likelihood of failure (Tobin, 1995), their presence may actually serve as a constant reminder of the flood hazard for inhabitants, which may in turn increase these inhabitants’ flood awareness contrary to what may be predicted by the “levee effect” or the “seawall effect.” Moreover, we also hypothesized that social, geographical, and informational factors that have been found to influence flood awareness in previous studies can partly mediate the influence that the “seawall effect” has on inhabitant’s spatial flood risk awareness.

1.2. Flood Awareness and Socio-Hydrology

Given that the frequency and impacts of flooding are becoming more severe, there is no shortage of studies on human awareness of flood risk. Social scientists mainly focused on the socio-economic, psychological, and geographical drivers of flood awareness (Brilly & Polic, 2005; Burningham et al., 2008; Heitz et al., 2009; Knocke & Kolivras, 2007; Wachinger et al., 2013). Based on a review of the risk perception literature, Wachinger et al. (2013) classified factors affecting flood awareness into the categories of risk factors (probability, magnitude), informational factors (exposure to information), personal factors (age, gender, experience, trust in authorities), and contextual factors (home ownership, family status, area of living, proximity to hazard).

In their study of residents' perception of flood risk, Brilly and Polic (2005) examined factors such as "demography, perceived frequency and characteristics of floods, concerns about them, opinions about countermeasures and responsibilities, and certain warning characteristics," and found that perception of threat depends on one's place of residence and personal experience with floods (p. 348). In an attempt to understand factors that contribute to people's awareness of flood risk, Burningham et al. (2008) surveyed and interviewed individuals who reside in areas designated as at-risk of flooding by the United Kingdom's Environment Agency or areas that have suffered severe flooding in the past. The study concluded that social class, flood experience, and length of time at residence have significant influence on flood awareness. In Knocke and Kolivras' (2007) study of flash flood awareness, the authors found that young adults have the lowest awareness of flash flood risk, while respondents with recurring flash flood experience as well as those living in the floodplains tend to have higher awareness. In Heitz et al.'s (2009) study of stakeholders' awareness of muddy flood risk, it was found that respondents' residential locations as well as their trust in mitigation measures and the party responsible can influence people's flood awareness.

While we presented only a small selection of studies on flood risk awareness (see Kellens et al., 2013 for a more detailed review of literature on this topic), they all showed that human flood awareness is driven not only by complex social, informational, and geographical factors, but also the interactions and feedback between these factors. Thus, in an effort to understand how human hydrological interventions (i.e. construction of flood defenses and their associated hydrological implications) influence one's spatial flood risk awareness and mitigation behaviors, it is imperative for researchers to adopt the socio-hydrological framework and "treat people as an endogenous part of the water cycle" (Sivapalan, 2012, p. 1274).

In order to understand "the dynamics and coevolution of coupled human-water systems," Sivapalan et al. (2012) proposed the science of socio-hydrology, and advocated for humans and their actions to be considered a part of the water cycle rather than external forcings that can be ignored (Sivapalan et al., 2012, p. 1271). To this end, scholars have begun to take into account the social and physical dimensions of flooding in an attempt to understand personal flood risk awareness. Ludy and Kondolf (2012) analyzed the influence that flood defenses such as the 100-year levees has on the risk perception of relatively affluent and educated individuals with different flood experience and knowledge about flooding. Di Baldassarre et. al (2013) modeled how flooding events can influence human behaviors and decisions, taking into account the size of human settlement and wealth (economic factor), distance of settlement from flood hazard (political factor), flood awareness and protective response (technological factor), and previous flood experience (social factor). Unlike previous research, this case study examines the influence that non-federally certified and locally maintained flood defenses have on the spatial flood risk awareness of residents. Moreover, the survey data collected for this case study enable us to examine the feedback between different social, geographical, and informational drivers of flood awareness in the presence of flood defenses, thus furthering our understanding of the mechanisms within the socio-hydrological process that are responsible for the seawall effect.

2. CASE STUDY CONTEXT

This study focuses on the highly urbanized low-lying coastal lowlands of the Newport Bay Estuary within the City of Newport Beach, California (Figure 1.1) and is part of the Flood Resilient Infrastructure and Sustainable Environments (FloodRISE) research project intended to promote resilience to coastal flooding in Southern California. The study area is divided into four sub-areas: (1) Upper Peninsula, (2) Lower Peninsula, (3) Lido Isle, and (4) Balboa Island (Figure 1.1). The city is densely populated, with a population density of 1,600 people per square mile compared to the California's population density of 251.3 people per square mile (US Census Bureau, 2015). Residents living within the study area is older compared to the county average (median age of 46.9 years old versus 36.2), more educated (22.03% with graduate or professional degrees versus 13.4%), and earn higher income compared to the rest of the county (median household income of $161,766 versus $101,134) (US Census Bureau, 2015). Gallien et al. (2013) showed that large portions of the city are below extreme high tide levels, while Tebaldi et al. (2012) concluded that flood events currently qualified as 100-year event in Southern California is expected to become annual occurrences by 2050 due to sea level rise. These studies highlight the importance of flood defenses for the City of Newport Beach especially given the concentration of people and wealth in the region.

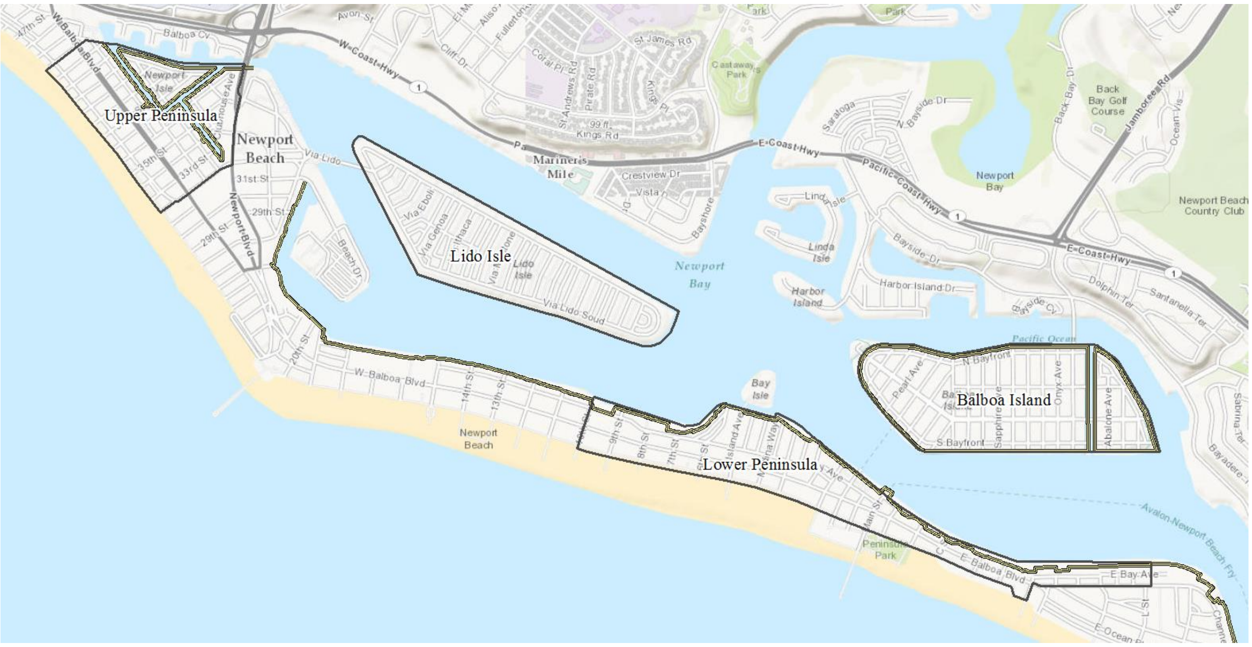

Figure 1.1. Study area within the City of Newport Beach divided into the four sub-areas of 1) Upper Peninsula, 2) Lido Isle, 3) Balboa Island, and 4) Lower Peninsula. Seawalls (thick yellow lines) are present in all of the sub-areas with the exception of Lido Isle.

The study area consists of a total of 12.69 kilometers of seawall (Figure 1.1). There are 2.69 kilometers of seawall in the upper peninsula sub-area, while 5.94 kilometers of seawall protect much of the lower peninsula from flooding. There are 4.06 kilometers of seawall on Balboa Island, and no seawall on Lido Isle given that it is on higher elevation than the other three sub-areas. Some of oldest seawalls in the study area are located on Balboa Island and were built in the 1920s and 1930s (Poon, 2011). They were estimated to have between 10 to 25 years of useful life left (Poon, 2011). Although the City of Newport Beach claimed that the seawalls around Balboa Island are high enough to protect against flooding, it also acknowledged that moderate storm surge at high tide has occasionally overtopped the seawalls as in December 2010, and the frequency of overtopping is expected to increase due to the rise in sea level (Poon, 2011) (Figure 1.2). In fact, Moftakhari et al. (2015) found a substantial increase in nuisance flooding along the Southern California coast due to sea level rise over past decades, and concluded that it is a trend that is expected to continue in the near term and midterm. The authors further contend that the increase in frequency of nuisance flooding "portends an increased risk in severe floods" (Moftakhari et al., 2015, p. 9846).

Figure 1.2. Wave overtopping seawall in the lower peninsula of Newport Beach in December 2012.

3. METHODS

To assess the social, geographical, and informational drivers of personal flood risk awareness, the research team surveyed 214 heads of household in Newport Beach, California. As stated before, the study area in Newport Beach was divided into four sub-areas: Upper Peninsula, Lido Isle, Lower Peninsula, and Balboa Island (Figure 1.1). Two island and two peninsula sub-areas were chosen based on the hypothesis that these areas could potentially have different experiences with flooding. These sub-areas have similar levels of vulnerability with comparable number of residential parcels considered at risk by two objective flood hazard models developed by the FEMA (Federal Emergency Management Agency) and the FloodRISE research team (Figure 1.3). About 25-40% of each sub-area's parcels are residential parcels that are within the "100-year flood" or 1% AEP floodplain as indicated by the FEMA and/or FloodRISE model.

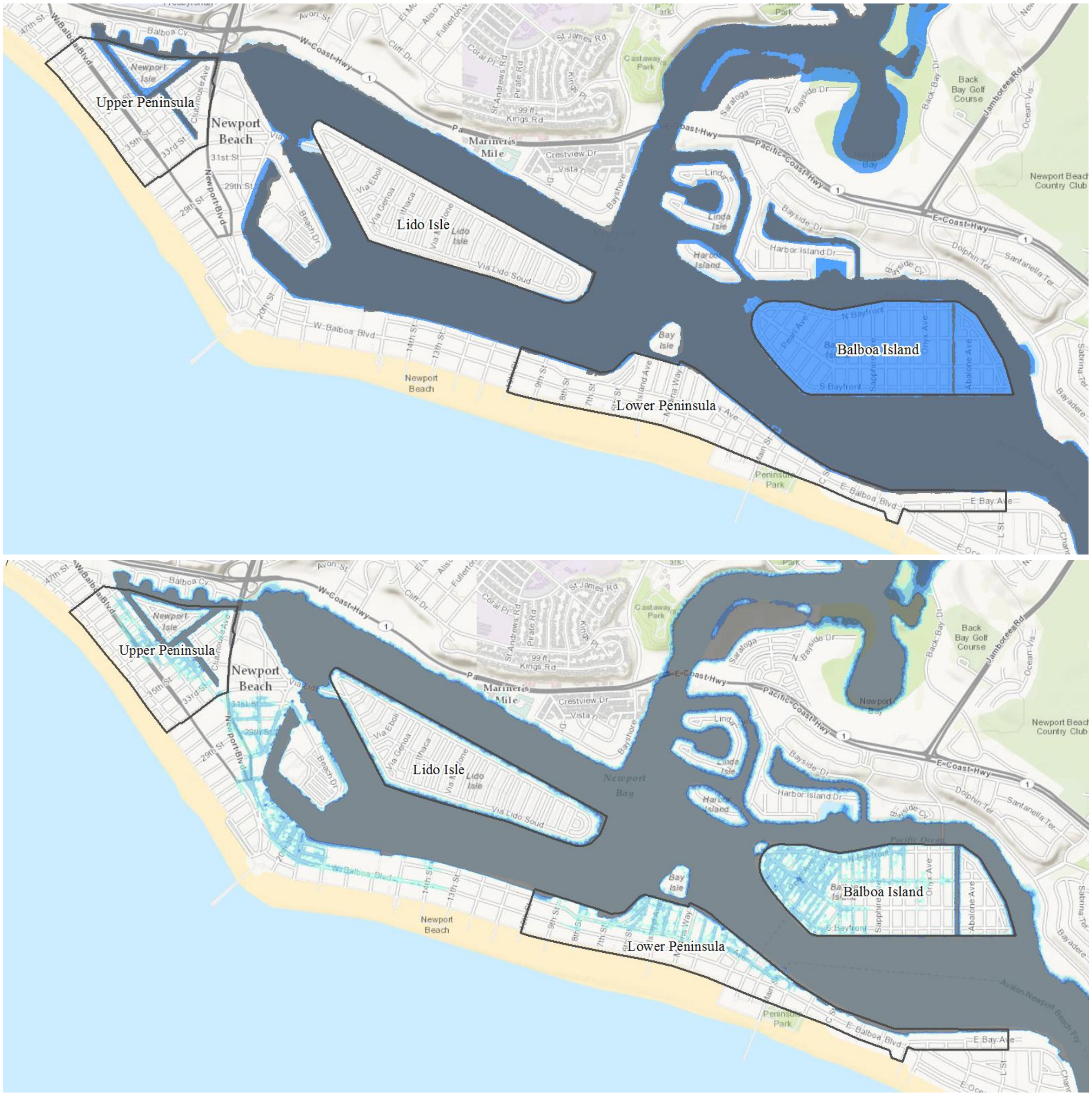

Figure 1.3: Two objective estimates of flooding given a 1% annual exceedance probability flood event (100-year flood event) produced by FEMA (top) and the FloodRISE research team (bottom). Inundated areas are shown in blue in the FEMA estimate. The different shades of blue correspond to various inundation depths in the FloodRISE estimate (e.g. dark blue-overhead high water depth, light blue-ankle high water depth).

The FEMA flood hazard mapping approach for the Newport Beach site entails one-dimensional hydrologic analysis of ocean water levels considering storm surge, waves, and wave runup followed by mapping still water flood elevations along the coastline and urbanized embayment by applying an equilibrium mapping approach (Gallien et al., 2011; National

Research Council, 2009). Unlike the FEMA model, the FloodRISE model is a two-dimensional hydraulic model that was developed at the University of California-Irvine, and has been used in this project for flood hazard mapping in Newport Beach, California. The model relies on an unstructured grid of triangles, which can be locally refined for accurate topographic representation of the site's terrain and infrastructure geometries, such as streets and flood defenses. The model is also able to account for a wide range of flow regimes resulting from abrupt changes in topography like those caused by seawalls. The model has been previously validated for the modeling of stormtides and wave overtopping in Newport Beach (Gallien et al., 2014; Gallien et al., 2011).

We sent a pre-notice letter to sampled households which described the purpose of the study and survey procedures, indicated the general time period when the survey team planned to visit the household's neighborhood to conduct surveys. During the months of April, May, and June in 2014, survey teams visited sampled households and invited a head of household who was 18 years or older to participate. Potential respondents could choose to complete the survey at that time, schedule a subsequent time the team could visit to complete the survey, or refuse to participate. The survey consisted of a spatial component (i.e. sketch mapping exercise) and a non-spatial component (i.e. key questions on personal and social characteristics), and lasted approximately 40 to 60 minutes.

We stratified our sample of parcels in an effort to gather an equal number of responses from island sub-areas and peninsula sub-areas, and within each of these sub-areas we stratified the sample further to obtain comparable responses from each of the following categories of parcels based on modeled flood hazard classifications: (1) those outside of both the FEMA and FloodRISE impacted areas, (2) those within the FEMA impacted area but outside the FloodRISE impacted area, (3) those outside the FEMA impacted area but within the FloodRISE impacted area, and (4) those inside both the FEMA and FloodRISE impacted areas. Although we initially sought to obtain a random sample of residents, we ultimately implemented quota sampling in order to obtain enough respondents in each of these four categories. Due to low response rates, we used limited snowball sampling and added 22 additional respondents, resulting in a total sample of 214 respondents. Our final analysis sample included 176 survey participants who provided complete responses for key questions regarding their social, geographical, and informational characteristics. Specifically, the sample was reduced from 214 responses to 176 responses due to missing values caused by technical difficulties (e.g. data collection device malfunction) and/or data entry errors (e.g. entry of invalid respondent ID). The final analysis sample for the sketch mapping exercise (see below) included 166 observations as we excluded participants whose sketches fell entirely outside of the study area.

The term “cognitive maps” was first introduced by Tolman (1948), and has since been used in fields such as urban planning (Lynch, 1960; Downs & Stea, 2005; Appleyard, 1970), public safety (Curtis, 2012; Lopez & Lukinbeal, 2010), and environmental planning (Tung-Wen Sun, 2009) to assess individuals’ environmental perception and spatial knowledge. Cognitive mapping (also referred to as sketch mapping) have also been used in the analysis of natural hazards and vulnerability. For example, Ruin et al. (2007) used cognitive mapping to gauge motorists’ flash flood risk perception, Leone and Lesales (2009) asked interviewees to sketch zones that they considered to be susceptible to volcanic eruptions, and O’Neill et al. (2015) evaluated residents’ risk perception by requesting them to sketch areas at risk of inundation during a severe flood event.

During the mapping exercise, each participant was asked to sketch areas that he/she considered to be at risk of flooding on a tablet computer. Rather than requesting participants to cognitively map out their neighborhoods or its hazards on a blank piece of paper without predetermined geographic reference points as was done in Lynch (1960) or Brilly and Polic (2005), we followed Bell's (2002) recommendation to provide all participants with the same pre-determined mapping control points and geographic boundaries within which they can sketch their perceptions and knowledge. Specifically, we provided respondents with an interactive map showing the study area boundary, major roads, and landmarks, and then asked them to sketch areas that were prone to flooding. Unlike previous studies in which participants entered responses using a map at a static scale, our use of tablet devices enabled participants to interactively adjust the level of details (e.g. zoom in/out) in the map as they sketched flood-prone areas (Bell, 2002). Participant sketch maps were stored digitally in the ArcGIS Online cloud, downloaded, processed, and analyzed using the ArcGIS Desktop software. Portions of participant sketch maps that were outside of the pre-defined study area were excluded for the purpose of analysis. Individual sketch maps from the mapping exercise were compared with objective models of flood risk developed by FEMA and the FloodRISE research team using the methodology outlined in Cheung et al. (2016). Specifically, the level of agreement between the sketch maps and the two objective estimates of flood risk were quantify using the composite alignment index (CAI). The CAI provides an integrative measure of the spatial agreement between sketch maps and the two objective flood hazard estimates, by comparing the total area estimated to be hazardous by participant sketches *or* the models with what was regarded as hazardous by participant sketches *and* the models (Cheung et al., 2016). The value for the CAI range from 0 (no alignment between participant sketches and the models) to 1 (complete alignment between participant sketches and the models) for each participant sketch.

We also collected supplemental survey data about residents' social characteristics, as well as their attitudes towards local flood defenses. As stated previously, a number of these factors have been shown to influence individual flood awareness by past research (Brilly & Polic, 2005; Burningham et al., 2008; Heitz et al., 2009; Knocke & Kolivras, 2007; Wachinger et al., 2013; Ruin et al., 2007). For example, we asked respondents a series of 11 questions[2] related to their nonspatial perception of flooding in order to arrive at their average flood risk perception. As another example, we gauged respondents' average trust in government by asking them six questions[3] related to their attitudes toward the government. In addition to social factors, we also seek to understand how one's spatial awareness of flood risk is influenced by informational factors such as the exposure to flood hazard maps of different spatial resolutions. To facilitate this, we divided the study sample into two groups. One group of participants were shown the flood map based on the FEMA 1% AEP model, whereas another group of participants were

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[2] Average risk perception is based on the average of 11 measures of risk perception based on the works of Slovic (1987) and Wachinger et al. (2013):

1. My community is vulnerable to the risk of major floods.
2. It is very likely that a major flood will occur in my community in the next 10 years.
3. A major flood would be an extreme danger to people in my community.
4. A major flood is likely to cause major property damage to my community.
5. There is nothing people in my community can do to prevent major damage from a flood.
6. People in my community have a great dread of major floods.
7. People in my community have learned to live with the risk of a majoring flood.
8. People in my community are unprepared to respond to a major flood.
9. I think about the risk of flood a great deal.
10. I am concerned about the possibility of a major storm affecting my community.
11. A major flood is certain to be fatal to people living in my community.

[3] Average trust in government is based on the average of six measure of individuals' attitude toward the government:

1. I can trust the government to do what is right.
2. The government is pretty much run for the benefit of all people.
3. I trust government officials to act in the best interest of the people.
4. Quite a few of the people running the government are crooked.
5. The government is pretty much run by a few big interests looking out for themselves.
6. People in the government waste a lot of money we pay in taxes.

shown the results based on the FloodRISE 1% AEP model. Participants were asked to rate their spatial awareness of flood risk before and after viewing either the FEMA or FloodRISE flood map. In addition, the supplemental survey data were examined in conjunction with the respondent's geographical characteristics derived from Geographic Information System tools (e.g. distance from water feature, location within floodplain, area of residence), in order to understand how one's residential location relative to flood defenses interact with social, informational, and geographical factors to influence one's spatial flood risk awareness.

4. RESULTS

4.1. Pre-flood hazard map exposure – self-rated spatial flood risk awareness

Given the findings from previous studies regarding the impacts of federally certified 100-year levees on spatial flood risk awareness, one would expect flood awareness to have an inverse relationship with one's proximity to levees or other manmade flood defenses. However, the results from this study indicate that individuals living near (i.e. within 100 meters) locally maintained seawalls in Newport Beach self-reported a significantly greater sense of spatial awareness of flood risk relative to those who do not (Table 1.1, Model 1). However, when geographical variables such as one's place of residence, one's location within the FEMA designated 100-year floodplain, elevation, and one's distance from the ocean are taken into account, only the place of residence variable has statistically significant effects on self-rated spatial flood risk awareness (Table 1.1, Model 2). Specifically, individuals living on Lido Isle reported significantly greater flood risk awareness. Especially noteworthy is that as geographical variables are added to the regression model, one's proximity to seawalls no longer has a significant effect on the respondent's flood risk awareness. Furthermore, by including relevant social factors identified by previous studies (Brilly & Polic, 2005; Burningham et al., 2008;

Heitz et al., 2009; Knocke & Kolivras, 2007; Wachinger et al., 2013) into the regression model, we found that one's age and average perception of floods have a positive impact on one's spatial flood risk awareness, and the proximity to seawalls has no significant impact on awareness (Table 1.1, Model 3). Lastly, we found that the inclusion of additional variables related to one's awareness of local flood defenses and one's sense of security given those defenses neither significantly impact spatial flood risk awareness nor mediate the effects of other variables in the model (Table 1.1, Model 4).

4.2. Pre-flood hazard map exposure – participant sketch maps

We found that 62 of 166 (37%) participants included at least a portion of a seawall in their sketches. The results from the analysis of sketch maps showed that there are no significant differences in the sketches of those who live near or far from a seawall. Specifically, the size of the area sketched as prone to flooding by inhabitants living within 100 feet of a seawall is not significantly different than the study area average (Table 1.2). However, when comparing the size of area sketched as prone to flooding by inhabitants who included at least a portion of a seawall against the study area average, we found that those individuals who included seawall in their sketches tend to consider a significantly larger area as being prone to flooding with respect to the study area average (Table 1.2). Conversely, those individuals who did not include seawall in their sketches tend to consider a significantly smaller area as being prone to flooding. Future research is needed to determine whether it is those individuals' insecurity about seawall (i.e. considering it prone to overtopping) that caused them to overestimate flood prone areas (i.e. sketch larger areas), or if it is their tendencies to overestimate flood hazard that caused the seawall to be included in their sketches.

Table 1.1: Regression analysis of factors predicting respondent's spatial flood risk awareness before exposure to flood hazard maps.

	Model 1	Model 2	Mod	Model 4
Within 100 feet of Seawall				
Yes	0.55*	0.59	0.17	0.19
No	Ref. Category	Ref. Category	Ref. Category	Ref. Category
Aware of flood defenses				
Yes				0.30
No/Not sure				Ref. Category
Feel secure given flood defenses				0.08
Geographical Factors				
Place of Residence				
Balboa		1.56	0.56	0.45
Lido		1.29*	0.46	0.57
Upper Peninsula		-0.18	0.39	0.57
Lower Peninsula		Ref. Category	Ref. Category	Ref. Category
In FEMA floodplain				
Yes		-1.12	-0.10	-0.04
No		Ref. Category	Ref. Category	Ref. Category
In FloodRISE floodplain				
Yes		0.48	0.13	0.18
No		Ref. Category	Ref. Category	Ref. Category
Distance to Coast		0.002	0.003	0.004
Elevation of Residence		-0.13	-0.14	-0.13
Social Factors				
Experience with Flooding				
Yes			0.05	0.05
No			Ref. Category	Ref. Category
Age			0.05**	0.05**
Gender				
Female			-0.30	-0.25
Male			Ref. Category	Ref. Category
Education				
Less than Bachelor's Degree			Ref. Category	Ref. Category
Bachelor's Degree or Higher			-0.18	-0.19
Average Annual Income[4]			0.01	-0.001
Homeowner				
Yes			0.45	0.41
No			Ref. Category	Ref. Category
Average Risk Perception			0.31*	0.36**
Average Trust in Government			0.11	0.12
Model Statistics				
Number of Observations	176	174	131	131
Adjusted R^2	0.02	0.08	0.41	0.42

In terms of agreement with objective models of flood risk as quantified by the composite alignment index (CAI), the results show that one's proximity to a seawall is not necessarily

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[4] Coded as ordinal values with a range of 1 to 4, where 1 is Lo ($42,500 or less), 2 is Mid (More than $42,500, but $87,500 or less), 3 is Hi (More than $87,500, but $175,000 or less), and 4 is Very Hi (More than $175,000).

associated with significantly more or less agreement with the FEMA 1% AEP or FloodRISE 1% AEP flood model estimate relative to the study area average (Table 1.2). However, it was found that the sketches of inhabitants who included at least a portion of the seawall in their drawings have significantly greater alignment with the FEMA 1% AEP and FloodRISE 1% AEP models relative to the study area average, while those sketches that did not included seawall have significantly lower alignment with the FEMA and the FloodRISE models (Table 1.2).

Table 1.2: Analysis of sketch maps from sketch mapping exercise.

	Entire Study Area	Within 100 Feet of Seawall	Not Within 100 Feet of Seawall	Sketch Included Seawall	Sketch Did Not Include Seawall
Number of Observations	166	77	89	62	104
Size of Area Sketched (km^2)	3.30	3.60	3.04	6.78**	1.22**
FEMA CAI	0.24	0.25	0.23	0.37**	0.16**
FloodRISE CAI	0.17	0.16	0.17	0.25**	0.12**

4.3. Post-flood hazard map exposure – self-rated spatial flood risk awareness

We found that factors influencing one's spatial awareness of flood risk to be very different before and after viewing flood hazard distribution maps. Specifically, upon viewing the flood hazard maps based on either the FEMA or FloodRISE model, we found that one's proximity to seawall has no significant influence on individuals' self-rated awareness (Table 1.3, Model 1). Moreover, an unexpected finding is that data resolution (i.e. finer spatial resolution and depth information provided by the two-dimensional FloodRISE model) has a positive effect on self-rated spatial flood risk awareness, since our results show that those who viewed the FloodRISE model estimate rated their awareness significantly higher than those who viewed the FEMA model estimate (Table 1.3, Model 2).

When taking into account additional geographical variables such as one's place of residence, one's location within flood prone areas according to the FEMA or the FloodRISE model, elevation, and one’s distance from the ocean, only the data resolution variable (i.e. whether one viewed the FEMA as opposed to the FloodRISE flood hazard map) has a significant impact on one’s awareness of flood risk (Table 1.3, Model 2).

Variables such as place of residence and elevation, which had significant influence on flood awareness prior to viewing either of the flood hazard maps no longer have significant impact under this condition. By including other relevant social factors into the full regression model (Table 1.3, Model 3), we found a very different set of factors influencing one’s risk awareness after exposure to objective flood hazard information compared to before exposure (i.e. informational factor). In particular, we found that data resolution, previous experience with floods, and one’s place of residence all have positive relationships with flood awareness, while interestingly, one’s average trust in government has an inverse relationship with awareness (Table 1.3, Model 3). In other words, individuals who place more trust in government are likely to consider themselves to have lower spatial flood risk awareness after seeing the flood hazard maps. Lastly, similar to the findings from the pre-flood hazard map exposure portion of the study, one’s awareness of local flood defenses and one’s sense of security given those defenses did not significantly impact flood risk awareness nor change the effects of other variables in the model (Table 1.3, Model 4).

5. DISCUSSION

Similar to previous studies on the levee effect, this study considered the social and hydrological dimensions of human flood risk awareness and human adjustments through the lens of what may be termed a “process socio-hydrology” study (Sivapalan et al., 2012). In short, this study investigated “a small number of human-water systems in more detail, including routine monitoring, to gain more detailed insights into causal relationships” between hydrological

Table 1.3: Regression analysis of factors predicting respondent's spatial flood risk awareness after exposure to flood hazard maps.

	Model 1	**Model 2**	**Model 3**	**Model 4**
Within 100 feet of Seawall				
Yes	0.19	0.06	0.23	0.20
No	Ref. Category	Ref. Category	Ref. Category	Ref. Category
Aware of flood defenses				
Yes				0.36
No/Not sure				Ref. Category
Feel secure given flood defenses				0.03
Informational Factor				
Objective Estimate Shown				
FloodRISE		0.42*	0.45*	0.44*
FEMA		Ref. Category	Ref. Category	Ref. Category
Geographical Factors				
Place of Residence				
Balboa		-0.02	0.60	0.58
Lido		0.72	1.12*	1.15*
Upper Peninsula		-0.02	0.45	0.58*
Lower Peninsula		Ref. Category	Ref. Category	Ref. Category
In FEMA floodplain				
Yes		0.25	0.07	0.07
No		Ref. Category	Ref. Category	Ref. Category
In FloodRISE floodplain				
Yes		0.08	0.01	0.02
No		Ref. Category	Ref. Category	Ref. Category
Distance to Coast		-0.001	0.002	0.002
Elevation of Residence		-0.06	-0.04	-0.03
Social Factors				
Experience with Flooding				
Yes			0.36**	0.35*
No			Ref. Category	Ref. Category
Age			0.01	0.002
Gender				
Female			0.08	0.10
Male			Ref. Category	Ref. Category
Education				
Less than Bachelor's Degree			Ref. Category	Ref. Category
Bachelor's Degree or Higher			0.17	0.16
Average Annual Income[6]			0.09	0.09
Homeowner				
Yes			0.07	0.04
No			Ref. Category	Ref. Category
Average Risk Perception			0.02	0.04
Average Trust in Government			-0.18*	-0.17*
Model Statistics				
Number of Observations	173	167	126	126
Adjusted R^2	0.001	0.03	0.15	0.17

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[6] Coded as ordinal values with a range of 1 to 4, where 1 is Lo ($42,500 or less), 2 is Mid (More than $42,500, but $87,500 or less), 3 is Hi (More than $87,500, but $175,000 or less), and 4 is Very Hi (More than $175,000).

and sociological processes (Sivapalan et al., 2012, p. 1275). Unlike previous engineering studies that investigated how levees affected floodplains or how seawalls affected coastlines, we analyzed a variety of local residents' geographical and social characteristics as well as informational conditions in order to gain a deeper understanding of how seawalls interact with other factors to impact flood awareness. This section will explore the implications that the findings of this study have for future research in the fields of socio-hydrology and disaster studies, and for decision makers seeking to enhance their constituents' spatial flood risk awareness.

In sum, the most significant conclusions of our study are as follows:

First, there is a need to move beyond the levee effect or seawall effect, particularly for areas with aging flood defenses with limited effectiveness. In other words, although it may seem logical to conclude that flood defenses can instill a false sense of security among local communities, the hydrological impact and effectiveness of levees and seawalls may vary depending on their age and condition, while the unique social, economic, and political contexts of different communities may attenuate or amplify the sense of security and spatial flood risk awareness associated with the presence of these flood defenses. Therefore, rather than accepting the levee effect or the seawall effect as a foregone conclusion, it is imperative for future empirical studies to test and elucidate the processes in which different social, geographical, and informational factors interact with flood defenses to influence one's spatial flood risk awareness.

By looking at the result of our bivariate analysis (Table 1.1, Model 1), a plausible explanation for the higher awareness reported among residents living close to the seawall is that the limited effectiveness of the seawall may have resulted in flood events that increased one's awareness of local flood risk. However, the fact that neither one's awareness of flood defenses nor one’s sense of security given the presence of flood defenses (a proxy variable for one’s trust in the effectiveness of flood defense) has a significant impact (Table 1.1, Model 4) suggests that one’s spatial flood risk awareness is not related to one’s distance from, one’s awareness of, or one’s trust in flood defenses. Instead, when the flood defense related variables were analyzed in conjunction with other variables that have been shown (by previous studies) to influence flood awareness (Table 1.1, Model 2-4; Table 1.3, Model 2-4), flood defense related variables consistently have no significant impact on flood awareness whether before or after one was exposed to flood visualizations. Thus, in addition to modeling the feedback between hydrological and social variables, our findings suggest that more process-based empirical case studies such as this one is needed to reexamine and clarify how flood defenses interact with social, informational, and geographical factors to influence spatial flood risk awareness.

Second, of the variables related to flood defense as well as the social and geographical variables examined, this study showed that variables which influence one’s self-rated awareness of flood risk may be dramatically different before and after exposure to flood hazard maps. Our findings indicate that exposure to information (i.e. informational factor) can change the relationship between spatial flood risk awareness and various geographical and social factors – a key lessons of the present study. In particular, prior to seeing the flood hazard maps, one’s self-rated flood awareness is predicted to increase with an increase in one’s age and one’s nonspatial perception of flood risk. These findings are in alignment with previous studies on flood risk awareness, where Kellens et al. (2011) found that individuals who are older have higher perceived level of coastal flood risk, and O’Neill et al. (2016) and Botzen (2009) have found that flood awareness is related to flood perception. While prior studies such as Wachinger and Renn (2010) and Burningham et al. (2008) have found that individuals with prior flood experience reported significantly greater awareness of flood risk, our results indicated that prior flood experience along with variables such as place of residence and average trust in government only significantly impacted flood awareness after one has been exposed to flood hazard maps.

In addition, a collateral finding of this study is that individuals who were exposed to flood model estimates that are of higher spatial resolution with information on water depths (i.e. FloodRISE estimate) tend to report higher awareness of flood risk. Previous research in landscape visualizations have suggested that the realistic depiction of natural hazards in a personally meaningful way can have positive cognitive, affective, and behavioral impacts on the users (Sheppard, 2005). This led us to hypothesize that the higher awareness among viewers of the FloodRISE flood hazard map (relative to the FEMA flood hazards map) is partly a result of the maps' ability to convey street-level details needed to inform mitigation behaviors. However, further studies are needed to examine the utility and resonance of high resolution flood hazards maps for different stakeholder groups, and how they influence one's spatial flood risk awareness.

Lastly, it is particularly interesting to note that as one's self-rated average trust in government increases, one's self-rated spatial awareness of flood risk decreases. This can be attributed to two potential phenomena. The first explanation has been analyzed in previous studies, where individuals who believe in the government's capacity to provide adequate flood protection for its citizens may see little need to be personally aware of their flood risk or to take personal responsibility for it (Pielke, 1999; Terpstra et al., 2009; Hung, 2009). A second explanation is what we called the "erosion in trust" hypothesis, where respondents may initially regard the government as trustworthy and responsible for public safety by only permitting development in safe areas. However, upon viewing the scientific estimates of flood hazards, these individuals quickly realized that there are significant developments in flood prone areas despite their trust in government to regulate against such behaviors. This caused individuals to realize and acknowledge that they may not be as aware of flood hazards as they once thought, thus prompting them to rate their flood awareness as low after viewing the flood hazard maps. However, further studies are needed in order to investigate the inverse relationship between trust in government and flood awareness, which only came about after exposure to flood hazard maps.

In sum, this study contributed to the fields of socio-hydrology and disaster studies by showing that local flood defenses can have unexpected impacts on individuals' spatial flood risk awareness in different social, geographical, and informational contexts. Specifically, while previous studies suggested that the construction of federally certified 100-year flood levees can instill a false sense of security and decrease individual flood awareness, this study demonstrated that local flood defenses that are not federally certified do not necessarily have the same effect. Specifically, since history has shown that many local flood defenses may be more prone to failure than federally certified flood defenses (Tobin, 1995), this study showed that proximity to older, vulnerable seawalls (when considered in isolation of social, geographical, and information factors) is actually associated with a heightened sense of flood awareness, possibly because these seawalls serve as a visual reminder of the threat of flooding. Moreover, these seawalls' failures due to disrepair or sea level rise may serve to remind inhabitants about the residual risk of flooding, thus reducing the cognitive biases and the potential for surprise in flood risk management (Merz et al., 2015).

5.1 What is the policy significance of these findings?

First, we are not advocating for the government or the U.S. Army Corps of Engineers to stop seawall construction or upkeep. Rather, the findings from this study suggest that local communities and decision makers may wish to consider the unintended consequences of new flood defense construction or upgrades. Given that the flood defenses considered in this study are limited to locally maintained structures that are not federally certified much like the majority of the flood defenses in the U.S. (Tobin, 1995), it is conceivable that an upgrade of the existing seawall at Newport Beach to meet the federal 100-year flood certification standard may inadvertently introduce a false sense of security among the local population as described by previous studies on the levee effect. Second, since properties that are protected by federally certified flood defenses within the floodplain are not required to purchase flood insurance nor provide home buyers with flood risk disclosure (Ludy & Kondolf, 2012), another unintended consequence of flood defense upgrade or construction is the reduction of flood awareness among new residents who may not even know that their properties are in a flood-prone area. Both of these reasons point to the need for flood defense upgrades or construction to be accompanied by outreach campaigns to target specific populations (e.g. new residents) that may be prone to cognitive biases, thus reducing the "potential for surprises and devastating consequences." (Parker et al., 2009; Merz et al., 2015, p. 1)

5.2 Future research

Future research should consider implementing longitudinal studies that assess one's spatial flood risk awareness over time. These studies can provide additional insights on the interactions between natural and social system components, validate the results from previous socio-hydrological modeling studies (Viglione et al., 2014; Di Baldassarre et al., 2013), and investigate how changes in natural environment (e.g. sea level rise) influence flood awareness over time. This will surmount a shortcoming in previous studies, where risk taking attitudes and trust were assumed to remain stationary over time despite changes in the natural environment, which may interact with psychological, social, institutional, and cultural factors in ways to amplify public responses to flood risk (Kasperson, 1988). Based on the social amplification of risk framework introduced by Kasperson (1988), we argue that the relationship between flood damages, flood protection levels, and flood awareness is not as predictable as some socio-hydrological models may suggest. In particular, the social amplification of risk framework has shown that even minor events (e.g. nuisance flooding) can lead to significant changes in awareness or responses if the risk signal (e.g. news report on the event) is amplified by individuals, social groups, or the media. Thus, future modeling studies in socio-hydrology must not assume that social processes like attitudes and trust will remain stationary over extended periods of time. Rather, researchers should be prepared to control for intrinsic threats to internal validity (i.e. history, maturation) through the use of control groups in longitudinal studies (Nachmias & Nachmias, 2000).

Finally, previous research has already shown that flood defenses like levees and seawalls can alter regional hydrology, but future socio-hydrological research may want to pay more attention to how specific flood defense characteristics such as condition, effectiveness, cost, and ownership of flood defenses, interact with social, geographical, and informational factors to influence flood awareness. Additionally, future socio-hydrological research should justify the scale and extent of its study area. Specifically, rather than solely focusing on the hydrological and social impacts that flood defenses have on the settlement where the structures are located, settlements adjacent to and downstream of the structures may be adversely affected (Heine & Pinter, 2012), and should also be considered and modeled. It follows from this last point that effective flood management requires coordination at the watershed or river basin level, because "no flood-vulnerable community can effectively address its flood problem without having its response affect other communities both up and down stream" (Pielke, 1999, p. 432). Only by considering the disparate impacts of flood defenses on different populations and incorporating their responses in the feedback can we hope to arrive at a socially optimal solution for flood risk management.

6. CONCLUSION

While social scientists traditionally focus on the psychological and economic consequences of flooding and the vulnerability of institutions, natural scientists are mostly concerned with the probability and magnitude of hazards (Di Baldassarre et al., 2013; Spiekermann et al., 2015). The advent of the science of socio-hydrology integrated the social and natural science perspectives, and promoted the transdisciplinary study of the physical and social dimensions of flooding. Instead of treating social processes and human activities in the floodplain as a boundary condition, socio-hydrology recognizes social processes as an intrinsic part of the hydrologic cycle, and acknowledges the complex feedback between various social and hydrological system components.

This case study examined the social, geographical, and informational components within the human social system, in relations to flood defenses that are known to alter regional hydrology. We found that vulnerable flood defenses (i.e. seawalls) that are prone to overtopping with a limited useful life left did not necessarily decrease individuals' flood awareness as predicted by the levee effect literature. Moreover, by considering other components within the human social system (e.g. age, perception, trust), we found that one's proximity to seawalls had minimal impact on individuals' spatial flood risk awareness. Additionally, we also found that the social and geographical drivers of spatial flood risk awareness can change significantly before and after one is exposed to flood hazard information. All of these findings highlight the importance of studying and understanding the mechanisms in which one's flood awareness may be modified in different contexts, as flood defenses may interact with different social, geographical, and informational process components to shape one's spatial flood risk awareness.

While enhancing the spatial awareness of flood hazards is one of the key steps in reducing vulnerability to flood risk, promoting self-protective behaviors, and creating more flood resilient communities (Zein, 2010; Chap & Smith, 2015; Fuchs et al., 2011; Kellens et al., 2011; Grothmann & Reusswig, 2006; Burningham et al., 2008; Ludy & Kondolf, 2012; O'Neill et al., 2016; Paton, 2003), "in order to raise awareness of a particular risk within a community, it is necessary to consider many of the specific social, cultural and psychological issues that are present within it" (Homan, 2001, p.15; Spiekermann et al., 2015). Our study showed that not only can spatial flood risk awareness be influenced by social, geographical, and informational factors, but key drivers of flood awareness can change over time. Thus, future socio-hydrological studies should be validated by empirical case studies that can reveal latent feedbacks between hydrological and social system components. Moreover, the scale of future research must be carefully considered since the hydrological impacts of flood defense renovation and construction can shift the distribution of risk. By carefully considering the mechanisms and processes in which spatial flood risk awareness can be modified, we can better ensure that the costs and benefits of flood management are equitably allocated among different populations.

Integrating resident digital sketch maps with expert knowledge to assess spatial knowledge of flood risk: A case study of participatory mapping in Newport Beach, California

ABSTRACT

Public participation geographic information systems (PPGIS) have been increasingly used to study residents' spatial knowledge of environmental hazards and to validate and supplement expert estimates of hazardous areas with local knowledge, but few studies have demonstrated methods for directly comparing local and expert knowledge of the spatial distribution of hazards. This study collected PPGIS digital sketch maps of flood-prone areas from 166 residents living adjacent to the Newport Bay Estuary in Southern California to examine variations in spatial knowledge of flood risk. First, we assessed agreement among participants and found that residents of areas with a higher percentage of homeowner, older, and higher income residents had greater agreement regarding areas at risk of flooding. Second, we introduced composite indices to assess the agreement between participant sketches of flood-prone areas with modeled estimates of the distribution of flood hazards, and found that the level of agreement between local and expert knowledge varied by the scale of analysis and by personal and contextual factors. Respondents with higher educational attainment, household income, and homeownership were associated with greater agreement between resident sketch maps and expert estimates of hazardous areas. Results inform spatial aspects of flood risk management by demonstrating how digital sketch maps can be used to identify potential shortcomings of expert hazard models, as well as hazardous areas where resident risk perception may be weak.

1. INTRODUCTION

Sketch maps have been increasingly used in conjunction with digital mapping tools in environmental hazard research to characterize spatial awareness of environmental risk and to validate and supplement expert estimates of hazardous areas with local knowledge (O'Neill, Brennan, Brereton, & Shahumyan, 2015). This approach builds on the cognitive mapping research by geographers, urban designers, and environmental psychologists, who used sketches or maps to provide important insights regarding how individuals perceive and orient themselves to their environment, and how such spatial perceptions are influenced by age, gender, economic class, familiarity, and physical dimensions (Appleyard, 1981; Golledge, 2008; Kitchin, 1994; Lynch, 1960). Sketch maps have also been used to help delineate neighborhood boundaries and perceptions of place (Coulton, Korbin, Chan, & Su, 2001; Haney & Knowles, 1978), assess spatial aspects of crime perception and fear (Curtis et al., 2014), and understand variations in spatial knowledge by travel mode (Mondschein, Blumenberg, & Taylor, 2010).

Although early studies required participants to sketch maps of their perceptions in a free-form fashion using a blank sheet of paper or on a hardcopy base map, in recent years sketch maps have been integrated with and analyzed using Geographic Information Systems (GIS). Researchers often digitize participant hardcopy sketch maps into GIS or have participants draw sketches and/or record spatial data directly into GIS using web-based tools which enable interactive and dynamic mapping (Brown & Kyttä, 2014; Cadag & Gaillard, 2012; Curtis, 2012). This shift has given rise to the field of public participation GIS (PPGIS), which engages non-experts using mapping technologies to identify spatial aspects of social and ecological problems (Brown & Kyttä, 2014; Elwood, 2006). PPGIS has been used as a decision support tool in the fields of agricultural systems (Debolini, Marraccini, Rizzo, Galli, & Bonari, 2013), coastal ecosystem management (Levine & Feinholz, 2014), and urban forest and greenspace management (Hawthorne et al., 2015).

A few environmental hazard studies have used participatory data collection integrating paper sketch maps and/or PPGIS to characterize spatial awareness of environmental risk, and to integrate local and non-expert knowledge into decision-making processes. Assessing resident spatial awareness and knowledge of hazards and hazardous areas is particularly important because it could improve our understanding of individual actions and decisions prior to and during a disaster event, inform public debate about flood risk management, help identify areas where public perceptions or science-based assessments might be weak, and contribute to research on how risk perception might affect variables such as mental health or policy support (Blum, Silver, & Poulin, 2014). Moreover, given the prohibitive cost associated with hiring professional engineers to develop products such as fine resolution flood models, alternative tools such as PPGIS can be used to create cost effective preliminary flood hazard assessments that can be widely disseminated. Sketch maps and/or PPGIS have been used to collect information on spatial awareness of natural hazards including riverine flooding (Brilly & Polic, 2005; Hung & Chen, 2013) and volcanic hazards (Gaillard, 2008; Leone & Lesales, 2009). These studies compared spatial knowledge and risk perception across different respondents to support planning and decision-making, but they did not quantify the level of spatial agreement between sketch maps and official warnings systems or scientific forecasts.

A handful of studies have compared non-expert spatial environmental knowledge collected through sketch maps and/or PPGIS with knowledge from official hazard designations or historic impact zones to support decision-making. In the area of conservation planning, Brown (2012) found an error rate of only about 6% when comparing participant PPGIS locations of native vegetation to official land cover data, and Brown et al. (2015) found that over 70% of PPGIS points identified as having biological/conservation value were aligned with modeled areas of high conservation importance. In the area of spatial awareness of flood risk, Ruin et al. (2007) asked 200 participants in Southern France to draw sketch maps of roads prone to flooding, and subsequently compared respondents' drawings with official sources. They found that motorists who traveled on short daily itineraries in close proximity to their residences had high flood risk perception. Pagneux et al. (2011) compared sketch maps of areas perceived to be at risk of flooding from 90 residents in Iceland with areas impacted by historic flood events, and found that spatial knowledge of the boundaries of previous inundations was very poor. O'Neill et al. (2015) collected sketch maps of areas vulnerable to inundation during a severe flood event from 305 participants in Ireland, and found significant deviations between the participant risk perceptions and the extent of a historic major flood.

Our research investigates the application of digital sketch maps of flood-prone areas collected from 166 residents living adjacent to the Newport Bay Estuary in Southern California as a potential decision support tool given increasing flood hazard in coastal areas due to climate extremes, extensive urban development, and sea level rise (Burby, 2002). This study has two objectives: (1) to assess the level of agreement among participants with regards to their perceptions of areas vulnerable to flooding, and (2) to assess the level of agreement between participant sketches of flood-prone areas with modeled estimates of the distribution of flood hazards. It contributes to the geography and environmental hazard literatures, as well as advances disaster response planning. First, given the limitations of flood hazard models (Gallien, Sanders, & Flick, 2014; Thompson & Frazier, 2014), it demonstrates how local knowledge of hazards could help validate and inform expert models by identifying potential model shortcomings and hazardous areas that may have been overlooked by the models. Second, it demonstrates how digital sketch maps can be used to identify hazardous areas where resident risk perception may be weak, and to inform spatial aspects of flood risk planning and communication.

2. METHODS

2.1 Study area

This study focused on the highly urbanized low-lying coastal lowlands of the Newport Bay Estuary within the City of Newport Beach, California (Figure 2.1), and is part of the Flood Resilient Infrastructure and Sustainable Environments (FloodRISE) research project to promote resilience to coastal flooding in Southern California. The city encompasses Newport Harbor, which includes the constructed islands of Lido Isle and Balboa Island, and the urban coastal lowlands of Balboa Peninsula. Large portions of the city are below extreme high tide levels, and one study estimates that four decades of sea level rise could transform the present 100-year flood event along this coast into an annual occurrence (Gallien et al., 2014; Tebaldi, Strauss, & Zervas, 2012).

2.2 Modeled estimates of the distribution of flood hazards

Our analysis incorporates two modeled estimates of the distribution of flood hazard in the study area: (1) 2009 areas predicted by FEMA (Federal Emergency Management Agency) to flood from an event with a 1% annual chance (100-year flood), and (2) 2014 areas predicted by our street-level FloodRISE model to flood from an event with a 1% annual exceedance probability (100-year flood). The FEMA flood hazard mapping approach for the Newport Beach site involved one-dimensional hydrologic analysis of ocean water levels considering storm surge, waves, and wave runup followed by mapping stillwater flood elevations along the coastline and urbanized embayment by applying an equilibrium mapping approach (Gallien, Schubert, & Sanders, 2011; National Research Council, 2009). FEMA flood hazard maps are used by lenders during real estate transactions, federal and state agencies, and the National Flood Insurance Program to determine whether a property is inside a Special Flood Hazard Area.

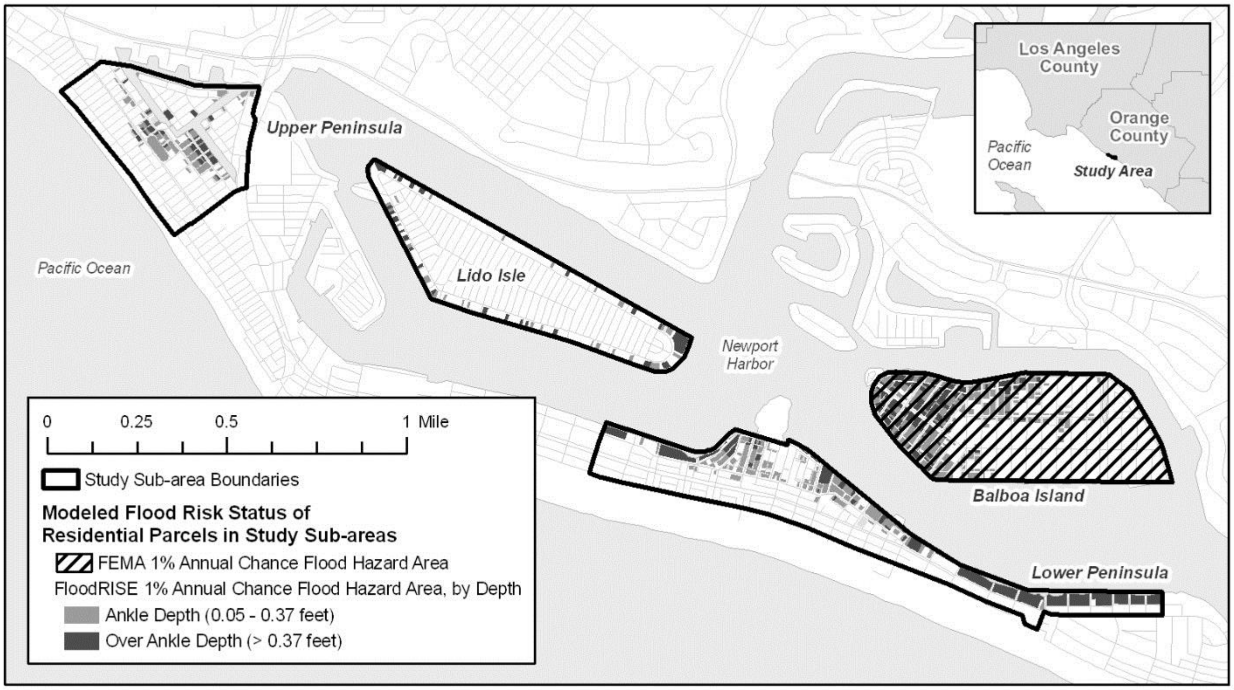


Figure 2.1. Study sampling areas and modeled flood hazard estimates

The FloodRISE model is a two-dimensional hydraulic model that was developed at the University of California, Irvine, and has been used in this project for flood hazard mapping in Newport Beach, California. The model relies on an unstructured grid of triangles, which can be locally refined for accurate topographic representation of the site's terrain and infrastructure geometries, such as streets and flood defenses. The model is also able to account for a wide range of flow regimes resulting from abrupt changes in topography like those caused by flood walls. The model has been previously validated for the modeling of stormtides and wave overtopping in Newport Beach (Gallien et al., 2014; Gallien et al., 2011).

Results of our quantitative comparison of resident digital sketch maps with each of the two modeled hazard estimates (i.e. FEMA, FloodRISE) could differ substantially since the predicted distributions of impacts are substantially different between the models. For example, although the FEMA model indicates all of Balboa Island is at risk, the FloodRISE model provides a more spatially refined street level estimate of at-risk areas and indicates that only some areas on the western portion of Balboa Island, the bayside of the Lower Peninsula sub-area, and portions of the Upper Peninsula sub-area are at risk (Figure 2.1). Given that the FloodRISE model is more spatially refined, incorporates finer resolution topographic datasets, and accounts for coastal flood defenses, it could more accurately reflect local conditions and correspond with local knowledge. Residents may be more familiar, however, with the flood hazard designations by FEMA given these data are used by federal and state agencies, and are revealed as part of real estate transactions.

2.3 Survey design

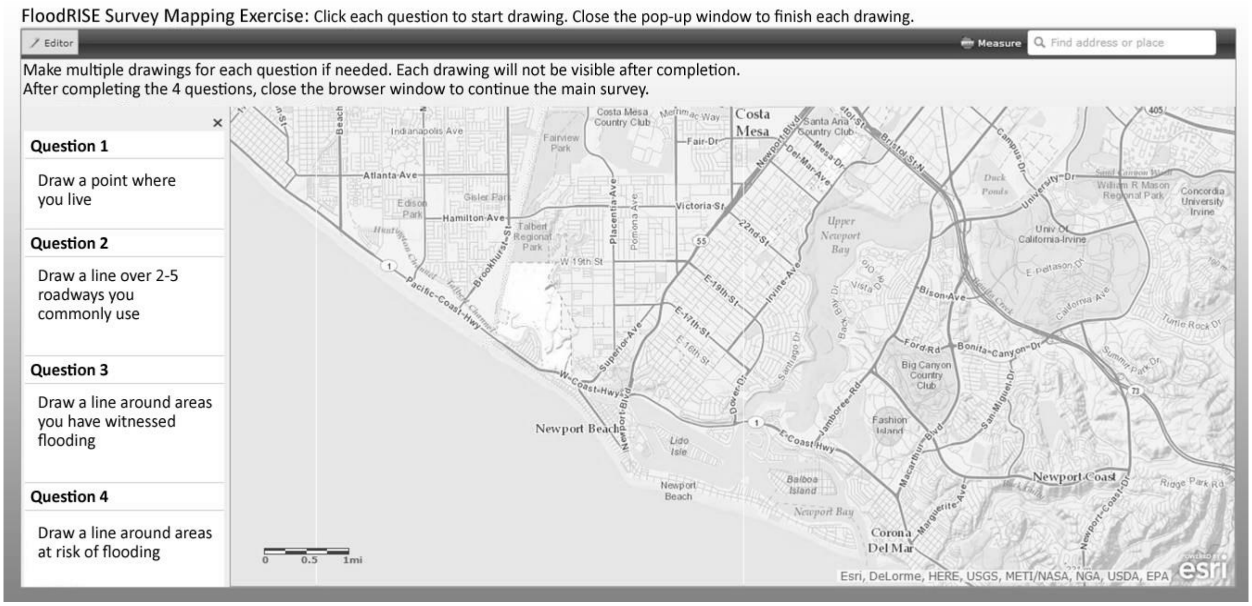
Based on the distribution of residential parcels as well as the FEMA and FloodRISE estimates of areas at risk of flooding, the study area in Newport Beach was divided into four study sub-areas: Upper Peninsula, Lido Isle, Lower Peninsula, and Balboa Island (Figure 2.1). These sub-areas were delineated to contain a comparable amount of residential addresses and parcels within and outside of the areas designated to be at risk by the models. About 25-40% of each sub-area’s parcels are residential parcels that FEMA and/or FloodRISE models suggest could experience future flooding. Two island and two peninsula sub-areas were chosen based on the hypothesis that these areas could potentially have different experiences with flooding. The sub-areas each include about 33-50% multi-family residential parcels (remaining residential parcels are single-family residential).

We stratified our sample of parcels in an effort to gather an equal number of responses from island sub-areas and peninsula sub-areas, and within each of these sub-areas we stratified the sample further to obtain comparable responses from each of the following categories of parcels based on modeled flood hazard classifications: (1) those outside of both the FEMA and FloodRISE impacted areas, (2) those within the FEMA impacted area but outside the FloodRISE impacted area, (3) those outside the FEMA impacted area but within the FloodRISE impacted area, and (4) those inside both the FEMA and FloodRISE impacted areas. Although we initially sought to obtain a random sample of residents, we ultimately implemented quota sampling in order to obtain enough respondents in each of these four categories. To this end, in island sub-areas we oversampled parcels in category #3 and #4, whereas in peninsula sub-areas we oversampled parcels in categories #2. For island sub-areas we had a response rate of 7.5% resulting in 90 overall respondents. For peninsula sub-areas we had a response rate of 8.4% resulting in 102 respondents. Due to low response rates, we used limited snowball sampling in order to enhance our sample. We added 7 residents from the island areas and 15 residents from the peninsula areas to the sample based on snowball sampling, resulting in a total sample of 214 respondents. Although our final sample was not truly random, our survey provides valuable insights for understanding factors associated with spatial knowledge of flood hazards. Our final analysis sample for the current sketch map analysis included 166 survey participants (75 island residents and 91 peninsula residents) who provided complete responses for key questions regarding personal and household characteristics and the sketch mapping exercise. Specifically, the sample was reduced from 214 responses to 166 responses due to missing values caused by technical challenges (e.g. overheating of tablet units, program crashes, dead batteries) and/or data entry errors (e.g. entry of invalid respondent ID).

We sent a pre-notice letter to sampled households which described the purpose of the study and survey procedures, indicated the general time period when the survey team planned to visit the household's neighborhood to conduct surveys. During April, May and June in 2014, survey teams visited sampled households and knocked on participant doors or rang doorbells and invited a head of household who was 18 years or older to participate. Potential respondents could choose to complete the survey at that time, schedule a subsequent time the team could visit to complete the survey, or refuse to participate. Surveys lasted approximately 40 to 60 minutes.

During the mapping exercise each participant was asked to sketch areas that he/she considered to be at risk of flooding on a tablet computer. Rather than requesting participants to cognitively map out their neighborhoods or its hazards on a blank piece of paper without predetermined geographic reference points as was done by Lynch (1960) or Brilly and Polic (2005), we followed Bell's (2002) recommendation to provide all participants with familiar pre-determined mapping control points and geographic boundaries within which they can sketch their perception and knowledge. Specifically, we provided respondents with an interactive map showing the study area boundary, major roads, and landmarks, and then asked them to sketch areas that were prone to flooding (Figure 2.2). Unlike previous studies in which participants entered responses using a hardcopy map at a static scale, our use of tablet devices enabled participants to interactively adjust the level of details (e.g. zoom in/out, pan) in the map as they sketched flood-hazard areas. Participant sketch maps were stored digitally in the ArcGIS Online cloud, and downloaded, processed, and analyzed using the ArcGIS Desktop software. Portions of participant sketch maps that were outside of the pre-defined study area were excluded for the purpose of analysis.

We also collected supplemental survey data about residents' risk, informational, personal, and contextual factors, which have been examined by previous studies on flood risk perception (Grothmann & Reusswig, 2006). Given the influence of personal and contextual factors on an individual's risk perception is not consistent across the literature (Wachinger et al., 2013), we collected information on personal factors including age, gender, flood knowledge, and experience, and information on contextual factors including home ownership, areas of living, and closeness to waterfront.



FloodRISE Survey Mapping Exercise: Click each question to start drawing. Close the pop-up window to finish each drawing.

Make multiple drawings for each question if needed. Each drawing will not be visible after completion.
After completing the 4 questions, close the browser window to continue the main survey.

Question 1

Draw a point where you live

Question 2

Draw a line over 2-5 roadways you commonly use

Question 3

Draw a line around areas you have witnessed flooding

Question 4

Draw a line around areas at risk of flooding

Figure 2.2. Survey tablet computer sketch mapping interface

2.4 Agreement among participant sketch maps of flood hazards

In order to quantify the extent of agreement between our respondents' sketches, digital sketch map responses were combined, and vulnerable areas commonly sketched by different respondents were identified. We assessed agreement both for the study areas as a whole and for individual sub-areas since previous research cautioned that results of spatial analysis could vary depending on the level of aggregation used (Brilly & Polic, 2005; Hipp, 2007; Houston, 2014; Wong, 2009). To our knowledge, there is no universal approach for categorizing space based on sketch maps responses. Thus, we categorized the study area based on level of agreement quartiles, where areas included in 76%-100% of the sketches of flood-prone areas were considered areas of high agreement. Areas that were included in only 0%-25% of respondent sketches were considered areas of low agreement. Given previous research indicates that contextual factors such as place of residence may influence one's perception of flood risk (Wachinger et al., 2013), and one is likely to be most familiar with flood hazards in his/her immediate neighborhood (Brilly & Polic, 2005), we hypothesized that respondents from a particular sub-area will have high level of agreement with each other over the distribution of flood hazards within the sub-area in which they reside.

2.5 Agreement between participant sketch maps and modeled distributions

We developed three spatial alignment indices to assess and quantify the agreement (or alignment) between participant sketches of flood-vulnerable areas and modeled estimates of the distribution of flood hazards. In contrast to previous studies, our comparisons did not privilege one set of data as the gold standard against which local PPGIS knowledge should be compared. Instead, we assume that both modeled distributions of flood hazards and resident sketch maps provide important insights into the location of potential hazards. By understanding the causes of agreement (or lack of agreement) between expert models and resident sketch maps, we can provide the basis for future deliberation among residents, public officials, and emergency responders that supports greater integration of local and expert knowledge in our understanding, preparation for, and response to flood hazards.

Our spatial alignment indices were developed for each participant based on whether the respondent's sketch of hazardous areas overlapped with modeled estimates of hazardous areas (Table 2.1). They were developed by designating three types of areas: (1) Alignment (A) areas, which are areas estimated to be hazardous by both participant sketches *and* the models, (2) Sketch Miss (SM) areas, which are areas estimated to be hazardous by the models but not by participant sketches, and (3) Model Miss (MM) areas, which are areas estimated to be hazardous by participant sketches but not by the models.

Table 2.1. Components used to derive spatial indices to compare sketches with models

		Respondent sketched/perceived area at risk of flooding	
		Yes	**No**
Models indicated area at risk of flooding	**Yes**	Alignment (A)	Sketch Miss (SM)
	No	Model Miss (MM)	True Null

The Sketch Alignment with Model (SAM) index is the proportion of all areas estimated to be hazardous by the models (A+SM) that were also identified as hazardous by a participant (A), and can be represented by this equation: SAM=A/(A+SM). The Model Alignment with Sketches (MAS) index is the proportion of all areas estimated to be hazardous by participant sketches (A+MM) that were also identified as hazardous by the models (A), and can be represented by this equation: MAS=A/(A+MM). The Composite Alignment Index (CAI) provides a more integrative perspective on spatial alignment, represents the proportion of the total areas estimated to be hazardous by participant sketches *or* the models (A+SM+MM) that was estimated to be hazardous by both participant sketches *and* the models (A), and can be represented by this equation: CAI=A/(A+SM+MM). The value for these indices ranges from 0 to 1, where 0 indicates there was no spatial alignment in the hazardous areas estimated by the participant sketch and the models, and 1 indicates there was complete alignment in the hazardous areas estimated by the participant sketch and the models. Each index was calculated separately for the FEMA and FloodRISE model estimates.

Our use of composite indices improves on the methods of previous studies which conducted basic spatial comparisons of agreement between flood sketches and models (O'Neill et al., 2015; Pagneux et al., 2011; Ruin et al., 2007) or the analysis of self-reported (non-spatial) rating of risk perception (Burningham, Fielding, & Thrush, 2008; Grothmann & Reusswig, 2006). Our approach builds on confusion matrix or contingency table measures commonly used in fields such as atmospheric science, GIS, and remote sensing (Aghakouchak & Mehran, 2013). It enables us to take into account multiple sources of discrepancies, and provides additional insights into respondent's flood risk perception.

After the SAM, MAS, and CAI indices were calculated by comparing respondents' sketches with the FEMA and FloodRISE model distributions, average index values were calculated by taking the mean of the index values for respondents who were grouped by the entire study area, individual sub-areas, FEMA designated 100-year floodplain, FloodRISE modeled high and low impact zones, and various social and demographic groups. The Student's t-test was conducted to compare the various groups' average index values with the overall study area average in order to see if each group's average index value differed significantly from the study area's overall average.

3. RESULTS

3.1 Participant characteristics by study sub-area

We analyzed responses from 166 survey participants who provided complete responses for the mapping exercise and key questions regarding personal and household characteristics and self-rated awareness of nearby areas at risk of flooding. The participants in our sample were similar to the overall study area population profile in the sense that they were older (median age of 58), had higher income (median income of $125,000), and were more educated (36% of respondents with graduate degrees or above) than the county's population. Results from t-test show differences across sub-areas. Namely, the Upper Peninsula study sub-area had significantly lower percentages of respondents who were homeowners, younger, lower income, and had a lower self-rated awareness of flood risk compared to the study area average. The Balboa Island sub-area had a significantly higher percentage of respondents who were homeowners, older, higher income, and had a higher self-rated awareness of flood risk.

3.2 Agreement among participant sketch maps of flood hazards

We overlaid all participant sketches of areas they perceived to be at risk of flooding, and classified portions of the study area based on the percentage of participants who indicated a given area was at risk of flooding (Figure 2.3). Visual analysis revealed that more than half of all participant sketches were in agreement that the southern portion of the Balboa Island sub-area was at risk, but less than one quarter of participant sketches were in agreement that the northern portion of the Upper Peninsula sub-area was at risk of flooding. Participant sketches revealed moderate agreement that the remainder of the study area was at risk.

Since previous studies support our hypothesis that contextual neighborhood factors such as one's area of living could influence one's perception of flood hazards, we examined the level of participant sketch map agreement separately for each of the study's sub-areas (Figure 2.3). Results indicate over 50% of sketches from Balboa Island sub-area residents agreed that Balboa Island was at risk, and over 50% of sketches from Lower Peninsula sub-area residents agreed that most of the Lower Peninsula was at risk. Over 50% of sketches from Lido Isle sub-area residents agreed that the northern shore of Lido Isle was at risk, and interestingly, they agreed

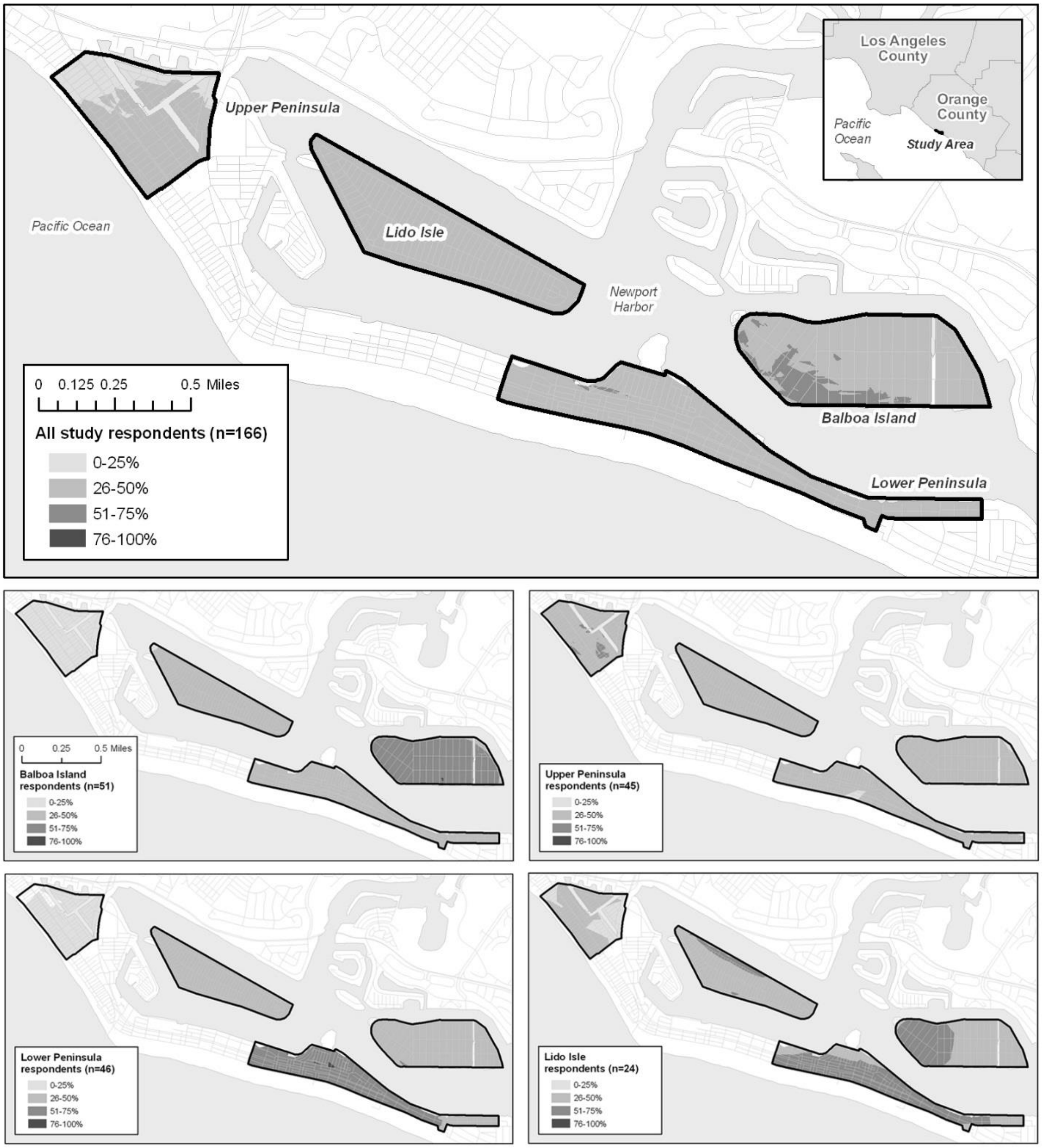


Figure 2.3. Percentage of residents who agreed particular areas were at risk of flooding

that the western portion of Balboa Island and most of the Lower Peninsula were at risk. Between 26-50% of sketches by participants from the Upper Peninsula sub-area indicated the entire study area was at risk of flooding, and unlike the other sub-areas, there was no majority consensus among Upper Peninsula residents (i.e. >50%) that the sub-area was at risk of flooding. This could reflect a low level of concern about flooding among Upper Peninsula residents, or this pattern could reflect that flood hazards identified by Upper Peninsula residents varies substantially.

The aggregated sketch maps for all study participants (Figure 2.3) did not consistently overlap with estimates of locations at risk of flooding identified by FEMA and FloodRISE models (Figure 2.1). The sketch maps for Balboa Island participants and FEMA estimates indicated that all of Balboa Island was at risk of flooding. Compared to the FloodRISE model, which indicated only the western half of Balboa Island was at risk, however, Balboa Island participant sketches could have overestimated hazardous areas. Although the sketch maps for Lower Peninsula residents were in agreement with FloodRISE estimates that the northern bay-side of the peninsula was at risk of flooding, sub-area sketch maps could have overestimated hazardous areas by indicating that the ocean-side of the peninsula (which models indicated were not at risk) was at risk of flooding.

3.3 Agreement between participant sketch maps and modeled distributions

3.3.1 Agreement by study sub-area

Given that aggregate participant sketch maps of hazardous areas diverge somewhat from estimates of hazardous areas identified by FEMA and FloodRISE models, we aggregated our respondent-level spatial alignment indices to examine differences between the average index value of survey participants from each sub-area and the average index value for all survey participants. All results discussed in this section were statistically significant. Indices comparing FEMA and sketch estimates of hazardous areas indicate that there was consistently higher alignment among Balboa Island participants compared to the entire study population (Table 2.2).

Their significantly higher SAM index (0.54 versus 0.42) indicates their sketches had higher alignment with FEMA model estimates compared to all study participants, and their higher MAS index (0.69 versus 0.39) indicates FEMA model results had higher alignment with their sketches. Balboa Island participants also had a significantly higher CAI index (0.34 versus 0.24), which provides a more integrative perspective of spatial alignment by comparing sketch areas to all areas designated as at risk by participants and the FEMA model. All three spatial alignment indices for Upper Peninsula participants were lower than those for all study participants combined, and the MAS index for Lower Peninsula participants was lower than that for all study participants combined.

The spatial alignment patterns when comparing FloodRISE and sketch map estimates by study sub-area were less distinct. Balboa Island participants had the highest MAS index (0.37) indicating that FloodRISE model results had higher alignment with their sketches; Lower Peninsula participants had the lowest MAS index (0.27) indicating that FloodRISE model results had lower alignment with their sketches. Upper Peninsula participants also had a lower CAI index than all study participants (0.13 versus 0.17).

Table 2.2: Agreement of flood prone areas by study sub-area: Participant sketch maps versus modeled distributions

	Comparison with FEMA Model					Comparison with FloodRISE Model				
	Entire Study Area	Balboa Island	Lido Isle	Upper Peninsula	Lower Peninsula	Entire Study Area	Balboa Island	Lido Isle	Upper Peninsula	Lower Peninsula
Total Participants	*166*	*51*	*24*	*45*	*46*	*166*	*51*	*24*	*45*	*46*
Sketch Alignment with Model: SAM=A/(A+SM)	0.42	0.54*	0.44	0.29*	0.39	0.40	0.43	0.46	0.33	0.41
Model Alignment with Sketch: MAS=A/(A+MM)	0.39	0.69**	0.30	0.23**	0.28**	0.31	0.37**	0.27	0.30	0.27*
Composite Alignment Index: CAI=A/(A+SM+MM)	0.24	0.34**	0.23	0.15**	0.20	0.17	0.18	0.18	0.13*	0.17

Significance indicates that the sub-area index average is significantly different from the overall study area’s average value.
Significance level based on a two-tail t-test: **p<0.01, *p<0.05

3.3.2 Agreement by residence flood hazard designation

All three indices comparing FEMA and sketch estimates of hazardous areas indicate that there was consistently higher alignment among participants residing in an area designated by FEMA as a floodplain compared to all study participants (Table 2.3). Although there was no statistically significant difference in these three mean index values between residents who resided in a lower impact FloodRISE-designated floodplain (risk of ankle depth flooding, 0.05-0.37 feet) and all participants, residents who resided in a higher impact FloodRISE-designated floodplain (risk of knee depth flooding, 0.37-1.48 feet) had significantly higher SAM index and MAS index. This respectively suggests that the sketch miss and model miss among participants in the high impact areas are smaller than all study participants. The only significant difference in the spatial alignment patterns when comparing FloodRISE and sketch estimates was that participants in a FEMA-designated floodplain had a statistically higher MAS index, which indicates that a higher percentage of hazardous areas identified by sketches of participants in these areas were also classified as hazardous by the FloodRISE model.

Table 2.3: Agreement of flood prone areas by modeled hazard designation: Participant sketch maps versus modeled distributions

	Comparison with FEMA Model				Comparison with FloodRISE Model			
	Entire Study Area	Within FEMA floodplain	Within FloodRISE low impact zone	Within FloodRISE high impact zone	Entire Study Area	Within FEMA floodplain	Within FloodRISE low impact zone	Within FloodRISE high impact zone
Total Participants	*166*	*53*	*30*	*20*	*166*	*53*	*30*	*20*
Sketch Alignment with Model: SAM=A/(A+SM)	0.42	0.54*	0.44	0.61*	0.40	0.43	0.43	0.51
Model Alignment with Sketch: MAS=A/(A+MM)	0.39	0.68**	0.43	0.55*	0.31	0.37**	0.33	0.30
Composite Alignment Index: CAI=A/(A+SM+MM)	0.24	0.34**	0.23	0.33	0.17	0.18	0.17	0.19

Significance indicates that the hazard zone's index average is significantly different from the overall study area's average value.
Significance level based on a two-tail t-test: **p<0.01, *p<0.05

3.3.3 Agreement by personal and household characteristics

We found no significant differences in the CAI index when comparing FEMA with sketch estimates of hazardous areas or the CAI index when comparing FloodRISE with sketch estimates of hazardous areas by gender, age, previous flood experience, self-rated flood awareness, length of home tenure, elevation of residence, and distance to the nearest water body (Table 2.4). Participants with higher educational attainment (a Bachelor's degree or higher), higher annual income (greater than $100,000), and participants who were homeowners had a statistically higher CAI average index when comparing FEMA with sketch estimates, but the CAI average index when comparing FloodRISE with sketch estimates is only significantly different for participants with higher educational attainment.

4. DISCUSSION

Our case study demonstrated how PPGIS digital sketch maps can provide valuable insights into the spatial knowledge of flood-prone communities. We found spatial knowledge of flood hazards varied substantially by the scale of analysis and by personal and contextual factors among residents living adjacent to a major coastal estuary in Southern California. Consistent with previous research indicating greater risk perception in areas of moderate or substantial flood hazard (Siegrist & Gutscher, 2008), we also found evidence that the sketch maps of residents living in areas at risk of higher-depth flooding had greater agreement with modeled hazard estimates.

Table 2.4. Analysis of Composite Alignment Index (CAI) by socio-demographics

Variable	Variable Categories	Average FEMA CAI	Statistical results FEMA	Average FloodRISE CAI	Statistical results FloodRISE	Conclusion
Gender	1=Female 0=Male	0.27 0.22	t = -1.26, p = 0.21	0.17 0.16	t = -0.28, p = 0.78	No relationship
Age	1= >= 65 years 0= <65 years	0.25 0.23	t = -0.38, p = 0.70	0.16 0.17	t = 0.93, p = 0.35	No relationship
Educational Attainment	1=Bachelor's degree or above 0=Less than bachelor's degree	0.26 0.14	t = -2.88, p = 0.0054	0.18 0.13	t = -2.83, p = 0.0063	Residents with higher educational attainment had higher CAI
Annual income	1= greater than $100,000 0= not greater than $100,000	0.27 0.19	t = -2.07, p = 0.04	0.18 0.15	t = -1.71, p = 0.09	Higher income participants had higher FEMA CAI No relationships with FloodRISE CAI
Flood experience	1=Has experience 0=No experience	0.20 0.26	t = 1.68, p = 0.10	0.16 0.17	t = 1.01, p = 0.31	No relationship
Self-rated flood awareness	1= Above slightly aware 0= Slightly aware or below	0.24 0.24	t = -0.20, p = 0.84	0.17 0.15	t = -0.82, p = 0.42	No relationship
Home ownership	1=Home owner 0=Not home owner	0.27 0.19	t = -2.19, p = 0.03	0.18 0.15	t = -1.77, p = 0.08	Homeowners had higher FEMA CAI No relationships with FloodRISE CAI
Length of home tenure	1= >= 10 years 0= < 10 years	0.23 0.24	t = 0.23, p = 0.82	0.16 0.17	t = 0.10, p = 0.92	No relationship
Elevation of residence	1=Elevation above 10 ft. 0=Elevation below 10 ft.	0.20 0.25	t = 1.24, p = 0.22	0.17 0.17	t = 0.0038, p = 1.00	No relationship
Distance, residence to water body	1=Within 100 meters 0= >100 meters	0.24 0.24	t = -0.05, p = 0.96	0.17 0.16	t = -0.41, p = 0.68	No relationship

Significance level based on a two-tail t-test.

We found that the CAI method was particularly informative because it takes into account alignment, sketch misses, and model misses in a single composite measure. This is important since we observed that the level of precision respondents used in creating their sketch maps varied. It is conceivable that a respondent who drew a small area as prone to flooding could receive a high MAS alignment score if the small area identified by the respondent's sketch was also identified as hazardous by the models. However, this participant would receive a low SAM alignment score since the sketch identified only a small portion of the overall area identified to be at risk by the models. For this reason, it is important to simultaneously account for alignment, sketch misses, and model misses using the CAI measure.

While this research produced important findings in the application of PPGIS and quantitative geography, there are some limitations to our study. Since study respondents were drawn from a nonrandom sample, and the studied community was comprised of relatively affluent and older residents who may be at relatively higher risk of flood hazards due to climate extremes, extensive urban development, and sea level rise, the findings from this study may not be generalizable to other communities that may have different socio-demographic composition or suffer from other forms of flooding (e.g. riverine flooding). In particular, less affluent communities may have fewer resources to cope with flooding, and could be more likely to deny flood hazards in order to minimize the cognitive dissonance created by the intractable hazard. The high population density and high degree of urbanization of the Newport Beach coastal community, however, is typical of many coastal settlements. Thus, our findings and proposed methodology might be transferable to coastal settlements with similar characteristics. Moreover, our study methods which value and integrate both expert and non-expert spatial knowledge could be useful in future assessments of flood hazards in disadvantaged and diverse communities.

In summary, we believe that our approach of valuing and integrating both expert and non-expert spatial knowledge in the assessment of flood hazards could foster greater collaboration between residents, public officials, and emergency responders, and could encourage a larger two-way communication process of flood hazard planning and communication between experts and non-experts. Integrating resident spatial knowledge using tools such as digital sketch maps could be particularly important because it could shape individual actions and decisions during a disaster event. The identification and understanding of discrepancies between expert and non-expert knowledge could not only inform the development of outreach strategies to build trust between experts and citizens, but could also reduce flood vulnerability by motivating individuals and communities to adopt self-protective measures against flood hazard.

Advancing flood risk communication through genuine engagement and collaboration: A flood visualizations experiment

ABSTRACT

Hazards and long-term impacts from flooding are increasing worldwide due to climate change and extensive coastal urban development. While scientists have advanced their modeling capacity, there is mounting evidence that the newfound forecast and modeling knowledge alone are inadequate to influence risk perception due to the public's inability to access or relate to these scientific products. This case study engaged three key stakeholder groups (city and emergency planners, home and business owners, civil society groups) from the coastal lowland City of Newport Beach (California) in focus group discussions, in order to understand how these groups negotiate their experience and understanding of flooding with six different types of flood visualizations produced by hydrological experts. We discussed key components of a genuine collaboration between experts and non-experts, and show how such collaboration can cogenerate recommendations for improving map contents and the depiction of hazards in flood visualizations. Specifically, we found that the genuine collaboration of experts and non-experts must include diverse viewpoints and values, and present scientific data in useful and relatable ways. By structuring collaboration around the democratic process criteria, we found a range of social and equity issues (e.g. information accessibility, risk to nonhuman ecosystems) that should be considered in the development of future flood visualizations, thus promoting opportunities for modifying risk perception, mitigating flood hazards, and minimizing flood vulnerability.

1. BACKGROUND

Flooding is a growing social, economic, political, and public safety concern in the United States and around the world. Whether caused by precipitation, high tides, sea level rise, storm surge, or a combination of those drivers, the impacts of floods are predicted to increase as population density in coastal shoreline counties continue to rise (Gallien et al., 2013; Di Baldassarre et al., 2015; Loucks, 2015; Helmer & Hilhorst, 2006; Warner & Ore, 2006; Newell et al., 2015; Hinkel et al., 2014; Jongman et al., 2014). Morrow et al. (2015) reported that the average density in coastal shoreline counties in the United States is 446 persons per square mile, while the density in other parts of the country is just 105 persons per square mile. Combined with the fact that sea levels in states such as California are projected to rise on the order of 1-1.3 m in the next century (Cayan et al., 2009), a number of studies examining tidal ranges (Flick et al., 2013), frequency of extreme events (Tebaldi et al., 2012), and nuisance flooding (Moftakhari et al., 2015) all agreed that the frequency of flooding is likely to increase, which portends an increased exposure to flooding as well as loss in life and property.

In light of the growing threat of flooding and the rapid pace of urbanization, it is imperative for coastal lowland urban communities to understand flood risk before and during flood events in order to mitigate potential impacts. “Although important technical advances have been made in the ability to characterize and quantify hydrometeorological forecast uncertainty, new tools are required to translate this information into clear and effective visualizations that might be easily communicated to decision makers and the general public at large” (Pappenberger, 201, p. 132; Dottori et al., 2013). However, as Thomalla et al. (2006) pointed out, even among experts (i.e. scientists and modelers), “there is an emerging perceived need to strengthen significantly collaboration and to facilitate learning and information exchange between them" (p. 39). Thus, as a first step in improving risk communication and mitigating flood risk, there is a need to promote the exchange of flood knowledge among experts as well as non-experts, in order to enhance the usefulness of flood visualizations to a wide range of audience.

For risk communication efforts, the effective translation of information on flood hazards requires carefully tailoring the message and its meaning to diverse decision-makers who have varied responsibilities, and to members of the public who have wide-ranging experiences with these hazards. This is especially important given that the Social Amplification of Risk Framework (SARF) (Kasperson et al., 1988) and previous studies on risk perception have suggested that social group memberships and affiliations can amplify or attenuate how one understands risk information (Champ & Smith, 2015; Terpstra et al., 2009). The SARF posits that the consequence associated with risk events (e.g. floods) is partly determined by how a hazard or risk event is portrayed by scientists, news media, or other actors and understood by individuals. The subsequent response by individuals can result in a wide-range of possible outcomes – from social movements or protests to demands for more stringent regulations. This highlights the need to examine how to best translate and present such information to non-expert audiences as well as decision-makers (Loucks, 2015; McNie, 2007; Hammond et al., 1983). This information can advance the development of flood visualizations and help different audiences understand their exposure to flood hazard, which can in turn lead to a change in flood risk perception and promote mitigation behaviors (Paton, 2003; Sheppard, 2005).

Since one's risk perception is "found to be influenced by a combination of cognitive, socioeconomic, and geographical factors" (O'Neill et al., 2016, p. 2), and such perception could be amplified or attenuated by psychological, social institutional, and cultural processes (Viglione et al., 2014; Kasperson, 1988), a greater understanding of how different stakeholder groups perceive flood risk is critical as it is related to their understanding of flood hazard information, flood mitigation behaviors, and may ultimately influence the effectiveness of flood risk management plans (Kellens et al., 2011; O'Neill et al., 2015; Dash & Gladwin, 2007). Therefore, this study aims to examine ways in which collaboration between experts and non-experts can uncover the social and political contexts of flood risk, and cogenerate strategies for advancing flood risk communication by improving flood visualizations. Experts in this study are defined as individuals (e.g. social and physical scientists, modelers) with specialized technical knowledge most often drawn from scientific institutions and universities (Thomalla et al., 2006), while non-experts in this study consisted of opinion leaders, practitioners, and decision-makers from the community who may use, but rarely develop, flood models or visualizations. In particular, this study will analyze and compare the feedback provided by different community stakeholder groups on flood visualizations, since "it is not sufficient to simply provide the same message to all individuals at risk because they will perceive this information differently and will subsequently respond in different ways" (Kellens et al., 2013, p. 46; Fuchs et al., 2009).

Given that flood visualizations such as "flood maps are increasingly regarded as important for mitigating the impacts of natural hazards" (Meyer et al., 2012, p. 1701), previous studies have devised depiction (e.g. layout, symbology) and content guidelines for the development of flood visualizations. In the EXCIMAP project (Martini & Loat, 2007), experts from various European countries or organizations were invited to contribute their expertise to improve flood mapping practices as well as the communication of flood information. In the RISKCATCH project, Fuchs et al. (2009) studied the eye movement of different stakeholder groups (i.e. public authorities, experts in cartography, laypersons) that were exposed to flood risk maps with different layouts, symbology, scales, and levels of complexity, in order to generate recommendations for an efficient design of risk maps. Similar to the RISKCATCH study, Meyer et al. (2012) studied the eye movement of different stakeholder groups (i.e. strategic planners, emergency managers, members of the public) in order to enhance the utility of flood visualizations for different end users in the RISK MAP project. The RISKCATCH and RISK MAP projects also utilized surveys to capture participants' feedbacks for various flood maps. Similar to previous studies, this study employed focus groups and surveys to analyze how three different stakeholder groups with varying levels of technical expertise and different agendas react to different visualizations of flood hazard.

In addition to assessing the content and depiction preferences of different stakeholder groups as was done in previous studies, a distinct contribution of this study is its focus on one key precondition (i.e. genuine engagement) that encourages participants to suggest improvements to flood visualizations as part of a bottom-up approach (Bloschl et al., 2013) to flood risk management. In contrast to conventional approaches to flood risk management and their focus on <u>probable</u> flood scenarios, the bottom-up approach relies on community input to identify and analyze events that can <u>possibly</u> happen, thus reducing the shock or vulnerability that may be caused by surprise or wildcard events (Bloschl et al., 2013; Wardekker et al., 2010; Merz et al., 2015). The feedback from participants in this study are analyzed not only by gauging different stakeholder groups' expectations of flood visualizations, but also their meaning for the different groups. We contend that this knowledge can be obtained from the genuine engagement of experts and non-experts, and can assist in the development of flood visualizations with enhanced utility for different stakeholder groups.

2. MATERIALS AND METHODS

Our research team conducted three focus groups in the Southern California coastal lowland community of Newport Beach as part of a larger National Science Foundation funded project called Flood Resilient Infrastructure and Sustainable Environments (FloodRISE). As stated previously, coastal lowland communities such as Newport Beach are expected to face major increases in flood risk in the coming decades due to sea level rise and the growing concentration of wealth and infrastructure in these areas. Therefore, in an effort to promote resilience to flooding among coastal communities such as Newport Beach, the present study aims to show how knowledge gained from stakeholder engagement can not only improve flood visualizations, but can also inform the design of future activities intended to promote ongoing communication and collaboration between experts and non-experts. Focus group meetings were employed in order to understand how one stakeholder group consisting of people with similar backgrounds understand and interpret flood hazard information differently than another stakeholder group.

Each focus group was designed to concentrate on the flood visualization needs of a particular stakeholder group. The three stakeholder groups that were the foci of this study are (1) home and business owners, (2) civil society groups, and (3) emergency planners and city planners. Previous studies on flood risk communication (Meyer et al., 2012; Fuchs et al., 2009; Martini & Loat, 2007) and storm surge risk communication (Morrow et al., 2014) have similarly focused on the visualization needs of different stakeholder groups. In particular, much like the RISK MAP project described in Meyer et al. (2012), this study similarly assessed the content and depiction preferences of different stakeholder groups through focus group discussions and surveys. This study expanded upon the RISK MAP project's methodology by engaging stakeholders from civil society groups in addition to public authorities, emergency managers, and members of the public, thus providing new insights on the needs of a stakeholder group that has not been considered in past studies. Moreover, rather than recruiting our stakeholder groups from different countries with potentially different geopolitical contexts, this study focused on the preferences of three different stakeholder groups from the same urban coastal lowland community (i.e. Newport Beach, California), thus minimizing the role that geopolitical differences may play in influencing the flood risk perception and visualization preferences of our participants. Lastly, unlike the RISK MAP project, this study went beyond asking for participant feedback on current flood mapping practices and flood maps based on current conditions. Instead, participants in this study were presented with maps portraying not only events with different return periods or different annual exceedance probabilities, but also included maps for different near term and long term projections, which we believe can further stimulate participants to think about events that can possibly happen in the future, rather than events that can probably happen given current hydrological conditions.

2.1 Focus group structure and engagement

In designing the focus groups for this study, we were cognizant of the three rationales for citizen participation presented by Fiorino (1990), who argued that non-experts should be engaged in making risk decisions on substantive, instrumental, and normative grounds. Insofar as the substantive dimension is concerned, authors such as Slovic (1987) and Fiorino (1990) believed that non-expert judgments about risk can be as good as, if not better, than expert judgments. This is because non-experts are often more aware of the social and political context of environmental hazards relative to scientific experts, thus allowing non-experts to “see problems, issues, and solutions that experts miss” (Fiorino, 1990, p. 227; Isaacson, 1986; Fischer

2000). Moreover, Barber (2004) argued that ongoing reflections and “strong democratic deliberation” between experts and non-experts are vital in exposing uncertainties inherent in the scientific models that can influence the decision making process. In terms of the instrumental perspective, Fiorino (1990) and others (e.g. Arnstein, 1969; Krimsky, 1982; Fischhoff, 1995) have argued that broader and more effective non-expert participation can enhance the legitimacy of risk decision and reduce opposition by increasing public confidence in the decision making process, incorporating a range of values and perspectives, and reducing the probability of errors. Wachinger et al. (2013) went as far as stating that “public participation measures are probably the most effective means to create awareness of potential disasters, to enhance trust in public authorities, and to encourage citizens to take more personal responsibility for protection and disaster preparedness” (p. 1063). Building on Fiorino’s (1990) substantive and instrumental rationales, we wish to go one step further and argue that better scientific models and decision support systems produced by collaborations do not in themselves lead to more public support. Rather, the models and decisions must also resonate with the users’ social and personal experiences before they will garner support and trust. Thirdly, in terms of a normative rationale, citizens are considered the best judge of their own interests, and should be provided the opportunity to participate in decisions that can directly affect them (Fiorino, 1990; Fischer, 2000).

We hypothesized that different stakeholder groups have different personal and professional needs, and can offer potentially distinct recommendations for improving flood visualizations since they operate in different social and political contexts (substantive rationale). Moreover, by effectively engaging different stakeholder groups and incorporating diverse perspectives from experts and non-experts, both the democratic ideal of public participation (normative rationale) and the effective integration of local knowledge into flood visualizations would result. Both outcomes should respectively enhance the legitimacy of flood visualizations and the risk management decisions that are made based on them (instrumental rationale).

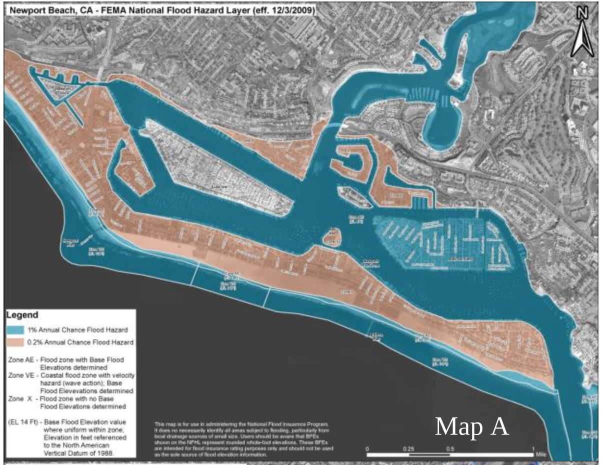
2.1.1 The focus group structure

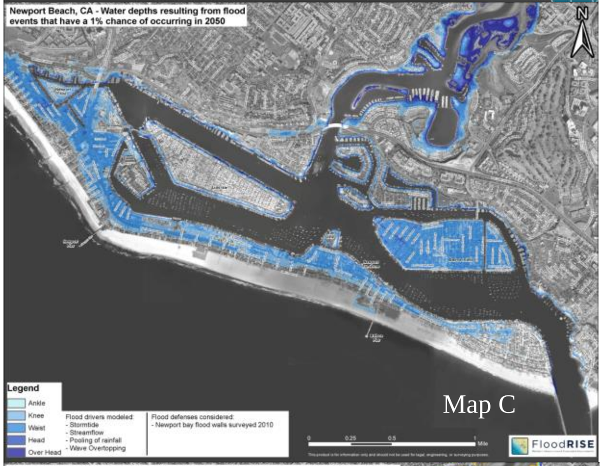
The participants for each focus group were recruited through personal communications and snowball sampling. Unlike previous studies which conducted focus groups with stakeholder groups from different countries within a much larger geographical extent (Meyers et al., 2012; Martini & Loat, 2007), the geographical focus of our study is much smaller in scale and our findings are not meant to be generalized across large regions. Due to the small geographical scale of our study area (city scale study vs. multinational scale study), the limited number of stakeholder representatives within the study area (i.e. limited number of emergency responders, city planners, and civil society groups) and the limited availability of respondents, it was not possible for us to repeat the focus group across different cohorts of stakeholders to strengthen the study's reliability. Nonetheless, previous focus group studies have been implemented successfully with small groups of four to six participants (Strong et al., 1994) – and this study conforms to this pattern. Moreover, previous findings on focus group research have found that the more homogenous the composition of a focus group, the more likely individual members are to voice their opinions (Sim, 1998; Krueger and Casey, 2000; Stewart and Shamdasani, 1990). In fact, in their study of flood risk perception through the use of focus groups, Terpstra et al. (2009) specifically cautioned that future research should employ homogenous participant samples in order to ensure that different perceptions between groups are not due to preexisting differences among group members. Thus, in an effort to create a nonthreatening atmosphere where participants can freely share their views and collaborate with other group members, we opted to keep each focus group small to three to six participants each. The entire study consisted of 14 participants, with three participants in the home and business owner focus group (two males, one female), six participants in the civil society focus group (five males, one female), and five participants in the planner focus group (three males, two females). The Back Bay Science Center at Newport Beach was chosen as the site for the focus groups, because of its proximity to study participants and its reputation in the community as a facility for public outreach and education.

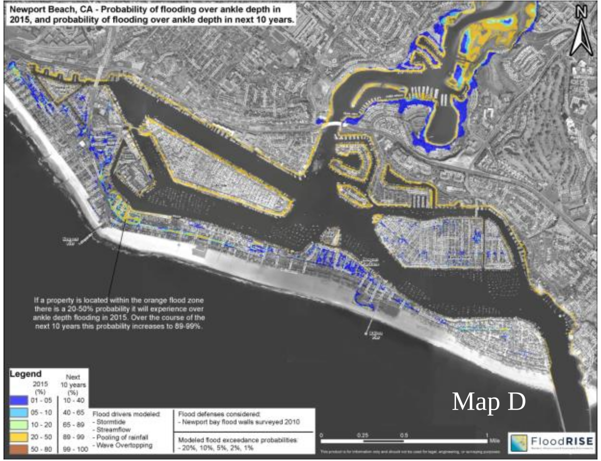
Each focus group lasted approximately 120 minutes, and was led by a moderator, a co-moderator with extensive background in hydrology and flood hazard modeling, and two assistant moderators who also acted as notetakers. Within each focus group, the co-moderator first introduced the participants to a hardcopy flood map (i.e. Table 3.1, Map A), then the moderator asked the participants to discuss their thoughts about the map. The topics of discussion included the perceived accuracy of the information shown, the ease in which one can interpret the map, and other suggestions for improving the map content and depiction. This process was repeated for five additional hardcopy maps developed by the FloodRISE research team in consultation with the professional user community prior to the focus groups (Table 3.1). The visualizations in the five FloodRISE maps were generated by hydrodynamic flood models that accounted for multiple flood drivers in a systematic way, which enabled different flood attributes to be depicted for different timeframes (e.g. 2015, 2025, 2050) and different exceedance probabilities (i.e. different return periods) at the street-level scale. While maps of events with different exceedance probabilities have been evaluated in previous studies, we believe that different timeframes can be useful in stimulating discussions about future scenarios, and in addressing stakeholders with different temporal and planning requirements (i.e. long range planning for city planners vs. short range planning for emergency responders). Short descriptions and thumbnails

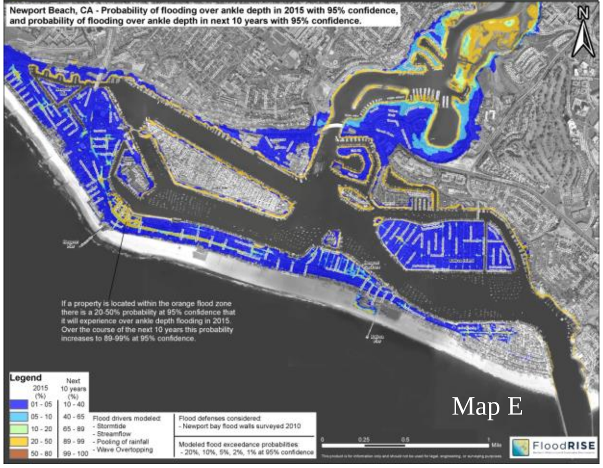
Table 3.1. Thumbnails and brief descriptions of maps shown in the focus groups. (Full size image of each map is provided in Appendix 1)

Map	Description
A	FEMA National Flood Hazard Layer (NFHL) for Newport Beach, CA
B	FloodRISE 1% annual exceedance probability (AEP) depth in 2015
C	FloodRISE 1% AEP depth in 2050
D	FloodRISE probability of flooding in 2015/over next 10 years
E	FloodRISE probability of flooding in 2015/over next 10 years with 95% confidence
F	FloodRISE roads accessible to vehicles in 2015









for the six maps can be found in Table 3.1, and more detailed explanations for each of the maps are provided in Section 4.2 (full size image of each map is provided in Appendix 1).

Before the conclusion of each focus group, each participant was asked to participate in a survey, where participants were asked to assess the maps that were presented according to the following criteria:

Most useful: Which of the six maps, for you and the work that you do, is most useful?

Most trustworthy: Which of the six maps do you find most trustworthy?

Most resonant: If you could share one of these maps with a friend or family member who lives in Lower Newport Bay, which map would you show?

This was followed by the participants' evaluation of the focus group process' genuineness. The evaluation included statements that reflected three of the four democratic process criteria discussed in the next section (i.e. Direct Participation, Decision Authority, Equality), as well as statements regarding the practical implications of flood hazard visualizations (i.e. Usefulness, Perception).

Direct Participation: I had the opportunity to directly provide feedback regarding ongoing efforts to map flood risk in Newport Beach.

Decision Authority: I feel that my input will help inform the future direction of flood risk mapping by FloodRISE researchers.

Equality: All participants in the focus group had equal opportunity to participate.

Usefulness: I feel that the products from this research project will be useful for a wide range of audience.

Perception: My perception of flood risk in Newport Beach changed as a result of this focus group.

The evaluation did not include a question on the democratic process criteria of face to face discussion, because the focus group itself was implemented as a face to face discussion between experts and non-experts. At the conclusion of the meeting, the assistant moderators presented the participants with an oral summary of the notes and debriefed with the research team following the focus group.

2.1.2 Designing genuine engagement

The three focus groups were structured and evaluated based on Fiorino’s (1990) four democratic process criteria. Based on the works of scholars such as Krimsky (1982), Barber (2004), and other participatory democracy theorists, Fiorino (1990) concluded that any successful mechanism for ideal democratic engagement must (1) allow for the direct participation of non-experts, (2) go beyond what Arnstein (1969) branded as “nonparticipation” or “tokenism” and truly enable participants to exercise decision authority, (3) provide opportunities for face to face discussion between experts and non-experts, and (4) empower citizens to participate on some basis of equality with technical experts. In short, we structured the focus groups to directly involve non-expert participants (practitioners, opinion leaders, decision-makers) in the discussion of expert models of flooding as depicted in flood maps, reassured participants that the experts (scientists, modelers) fully intend on implementing their recommendations if technically feasible (or why it may not be technically feasible), moderated face to face discussions between experts and non-experts, and respected each participant’s feedback and requested clarifications when necessary. As stated previously, in order to evaluate the focus groups’ genuineness based on the democratic process criteria, the research team asked each participant to complete an evaluation at the conclusion of the focus group. The evaluation did not include a question on the criterion of face to face discussion, because the focus group itself was already implemented as a face to face discussion between experts and non-experts.

3. DATA AND ANALYSIS

Verbal and nonverbal communications from the focus groups were audio and video recorded and transcribed. The transcript was analyzed through a grounded theory approach to data coding and analysis (Hesse-Biber & Leavy, 2011). The coding process took place in two stages. In the initial coding stage, words and literal phrases within the transcript were organized into broad concepts. Once initial coding is complete, we used a focus coding procedure to refine and group related concepts into analytical categories and analytical dimensions. This enabled us to apply the study's theoretical framework and relevant literature to analyze and interpret how different stakeholder groups conceptualize flood hazard and flood visualizations. A sample of the initial and analytical codes employed in this study is shown in Table 3.2. The analytical categories and key themes that emerged in the analysis of the transcripts were cross checked with field notes taken by the assistant moderators in order to maximize data reliability (Sim, 1998). After the coding process, memos were compiled to interpret and synthesize research findings, and were circulated among research team members in order to maximize the analysis' verifiability (Krueger and Casey, 2000).

The survey results from the participants' assessment of maps' trustworthiness, usefulness, and resonance, as well as the participants' evaluation of the focus group process were tabulated and analyzed based on their summary statistics.

4. RESULTS

This section reports results from the focus groups as well as the surveys and evaluations that were administered at the conclusion of the focus groups. It discusses general findings that emerged from all three focus groups about the contents and depiction within the flood hazard visualizations, specific recommendations for each of six maps discussed, participants' assessment of the maps' trustworthiness, usefulness, and resonance, and their evaluation of the focus group process' genuineness. With the exception of the FEMA National Flood Hazard Layer (NFHL), all of the maps discussed in this section were generated by the FloodRISE research team using a two-dimensional hydrodynamic model that accounted for multiple flood drivers (i.e. storm tides, stream flow, rainfall, wave overtopping) in a systematic way (Table 3.1).

Table 3.2. Initial codes and analytical codes derived from one sample passage from the focus group transcript.

Excerpt:	Initial Code:	Analytical Code:
I think these maps are good communication tools to help make points to change behavior potentially,	Maps are good communication tools	Importance of maps: behavior change
so even though it seems like we're just focusing on reacting, I think in that dialogue, in that discussion, we start bringing up the causes and we start being able to speak about them.	Maps can start discussion about causes	Importance of maps: simulate discussions
You have to have a digital tool or something similar to this to begin that discussion.	Digital tool needed	Map presentation: digital and interactive tool needed
One thing I'll just go back to though.		
I think it would be more valuable to see a reality of the combinations	Combination of layers	Modeling: combined probabilities
because they would make this map more believable if we put all three layers on it, and I think that would make that point more easily communicated.	Believable maps	Importance of maps: believable maps better communicate information

4.1 General map findings

4.1.1 Content: What is "flooding"?

From the comments provided by participants across the three focus groups, it is clear that there is no universal definition of "flooding" among study participants. As one participant puts it,

“…is flooding one inch of water in my house or is it a foot? Or is it eight feet? Or when it is flooded in the street in front of my house?” Moreover, in light of the increase in the frequency of nuisance flooding (Moftakhari et al., 2015), our emergency and city planner participants remarked that what may be regarded as minor flooding or “nuisance flooding” by hydrological experts is of particular interest to them, because “nuisances can become disasters very quickly” if they are impeding evacuation.

4.1.2 Depiction: Visualizations need to highlight not only hazards but also risk

In addition to including the parameters used in conventional technical assessment of flood hazard (probability, magnitude), participants expressed the need for flood visualizations to depict vulnerability and risk information. Specifically, rather than simply overlaying flood depth and extent information on an aerial photo, participants suggested highlighting entire affected property even if only one corner of the property is forecasted to be affected. Similarly, rather than simply overlaying forecasted flood information on a streets layer or a flood defense layer, participants recommended for vulnerabilities (e.g. weaknesses in flood defenses, vulnerable evacuation routes) to be highlighted in order to assist users with flood mitigation, disaster planning, and evacuation (e.g. identifying alternate evacuation routes).

4.1.3 Depiction: An interactive and customizable platform

Consistent with studies indicating emerging information communication technology’s (e.g. mobile devices, social media) potential to meet the needs of diverse stakeholders (Cutts et al., 2015), a majority of participants from all three focus groups advocated for the development of a digital interactive platform that can be customized to respond to different stakeholders’ needs in three ways. As Faulkner et al. (2007) noted, “model outputs can be increasingly visualized in a range of potentially useful ways (e.g. video clips) that have great potential as communication tools…When formulated graphically or as computer simulations that run in real time, these tools can potentially communicate in a very powerful way" (p. 697).

First, participants suggested that the ability to zoom to different map scales and pan to different areas could potentially enhance the usefulness of the flood hazard visualizations for a greater number of users. One homeowner participant expressed his dismay with the static hardcopy flood maps presented in the focus group meeting, "I'm literally one street off (the mapped area). I would love to be able to see if I'm okay." Second, aside from being exclusively used for disaster response, participants believed that animations and change visualizations (e.g. before/after comparisons) can be powerful tools in communicating and stimulating discussions about the impacts of potential flood events. One city planner remarked, "(we must) get the information out to the public in a way that they can grasp it and understand the impact…That's why we always use before-and-afters in our presentations for just about any types of projects." Lastly, participants from the home and business owner focus group also proposed the idea of enabling differential access to flood-related information for different stakeholder groups, in an effort to avoid overwhelming the public with too much information. As one homeowner suggested, "…anybody could get on (the flood visualizations website), but there would be a special key for the first responders and have more in depth information. Because I can see that you could give too much information to the general public and have confusion or panic."

4.2 Specific map findings

4.2.1 FEMA National Flood Hazard Layer (NFHL) for Newport Beach (Table 3.1, Map A)

The FEMA NFHL is a compilation of data from Flood Insurance Rate Map databases and Letters of Map Change (McAfee, 2016). It has been included in this focus group study because it is "considered the best online resource for official National Flood Insurance Program (NFIP) purposes when determining locations in relation to regulatory flood hazard information" (McAfee, 2016). The map depicts the 1% and 0.2% annual exceedance probability flood hazard zones and base flood elevations (BFE) for each flood zone.

There are two recurring themes in focus group participants' reaction to the FEMA NFHL map. These themes are (1) it is neither accessible nor familiar to non-experts, and (2) the map is confusing due to the volume of information being presented.

Participants from the homeowner and the civil society focus groups remarked that they have spent time looking for flood risk information, but some either never found it or do not recognize it. The following quote underscores this:

> "…maybe 6 months ago, I spent about half an hour looking for this sort of information for Orange County and finally found it in somebody's PowerPoint presentation… From my experience, this sort of information has not been easy to find."
>
> -Civil society group member, Orange County.

Even among respondents who were able to access the FEMA NFHL map, participants in the focus groups had a range of reasons for not finding the map useful. Some of the reasons included the overwhelming volume of information in the FEMA NFHL map, and the map was not relevant to their personal or professional needs. The following comment reflects these concerns:

> “From my perspective in planning, we have a zoning code regulation that requires new development, new homes, to be developed at 9 feet finish floor elevation regardless of what the FEMA map shows. From that perspective, it doesn’t matter what the FEMA map says.”
>
> -City planner, Newport Beach.

4.2.2 FloodRISE 1% AEP depth map in 2015 (Table 3.1, Map B)

The FloodRISE 1% AEP (annual exceedance probability) depth map in 2015 shows the areas that could be inundated and the depth of inundation by a flood event that has a 1% chance of occurring in any given year. The extent and depth of inundation modeled are based on sea level as of 2015 and does not take into account the impact of future sea level rise. The flood drivers considered in the hydrodynamic analysis used to create this map are stormtides, wave overtopping along the Balboa Peninsula, runoff and pooling from rainfall, and streamflow. The depth of inundation is quantified in relations to body heights (i.e. Ankle, Knee, Waist, Head, Overhead) as shown in the legend.

Focus groups participants appreciated not only the inclusion of depth information in the FloodRISE 1% AEP depth map, but also agreed with the presentation of information in a manner that is relatable to various stakeholder groups. They shared suggestions for improving the presentation of flood depth information that is applicable to the development of future flood hazard visualizations.

In contrast to the dichotomy of risk (i.e. flooded, not flooded) presented in the FEMA NFHL map, the FloodRISE 1% AEP depth map’s quantification of flood depths in anatomical terms helped civil society stakeholders relate the model results to historic flood events, and prompted other stakeholder groups to compare the depth information shown in the map with their personal and professional experience. Moreover, participants also remarked that the depth map was more accurate than the FEMA NFHL map given its finer spatial resolution (i.e. street level scale), and also depicted the extent and depth in which an area becomes inundated.

> “This (FloodRISE 1% AEP depth map) is much closer than what I would have expected than the other one (FEMA NFHL map)…You’ve got it (flooding) in the streets basically on Balboa Island, which is what happens.”
>
> -Resident, Newport Beach.

While the quantification of water depth was appreciated, participants cautioned against the inclusion of too much detail, which could be misleading and unnecessary for most stakeholders. Specifically, participants recommended for the legend to be simplified such that the number of classes should be reduced, and the classes should be defined based on some actionable thresholds (e.g. thresholds for evacuation).

> “Let me know where it matters. Whether it (flood water) comes up to my knees or my waist may be not so important. You may make it (the legend) 3 points (classes).”
>
> -Civil society group member, Orange County.

4.2.3 FloodRISE 1% AEP depth map in 2050 (Table 3.1, Map C)

The FloodRISE 1% AEP depth map in 2050 is similar to the FloodRISE 1% AEP depth map in 2015 with the exception that the 2050 map takes into account the effects of sea level rise as projected by the National Research Council (National Research Council, 2012). The sea level rise predictions from the National Research Council for the southern California coast were aggregated with an analysis of sea level variance based on 91 years of stormtide measurements recorded at National Oceanic and Atmospheric Administration's (NOAA) Los Angeles tide gauge (ID: 9410660).

Participants from the homeowner focus group described the FloodRISE 1% AEP depth map in 2050 as "fascinating" due to its ability to illustrate the probable future landscape and its potential to elicit "emotional impact" among residents. However, all participants were critical of the model parameters that went into creating this forecast of water depths in 2050. All three focus groups noted that the four primary drivers accounted for by the hydrodynamic model (i.e. storm tides, stream flow, rainfall, wave overtopping) used to generate the maps are unlikely to occur independently, and repeatedly emphasized the need for future flood models and visualizations to consider the combined probability of those drivers occurring simultaneously and the interactions between flood drivers.

> "If you've got a high tide on Balboa Island, they close all the drains. Then, if we have one or two inches of rain, it floods."
>
> -Resident, Newport Beach.

With respect to the technical assessment of flood risk, focus group participants also suggested the need to move beyond simply looking at probability (e.g. 1% AEP) and magnitude (e.g. depth). Instead, civil society respondents and emergency planners recommended that frequency and duration of inundation be considered in future flood models. For example, a short duration inundation event may be a nuisance, but a long duration inundation event may generate secondary effects (e.g. disease) that can lead to a disaster or an irreversible regime shift (e.g. ecosystem destruction) (Moftakhari et al., 2015; Gordon et al., 2007). However, there were also concerns among respondents that the inclusion of duration information (particularly for short duration events) could spur inaction or complacency.

> "If it's a couple of hours, that's one thing. If it's going to be submerged for a week or if it's going to happened regularly every day, it's going to have more of the marsh significantly covered…that would detriment some of the endangered species up there in the salt marsh itself."
>
> -Civil society group member, Orange County.

In addition to the combined probability of drivers and the inclusion of duration and frequency information, there were also concerns among participants as to whether the 2050 projection is too far out into the future to be of use to stakeholders. Generally, respondents requested multiple projections that focus on the "short term" (4-5 years), "mid term" (20 years), and "long term" (30+ years).

> "2100 might as well be the year 3000 to the public. I mean, even 2050."
>
> -Emergency planner, Orange County.

4.2.4 FloodRISE probability of flooding in 2015/over next 10 years (Table 3.1, Map D)

This map depicts the probability of flooding over ankle depth based on 2015 sea level condition, as well as the joint probability of flooding at least once over the course of the next 10 years without accounting for the impacts of sea level rise. The range of probabilities in this map depicts probable inundated areas under a variety of AEP scenarios (from less frequent to more frequent). Flood depths are not depicted in this map.

Participants from all three focus groups valued the probability map for its ability to stimulate discussions among residents and businesses about flood risk in the near future. However, participants also remarked that this type of visualizations would not be particularly useful for residents who are not at risk under current sea level conditions, and advocated for the inclusion of past events or familiar points of interest as means of quantifying potential flood impacts.

In general, participants noted that the use of the terms “probability” and “exceedance probability” may be difficult for members of the general public to understand. This highlights the need for new terminology (“likelihood” was suggested as an alternative), different ways of quantifying hazards and impacts (reference past events), or more explanation to accompany flood hazard visualizations.

> “(Refer to modeled event as) we might have another El Nino because that paints the picture to a lot of people of what the last El Nino did. I’m thinking really there’s an opportunity out there for someone to bring in some new nomenclature.”
>
> -Civil society group member, Orange County.

Once the co-moderator finished explaining the map, respondents from the focus groups suggested that the map could be used to mitigate flood risk by guiding future developments, as well as encourage residents to think about their current and future flood risk.

> “I like this map and this style because I think it gets the conversation going right away of what your risk is today. Then that’s going to, I think, engage people to look at what’s my risk over the next 5 to 10 years, what’s my risk over the life of my property.”
>
> -City planner, Newport Beach.

Despite the visualization’s ability to communicate present and future flood risk, some respondents were concerned that the visualization may be misinterpreted (hence highlighting the need for explanation to accompany visualizations), while other respondents remarked that this type of probabilistic visualization may not be helpful or may even mislead residents who are currently outside of the inundation areas.

> “I think if somebody happens to live in one of these areas that are susceptible to flooding now, it might be useful, but it might give a false sense of security being outside of those areas.”
>
> -City planner, Newport Beach.

4.2.5 FloodRISE probability of flooding in 2015/over next 10 years with 95% confidence (Table 3.1, Map E)

This map is similar to the FloodRISE probability of flooding in 2015/over next 10 years map in that it is depicting probabilistic estimates of inundated areas without considering the effects of sea level rise. However, unlike the previous map, it shows how uncertainty and extreme values in the model data affect flood zone predictions. Uncertainty consideration is limited to three model parameters (i.e. tide elevations, wave runup elevations, and streamflow). While the previous map was generated by adopting values at or below the median value for each of the model parameters, this map was generated by adopting values at or below the 95th percentile value for each parameter. In other words, relative to the previous map, this map shows the upper level flood zone for each exceedance probability by accounting for more extreme parameters values that may occur less frequently.

Similar to the probability map, participants in all three focus groups commented on the need for new nomenclature to describe the probability of flooding and the concept of statistical confidence. Moreover, although city planners acknowledged that there are uncertainties in model output, there were disagreements over whether such information would be useful for members of the public and decision makers.

Nearly all focus group participants had a hard time grasping the concept of statistical confidence. This may be due to the respondents' unfamiliarity with the models that were used to generate the maps, which contributed to their confusion over the drivers of uncertainty in the model parameter estimates.

> “I think that is one of those things which would not be terribly useful trying to explain to 90% of my neighbors. If I was showing them this map, I think they’d just look at me and their eyes would cross.”
>
> -Resident, Newport Beach.

Many members of the civil society focus group believe that the probability map with 95% confidence “offers a large amount of information in an easily understandable way,” but no one in the group gave specific reasons as to why the map depicting statistical confidence (i.e. uncertainty) information is preferred over other map types. Meanwhile, most members of the homeowner focus group and the planner focus group recommended against conveying statistical confidence information to the general public, but indicated that it may be of use to technically proficient planners and decision makers.

> “We just sat here and went over what does confidence mean and I don’t think the public is really going to…They’re going to see that and their eyes are going to glaze over.”
>
> -City planner, Newport Beach.

4.2.6 FloodRISE roads accessible to vehicles in 2015 (Table 3.1, Map F)

The FloodRISE roads accessible to vehicles in 2015 map shows the probability of streets being accessible to sedans and emergency vehicles under a variety of AEP scenarios given the sea level condition in 2015. The flood depth threshold used to determine if a road is accessibility to sedans is 18 inches (1.5 ft), while a threshold of 30 inches (2.5 ft) was used for emergency vehicles. Most road segments remain accessible to sedans under the different AEP scenarios, and all roads remain accessible to emergency vehicles.

A majority of respondents from all of the focus groups believed that the road accessibility map would be useful for a variety of users, including planners, emergency managers, public safety officials, residents, and visitors. Moreover, participants believed that the map should be disseminated to various stakeholder groups immediately, and should be constantly updated in order to account for changes in the landscape and worst case scenarios.

> "I mean this could be shared right away with our police and fire departments and our traffic folks to kind of look at it and have it on standby, be ready to go…and update it every year and send it out kind of thing."
>
> -City planner, Newport Beach.

A comment that was first raised by members of the civil society focus group and emphasized by members of the other focus groups was the need to consider worst case scenarios in all of the maps. In particular, respondents noted that the models assume flood management and mitigation measures are in working order, but unexpected circumstances such as sediment displacement, clogged drains, and stalled vehicles could exacerbate the impacts of the flood event. Thus, visualizations should be flexible and modifiable by users to handle unforeseen disturbances and highlight alternate evacuation routes.

> “Under normal conditions, we might have an area with multiple access points. But if an entire neighborhood…now only has one way in, one way out… then obviously that creates issues. Not just for evacuation, but also for providing emergency services.”
>
> -Emergency planner, Newport Beach.

4.3 Participant survey of map usefulness, trustworthiness, and resonance

Taking into account the votes casted by all the participants in our study across the three criteria, the FloodRISE 1% AEP depth map in 2050 received the most votes (12 votes) (Table 3.3). Looking at the voting pattern within each focus group across the three criteria, the FloodRISE 1% AEP depth map in 2050 received the most votes within the home and business owner focus group (6 votes) and the city and emergency planner focus group (4 votes), whereas the probability map with 95% confidence received the most votes within the civil society group focus group (8 votes).

When looking at the results for each focus group by individual criterion, most members within each focus group agreed in terms of which map was most trustworthy. Specifically, in the home and business owner focus group, 100% of its members agreed that the FloodRISE 1% AEP depth map in 2050 is the most trustworthy. In the civil society group focus group, 83% of its members agreed that the road accessibility map was the most trustworthy, whereas 75% of the members in the city and emergency planner group believed that the FloodRISE 1% AEP depth map in 2015 was the most trustworthy (Table 3.3).

4.4 Participant evaluation of the focus group engagement process

At the conclusion of the focus groups, each respondent filled out an evaluation of the focus group’s ability to genuinely engage him/her in the discussion of flood risk.

Table 3.3. Number of votes casted for each map by participants within each of the three focus groups during the survey of map usefulness, trustworthiness, and resonance.

Stakeholder Group	**Criteria**	**FEMA**	**FloodRISE 1% AEP 2015**	**FloodRISE 1% AEP 2050**	**FloodRISE probability in 2015**	**FloodRISE probability in 2015 with 95% confidence**	**FloodRISE roads accessi-bility**
Home and business owners	Most useful	1		1	1		
	Most trustworthy			3			
	Most resonant			2	1		
Civil society groups	Most useful	1	1			4	
	Most trustworthy	1					5
	Most resonant			2		4	
Emergency and city planners*	Most useful			2			2
	Most trustworthy		3				1
	Most resonant			2	2		
Total votes for each map		**3**	**4**	**12**	**4**	**8**	**8**

**One planner had to leave early and did not participate in the survey*

In terms of the democratic process criteria (Direct Participation, Decision Authority, Equality), the results from the evaluation (Table 3.4) indicated that all participants across the three focus groups strongly believed that they had the opportunity to directly participate in the discussion ($\bar{x}$ = 5), their feedback will make a difference in future flood models ($\bar{x}$ = 4.64), and that all participants were engaged on the basis of equality ($\bar{x}$ = 4.93).

While many respondents strongly agreed that the flood information from the research project will be useful for diverse audiences ($\bar{x}$ = 4.76), most respondents were much less enthusiastic when asked if the focus group changed their perception of flood risk ($\bar{x}$ = 3.09). Specifically, of the three focus groups, the planner focus group was most likely to disagree with the statement ($\bar{x}$ = 2.6) and also had the lowest variability (s.d. = 0.55), while respondents from the civil society focus group showed the highest variability in terms of whether the focus group changed their perception of flood risk ($\bar{x}$ = 3.3, s.d.=1.63) (Table 3.4).

Table 3.4. Stakeholder group average ratings of the focus group process based on participant evaluation of statements tied to the democratic process criteria and the implications of flood visualizations. (5=strongly agree, 1=strongly disagree)

Stakeholder Group	**Direct Participation***	**Decision Authority***	**Equality***	**Usefulness***	**Perception***
Home and business owners	5	4.33	5	5	3.33
Civil society groups	5	5	5	4.67	3.33
Emergency and city planners	5	4.6	4.8	4.6	2.6
Average rating across three focus groups	**5**	**4.64**	**4.93**	**4.76**	**3.09**

**Refer to section 2.1.1 to see the statement linked to each criterion.*

5. DISCUSSION

The results from this study expanded upon previous research by providing new insights into how different stakeholder groups within a coastal lowland urban community understand flood visualizations, and by highlighting the value of genuine engagement between experts and non-experts as a precondition for knowledge cogeneration (Morrow et al., 2015; Meyer et al., 2012; Opach & Rød, 2013). Moreover, the findings of this study provide empirical support for the types of visualization stimuli and responses included in Sheppard's (2005) theoretical framework of landscape visualizations (see section 5.1.4 and Appendix 2). In sum, we believe that engagement processes that are based on the democratic process criteria can reveal user preferences and needs, and advance flood visualizations in ways that invoke cognitive, affective, and behavioral responses necessary for the mitigation of flood risk. Specifically, the process must allow participants to genuinely contribute to the discussion by being cognizant of information accessibility, presenting information in a useful manner, and encompassing diverse stakeholder perspectives.

5.1 Stakeholder group recommendations

This section presents stakeholder-specific recommendations on appropriate content and depiction for flood visualizations based on a synthesis of feedback from our study participants, amplified by findings from previous studies.

5.1.1 City and emergency planners

This study grouped city planners who are responsible for long term flood risk mitigation with emergency planners into one focus group unlike Meyer et al. (2012), because these groups have significant overlaps in their professional duties before, during, and after flood events within our study area. Similar to previous studies, city planners within our focus group (relative to emergency planners) are likely to have the expertise to process "a high density of information displayed on the map and complex scientific contents" (Meyer et al., 2012, p. 1708). The expertise of this stakeholder group and its prior experience with flood visualizations may also be a reason that minimized the focus group's impact on this group's flood perception (Table 3.4). However, city planners and emergency planners both agreed that information such as water depths and events of different probabilities should be modeled and mapped. Moreover, economic, social, cultural, and environmental risks should be considered alongside information on existing flood protection (Meyer et al., 2012; Homan, 2001).

This is consistent with previous studies which indicated that study respondents called for additional information on vulnerabilities and flood defenses to be included in future flood visualizations (Opach & Rød, 2013; Meyer et al., 2012; de Moel et al., 2009). Specifically, city planners and emergency planners concurred on the need to highlight areas with limited access points. Moreover, while they supported depicting the extent and depth for events with different annual exceedance probabilities, they also cautioned against the inclusion of too much unnecessary details. For example, a city planner commented that in the interest of making administration more efficient, it is common for the city to impose regulations that require new developments to conform to a uniform finished floor elevation regardless of the variation in flood depths that may be shown in flood maps. Similarly, an emergency planner commented that it may be better to reduce the number of water depth classes because some residents are not likely to be concerned about ankle depth water. This finding is consistent with previous works on hazard risk modeling, which found that coarser data resolution and less precision may be adequate for the risk management and evacuation decision-making (Zerger, 2002). Furthermore, both types of planners in our focus group agreed that flood maps should be simplified by classifying flood depths into just three classes. This shows that although city planners and emergency planner have different backgrounds and expertise, they share similar preferences for information on vulnerabilities and water depth. However, attention needs to be paid to the ways in which such information is depicted and presented to different stakeholder groups, because different users are likely to have different professional needs and practical (i.e. time, legal) constraints.

5.1.2 Home and business owners

In contrast to other stakeholder groups, previous studies have shown that "public users, in most cases, do not use flood maps very frequently and therefore often have different needs and requirements" (Meyer et al., 2012, p. 1710). Given that citizens are not usually directly involved in the production of flood maps, they may be unfamiliar with concepts such as annual exceedance probabilities or return periods (Meyer et al., 2012). Moreover, our findings confirm this pattern by showing that residents tend to rely on contextual knowledge and experience to interpret and evaluate flood maps (Spiekermann et al., 2015). Consequently, information such as inundation extent and depth, potentially affected buildings, and evacuation information should be highlighted, while the use of technical language should be avoided (Meyer et al., 2012).

The discussions from the home and business owner focus group confirmed that members of the general public do not use flood maps very frequently. It was found that most respondents currently do not use publicly available flood maps (e.g. FEMA NFHL) because (1) the information is difficult to find and (2) they include too much irrelevant information. Given that previous studies have linked the lack of access to flood hazard information to the lack of risk awareness (Burningham et al., 2008; Kates, 1971), this highlights not only a need to make information accessible, but also an opportunity for information communication technology to enhance awareness by making flood hazard visualizations more accessible and customizable by the user. However, as the findings from this study and Feldman et al. (2016) suggest, solely increasing access to detailed information is not enough to effectively communicate flood risk to the public. The information must be presented in a credible manner that is compatible with the users' past experience and sociopolitical context, before the users will be open to accepting new information from experts or adopting mitigation behaviors (Cornell et al., 2013; Burningham et al., 2008; Spiekermann et al., 2015; Paton, 2003). In our study, the presentation of information (i.e. FloodRISE 1% AEP depth in 2015 map) that concurred with the respondents' past experience arguably paved the way for respondents to place their trust in similar information for future scenarios (i.e. FloodRISE 1% AEP depth in 2050 map) despite inherent uncertainties in our projection. Lastly, our findings also indicated that home and business owners have a wealth of knowledge about new developments, vulnerabilities, and flood drivers (e.g. high tide, rainfall, drain closure) in their neighborhoods. This suggested that experts (e.g. engineers and scientists) should consider complementing their flood model estimates by incorporating flood knowledge from non-experts obtainable from techniques such as public participation geographic information system and cognitive mapping (Cheung et al., 2016).

5.1.3 Civil society groups

Due to the diverse composition of many civil society groups (i.e. mix of experts and non-experts), this particular stakeholder group had some of the same recommendations as the other stakeholder groups. However, given the conservation and recreational focus of many civil society groups in our study, respondents commented that the flood hazard visualizations presented in the focus group “seem very human centric and not very habitat friendly,” and provided distinct recommendations for future iterations of flood modeling and visualizations that could better address ecological impacts.

Civil society groups also shared home and business owners’ concerns regarding the accessibility of flood information. The use of technical language (e.g. probability, statistical confidence) also appeared to be a source of confusion for civil society group members. In contrast to planners, civil society group members more forcefully advocated for the presentation of flood information in relatable terms (e.g. water depth in anatomical terms, references to historical events to contextualize magnitude) and the streamlining of visualizations to include only relevant information (e.g. minimize number of depth classes). Moreover, unlike the other stakeholder groups, civil society groups emphasized the inclusion of natural features in flood models. For example, rather than calling for the estimation of potential flood hazard with new manmade defenses in place (e.g. tide gate, retrofitted seawalls), civil society groups pushed for the inclusion of natural and nature-based flood defenses such as dunes and sand berms in future flood models. As another example, many respondents in this group called for the inclusion of information on the duration, velocity, and frequency of inundation, since they are all factors that can significantly impact sensitive ecosystems (especially immobile plant communities and bird nesting locations) and potentially cause irreversible changes to local ecosystems.

A particularly surprising finding from the civil society focus group was its preference for the probability map with 95% confidence (Table 3.1, Map E), where nearly 70% of the group rated it as the most useful in the participant survey (Table 3.3). Despite the group's confusion over the concepts of annual exceedance probability and statistical confidence during the focus group discussion, it is possible that respondents preferred the probability map with 95% confidence since it showed the largest inundation extent of all the maps discussed in the focus group. Specifically, one respondent from the civil society group justified his preference on the basis that "it's more dramatic than others because there's so much more that's going to be inundated to some level than anything else we see." Therefore, one explanation for this rather surprising finding is that respondents may feel the larger inundation extent supported their view that the inundation extent may have been underestimated in other maps (this was brought up during the focus group discussion), particularly by discounting flooded pervious areas where water may have percolated or by underestimating sea level rise. A second explanation for this surprising finding is the idea of "permissible drama" (Sheppard, 2005; Retchless, 2014), where civil society groups may have preferred the dramatic presentation of scientifically plausible information on the basis that it can "drive home the personal relevance of rising seas…(and) encourage deeper understanding of complex scientific information" (Recthless, 2014, p. 27). However, the key in the latter explanation is the term "permissible", where experts must not simply over-exaggerate information in flood visualizations to fit certain narrative. Rather, Sheppard (2005) cautioned that visualizations directed at influencing attitudes and behaviors should follow a set of ethical standards, which includes (1) disclosure of model uncertainties, (2) inclusion of dramatic and vivid, yet scientifically-plausible scenarios, and (3) defense against exaggeration, manipulation, and omission. These standards help ensure that the credibility of scientific flood models as well as co-produced flood visualizations are not damaged by the incredulous use of dramatization in them.

Overall, the group did not provide concrete evidence on why the probability map with 95% confidence was considered the most useful other than “it offers a large amount of information in an easily understandable way.” Thus, future research should seek to verify the two explanations offered here, or elaborate on the reasoning behind this stakeholder group’s visualization preference.

5.1.4 Empirical support for the theoretical framework on landscape visualizations

In his theoretical framework on landscape visualizations (see Appendix 2), Sheppard (2005) provided recommendations on how one may create persuasive visualizations that can subsequently invoke cognitive, affective, and behavioral responses from the public in order to adapt to and mitigate climate change impacts. Cognitive responses are related to awareness and understanding, affective responses are tied to attitudes and emotions, and both responses (i.e. cognitive and affective) are the precursors to behavioral responses, which are related to adoption of mitigation behavior (Sheppard, 2005). The responses from the participants of our focus groups have not only suggested some of the same techniques for creating persuasive visualizations as outlined by Sheppard (2005), but have also empirically demonstrated the impacts of these techniques as predicted by the theoretical framework on landscape visualizations.

In terms of techniques, participants across the three focus groups repeatedly emphasized the need to find the balance between the inclusion of too much detail which may cause panic and confusion (i.e. FEMA National Flood Hazard Layer (NFHL) for Newport Beach, Map A), with sufficient detail (i.e. street level detail found in the FloodRISE 1% AEP depth map in 2015, Map B) that is needed to help local users contextualize the visualizations in their community. This point was also emphasized by Sheppard (2005) as realism and detail at the local and neighborhood scale are expected to result in more robust knowledge construction and more positive affective response. As another example, while “fascinating”, a number of focus group participants questioned if the 2050 projection is too distant in the future to impact users, and opted for near term projections as well as long term projections. The need for near term conditions and projections was also noted in Sheppard (2005), which suggested for the depiction of “near-term conditions…combined with meaningful future considerations, such as their neighborhood as seen by the viewers’ grand-children” in order to obtain affective responses from visualizations users (p. 646).

With respect to empirically demonstrating the responses as predicted by the landscape visualization framework, our focus group participants noted that visualizations such as the FloodRISE probability of flooding in 2015/over next 10 years map (Map D) has the ability to promote flood risk awareness and stimulate discussions among neighbors about flood risk, which is an example of the cognitive responses (i.e. robust knowledge construction, engagement in collaboration learning processes) that can be expected from realistic computer visualizations according to the landscape visualization framework. A second example of empirical observations in support of the framework is the visualizations’ ability to elicit emotional or affective responses from our focus group participants. In particular, our participants noted that visualizations which demonstrated future consequences such as the FloodRISE 1% AEP depth map in 2050 (Map C) had an emotional impact on residents, which supported the idea that visualizations showing future consequences of people’s actions or inactions can invoke affective responses among visualization users. These examples from our focus groups demonstrated that realistic visualizations can have cognitive and affective impacts on users, which have been theorized to lead to behavioral modifications and mitigation behaviors according to the landscape visualization framework. However, since the behavior of our focus group participants were not assessed in this study, future research should collect longitudinal data on focus group participants, in order to empirically verify that the cognitive and affective responses invoked by realistic flood visualizations actually translate into behavioral modifications as theorized in Sheppard’s (2005) landscape visualization framework.

5.2 Limitations and future research needs

Two important methodological limitations of this study should be noted. First, despite the analysis of verbal and nonverbal information from the focus group discussion, participants who failed to respond to particular questions could either be indifferent or have informative reasons for their nonparticipation. Second, due to the modest number of representatives among the three stakeholder groups chosen for the study area, this study is limited to three focus groups with a limited number of participants. Thus, findings and discussions from this study should not be generalized to the entire Southern California region or other coastal areas. We are replicating the design of this study in other areas prone to similar flood hazards, in order to determine if our findings are transferrable to other geographical areas and, eventually, other natural hazards.

Despite these limitations, this study revealed how different stakeholder groups perceive flood hazard, and demonstrated that genuine engagement could cogenerate knowledge needed to enhance flood visualizations and promote positive cognitive, affective, and behavioral responses among users. First, this study found that different stakeholders’ definition of flooding may be influenced by their professional backgrounds. For example, hydrologists may equate nuisance flooding with minor flooding, whereas emergency planners may more cautiously view nuisance flooding as an event that can potentially endanger human lives by impeding evacuation. Second, a majority of participants advocated for information to be presented in a relatable fashion, be it highlighting risk in addition to hazard, or creating an interactive platform where users can customize map scale, depiction of uncertainty, or geographical extent. This highlights the need for future research to examine the best practices for implementing participants' recommendations in order to avoid confusion or misinformation. For example, in providing users with the ability to customize the map scale of flood visualizations, Retchless (2014) cautioned against giving users the ability to zoom in to levels that may not be appropriate given the resolution of the hydrological modeling data (e.g. digital terrain model). As another example, Retchless (2014) suggested that interactive tools such as an interactive slider may be an appropriate tool to communicate assessment uncertainty information to users, as it "allows the user to select different amount of sea level rise and explore the extent of flooding" (p. 22). Third, based on White et al.'s (2013) and Frewer's (2004) work on the role of prior attitudes in risk communication, we partly attributed the home and business owners' trust in uncertain and future projections (i.e. FloodRISE 1% AEP depth in 2050 map) to their experience with credible and relatable flood visualizations (i.e. FloodRISE 1% AEP depth in 2015 map) shown earlier in the focus group, future research should investigate the relationship between prior attitudes and public trust of uncertain scientific information presented in flood visualizations. Lastly, the comparison of recommendations and discussions across the three focus groups revealed some of the unique needs of different stakeholder groups (e.g. the civil society group's interest in nature based flood defenses and information on flood duration and frequency) and possible flood scenarios that may have been overlooked by experts. This confirms that the engagement of experts and non-experts can cogenerate knowledge needed to develop useful flood visualizations that can advance flood risk communication and inform mitigation activities.

6. CONCLUSION

This study demonstrated that the genuine engagement of non-experts and experts can contribute to the development of useful flood visualizations, potentially resulting in changes to risk perception and flood mitigation behaviors as highlighted in Sheppard's (2005) landscape visualization theoretical framework. First, the focus group process fulfilled Fiorino's democratic process criteria as reflected by the high ratings for direct participation, decision authority, and equality (Table 3.4). Consequently, as predicted by the substantive rationale for citizen participation and confirmed by this study's findings, the genuine engagement of stakeholders in the focus groups provided experts with concrete and actionable recommendations for future iterations of flood hazard visualizations. Second, the fact that a majority of participants regarded our visualizations as useful tools (Table 3.4) suggested that participants perceive the visualizations as useful and credible information, which demonstrated the instrumental rationale for citizen participation and collaboration. Third, while social interactions in the form of collaboration and engagement is a key precondition in overcoming the "serious disjuncture between expert and public assessments of risk and varying responses among different publics" (Kasperson, 1988, p. 179), it should be noted that collaboration cannot by itself change risk perception. This point is evident in the relatively low ratings by participants when asked if the focus group changed their perception of flood hazard. To put our findings within the context of Kasperson's (1988) Social Amplification of Risk Framework (SARF), while flood visualizations can be coproduced by experts and non-experts once the precondition (i.e. genuine engagement) for knowledge cogeneration has been satisfied, the information depicted in flood visualizations can be amplified or attenuated by societal actors such as scientists, civil society groups, and public agencies, resulting in changes (or the lack of change) in risk perception. Moreover, it is likely that the collaboration of various stakeholder groups can advance participants' understanding of flood risk through the key amplification steps within the SARF (see Appendix 3 for discussion of key steps), which can in turn result in "secondary impacts" (e.g. change in risk perception, change in regulations, change in mitigation and management practices) that can minimize risk consequences. Therefore, genuine engagement and collaboration should be viewed as one of the key precursors (rather than sole precursor) to the cognitive and affective components of risk perception change. Especially since risk perception change is complicated by factors such as experience, controllability, and the equitable distribution of risk (Di Baldassarre et al., 2014; Slovic, 1987; Fischer, 2000), which are outside the scope of this chapter. Despite this fact, this study showed that collaboration and genuine engagement can contribute to improving future flood visualizations and advancing flood risk communication.

We also showed that genuine engagement requires much more than just the one-way transfer of information from experts to non-experts. Instead, genuine engagement requires systematic planning and the two-way exchange of information between experts and non-experts. The toll associated with flood hazard has increased exponentially in past years due to a combination of natural factors (e.g. sea level rise) and manmade developments (e.g. urbanization and coastal development). Although experts have greatly advanced modeling capabilities and our understanding of flood hazard, many non-experts are unable to access the knowledge or simply consider the new knowledge irrelevant (Pappenberger, 2011). In an effort to amplify and broaden the dissemination of our new understanding of flood hazard and their associated risk, this study examined how different stakeholder groups contextualize and understand flood hazard visualizations. In line with previous criticisms of the deficit model (Feldman et al., 2016; Stone, 2012), we found that all stakeholder groups appreciate relevant details (e.g. extent, depth) in flood hazard visualizations, but the information must be presented in an understandable and relatable fashion (e.g. historical reference, simplified legend) that concurs with the stakeholder group's understanding of flood hazard. Furthermore, while various stakeholder groups share some common recommendations for future modeling efforts (e.g. model worst case scenarios, consider the combined probabilities of flood drivers), the study found that different stakeholder groups can have very different recommendations for improving flood visualizations due to their social and political values.

Finally, the design of this study can serve as a model for fostering genuine engagement between experts and non-experts in future flood management activities. Our findings showed that genuine engagement can not only enable researchers to better understand how different stakeholder groups view and utilize flood hazard visualizations, but can also cogenerate substantive recommendations for enhancing flood visualizations that can improve the communication of risk information to different stakeholder groups. Since "risk communication can strengthen people's risk awareness and motivate those at risk to take preventive actions and be prepared" (Kellens et al., 2013, p. 45), the enhancement of flood hazard visualizations through genuine engagement between experts and non-experts should not only be viewed as a precondition for improving the communication of flood risk, but also considered a precondition for changing flood risk perception and mitigating risks associated with flood hazards.

Discussion and conclusion

1. FROM FLOOD CONTROL TO COLLABORATIVE FLOOD MANAGEMENT

As we have shown, the problem of flooding is likely to become both deadlier and costlier. Although the geographical context of this dissertation is a Southern California community that comprised of relatively affluent and older residents that may not be representative of many coastal communities in other parts of the world, we contend that the findings from this dissertation is nonetheless significant given what Beck (1992) has called "the boomerang effect." Specifically, while less affluent communities with fewer resources to cope with flooding associated with sea level rise or extreme weather events may be the first to feel its impacts, Beck (1992) argues that the impacts will be felt by affluent communities that contributed to the creation of such a risk sooner or later. This is particularly true given that environmental hazards do not respect national border or social class. In addition, the damage potential is also much greater in an affluent community such as Newport Beach due to the concentration of wealth and infrastructure in this low-lying densely populated urban community. Thus, despite the socioeconomic and demographic makeup of our study area, the potential impacts of flooding and the need to mitigate flood risk are just as dire in Newport Beach as other flood-prone communities around the globe.

Hydrological scientists and engineers have historically focused on improving flood model estimates and minimizing the consequences of flooding through the construction of structural defenses such as levees, dikes, dams, and seawalls (Tobin, 1995). However, as flood losses continue to mount, researchers and practitioner have come to recognize the evolving complexity of the socio-hydrological system, and shifted from traditional attempts at “flood control” to flood management and adaptation by studying the interaction of flood hazard and human perception (Moser et al., 2012). A paradigm shift is needed to meet the flood adaptation challenge, where experts from different research communities must not only collaborate with each other, but also with non-experts from the community to re-conceptualize the problem of flooding given the ever-changing social and natural conditions. Through this effort, the social, hydrological, political, and economic implications of flooding can be better communicated between experts and non-experts, which can advance the development of relatable flood visualizations that convey actionable information, and promote the participatory management of flood risk as well as the development of more resilient communities.

While studies on risk perception and risk awareness exist for different types of natural hazards, including earthquakes (Lindell & Perry, 2000), volcanic risks (Leone & Lesales, 2009; Gaillard et al., 2001), flooding (Grothmann & Reusswig, 2006; Keller et al., 2006; Lave & Lave, 1991), hurricanes (Lazo, 2014), and storm surge (Morrow, 2015), these studies were mostly conducted by social scientists using traditional survey instruments with limited interactions between experts and non-experts. Consequently, the participation of non-experts in these studies was often limited to what Arnstein (1969) considered “consultation”. Specifically, participants in these studies solely answered questions provided by experts, while more involved tasks such as problem definition, study and model design, interpretation of research findings, and the translation of research findings in flood risk communication and management often remained under the purview of experts. This is particularly troubling as the research methods and traditional survey instruments developed by experts “may ignore important uncertainties, value judgements and social risks," potentially resulting in findings that fail to account for the meaning and experience of flooding or one's trust and confidence in flood defenses (Shrader-Frechette, 1995, p. 125; Fischer, 2000).

This chapter seeks to highlight the major findings from the previous three chapters and their interconnections, and advocate for enhanced collaboration between experts (scientist, engineers) and non-experts (opinion leaders, practitioners, decision-makers) under the interdisciplinary research paradigm of socio-hydrology. In acknowledging the need to include social processes in the hydrologic cycle, socio-hydrology scholars recognize that flooding is a product of the complex feedback between hydrological and human system components. Consequently, flood management becomes the joint responsibility of hydrological and social scientists, who need to engage with different stakeholder groups to focus on the different dimensions of the flooding problem, and ultimately integrate their findings in order to arrive at effective yet socially acceptable flood management solutions.

Much like previous studies on risk perception (Slovic, 1987; Slovic, 1993), the traditional household survey used in Chapter 1 was effective in analyzing how different factors influenced one's spatial flood risk awareness. While we found that spatial flood risk awareness is influenced by social, geographical, and informational factors (i.e. exposure to flood hazard maps), it exemplified a one-way communication strategy whereby respondents communicated their flood knowledge to researchers in hopes of aiding efforts to improve the communication and management of flood risk in the community. In Chapter 2, the use of sketch maps provided additional insights (i.e. orientation and extent of flood prone areas) into respondents' spatial knowledge of flood risk, and presented an opportunity for researchers to compare experts' spatial flood knowledge with non-experts' spatial flood knowledge. The findings indicated that respondent's spatial knowledge of flood risk as compared with expert estimates (FloodRISE and FEMA) varied by place of residence, which is correlated with different levels of education, income, and housing tenure. While sketch mapping or cognitive mapping exemplified a modified strategy for assessing additional dimensions of respondents' spatial knowledge of flood risk, it is very much still a one-way communication strategy.

In Chapter 3, focus group discussions provided researchers with a greater understanding of the ways in which different stakeholder groups understand the flooding problem, and the flood visualization needs of different stakeholder groups. Unlike Chapter 1 and Chapter 2, focus group discussions enabled the two-way exchange of information and ideas between experts and non-experts, which generated recommendations for future flood modeling, flood communication, and flood management efforts. Moreover, the focus groups generated strategies for enhancing public participation, which can facilitate the coproduction of effective flood communication and management practices.

Given the natural and human causes of flooding, and the different social, political, economic, and physical dimensions associated with flood risk awareness and management, we believe that different modes of public engagement can complement the interdisciplinary collaboration of experts in the search for adaptive solutions to the wicked problem of flooding.

2. WHY DOES PUBLIC ENGAGEMENT MATTER?

The call for public participation and engagement is not new, and has been a prominent issue in the planning literature going back to the 1960s (Arnstein, 1969; Connor, 1988; Innes & Booher, 2004). A resurgent interest in participatory research and citizen science in recent years have furthered the case for the meaningful engagement of experts and non-experts in research collaboration. This trend provided the motivation for this dissertation, which explored traditional and modified means of collecting non-expert flood knowledge, how such knowledge can be applied to further the development of flood models and flood risk visualizations, and its implications for flood risk communication and management. Moreover, by bridging the knowledge gap between experts and non-experts, we can devise creative and holistic solutions to the wicked problem of flooding, and facilitate the development of adaptive and resilient communities.

As shown in this dissertation, the genuine engagement of the public in flood risk communication, management, and resilience-related decision-making can be justified from the substantive, normative, and instrumental perspectives (Fiorino, 1990). Although it is crucial for hydrological and social scientists to work together to account for the physical, social, political, and economic aspects of the flooding problem, the sole collaboration between scientists and experts from different disciplines is not enough to address the problem. This is because non-experts' "basic conceptualization of risk is much richer than that of experts and reflects legitimate concerns that are typically omitted from expert risk assessments" (Slovic, 1987, p. 285). As we demonstrated in Chapter 3, the engagement of experts and non-experts in focus group discussions raised fundamental questions over the definition of flooding, the effectiveness of nature-based flood management techniques, and the strategies that can enhance the usefulness and accessibility of flood visualizations for different stakeholder groups. The last point is especially important in addressing the concern of risk variability (Frewer, 2004), as Chapter 1 and Chapter 2 have shown that different subgroups within the population may experience different levels of risk. Thus, flood visualizations must not only be informative, but need to pay attention to the concerns and informational needs of different stakeholders and population subgroups in order to be useful. These questions, which exemplify issues that have been overlooked by experts at times, support the notion that future flood risk communication and management efforts should be structured as a two-way process (Slovic, 1987). In this process, experts and non-experts are free to contribute substantively to the problem definition, solution formulation, decision making, implementation, and evaluation of policies aimed at combating the problem of flooding (DeLeon, 1999).

From the normative standpoint, the inclusion of stakeholders who will be directly and indirectly impacted by flooding should be viewed as an ethical obligation of experts seeking to reduce vulnerability and enhance community resilience (Shrader-Frechette, 1995). Public agencies such as the Department for Environmental, Food and Rural Affairs in England and Wales have acknowledged that engaging publics in flood science and flood risk management "not just involved efforts at better flood risk communication, but recognition that local people have a right for wider engagement in flood risk decision-making" (Lane et al., 2011, p. 20). In fact, authors such as Shrader-Frechette (1995) have gone a step further, and argued that since "human autonomy, consent, distributive equity, equal opportunity, future generations, civil liberties, social stability" are all potential causalities of flooding, scientific experts are obliged to engage the public and integrate social, ethnical, cultural and legal rationality in the decision-making process (Shrader-Frechette, 1995, p. 117). Moreover, we contend that the participation of stakeholders must take place early in the development of flood risk communication and management plans, as this is essential to ensuring the equitable collaboration between different stakeholder groups and the successful implementation of any proposed flood management plans (Ramsey, 2009; Connor, 1988; Renn et al., 1995). In addition, increased emphasis must be placed on providing stakeholders with access to information and expert advice, so they can provide feedback, question expert assumptions, understand available options, and arrive at reasonable decisions in their best interests (Stone, 2012; Renn et al., 1995; Krimsky, 1982; Shrader-Frechette, 1995). As researchers continue to look for sustainable and equitable floodplain management strategies, there is growing consensus among scholars that a new type of context-specific local knowledge is needed (Di Baldassarre et al., 2013). This new type of knowledge requires not only insights from hydrological and social scientists, but also "knowledge produced outside of academia" (Di Baldassarre et al., 2013, p.3236).

Lastly, the instrumental perspective of enhanced public participation in flood risk management contends that the engagement of non-experts will help generate public support for flood management by creating "a level of decision ownership on the part of the 'at risk' public" (Arnstein, 1969; House, 1999; Faulkner & Ball, 2007, p. 73). However, as pointed out by the social amplification of risk framework (Kasperson, 2012; Kasperson, 1988) and elsewhere in this dissertation, the engagement process must take into account the cultural and political contexts of risk, and include equitable means of participation, in order for the process' outcomes to be perceived as legitimate and attract public support (Jankowski and Nyerges, 2003). In a sense, the formulation of solutions to the problem of flooding can be largely perceived as a policy process, where the collaboration of experts across disciplines and the equitable participation of non-experts at all stages of process is conducive to the generation of optimal and socially acceptable solutions to the problem.

3. BARRIERS TO PUBLIC ENGAGEMENT

The three modes of stakeholder engagement (traditional household surveys, sketch mapping, focus group discussions) covered in this dissertation exemplified participatory research efforts similar to many citizen science projects, and encountered similar challenges that have been discussed in the citizen science literature. Citizen science projects are defined as "research collaboration involving members of the public in scientific research projects to address real-world problems" (Wiggins & Crowston, 2011, p. 1), and can be classified into the contributory, collaborative, and co-created categories (Rotman, 2012). Similar to many existing citizen science projects, the first two chapters of this dissertation are mainly contributory in nature, where citizens and stakeholders were asked to contribute their knowledge of flood risk to advance a scientific research project, but were not engaged in analyzing data nor framing the research agenda. While the third chapter shifted towards the collaborative category by engaging stakeholders in the definition of the problem and giving participants the power to influence the direction of future flood modeling efforts, it still fell short of being a co-created project, which would have required experts and non-experts to be involved in all parts of the project design in an iterative fashion. Much like the literature on public engagement, empirical studies in citizen science have shown that projects which are thoughtfully designed can elevate public understanding of and support for science, and generate "high quality data that lead to reliable, valid scientific outcomes as well as unexpected insights and innovations" (Wiggins and Crowston, 2011, p. 1; Dickinson, 2012). Therefore, in an effort to promote public engagement and move future research efforts in flood risk communication and management towards the co-created model, we will draw upon the citizen science literature and examine some of the barriers to citizen participation and potential solutions.

3.1 Incentivizing expert engagement

Experts must be incentivized to engage non-experts and experts from other research communities, in order to move towards a collaborative participatory research framework that is capable of addressing the different facets of the flooding problem. However, "researchers currently neither are rewarded nor have any incentive to contribute to these types of projects"

(Newman et al., 2012, p. 301; Brown, 1993). In fact, the current reward structure at many academic institutions encourages scientists to be “narrow and specialized,” instead of considering “other systems of thought, disciplines and worldviews and other sources of knowledge and learning” (Cornell et al., 2013, p. 68). This can be seen in climate science research, where “scientists’ room to investigate problems is often bounded by discipline and the professional norms,” and the existing academic reward system “rarely recognizes interdisciplinary work, outreach efforts, use-inspired research, and publications outside of academic journals” (Feldman & Ingram, 2009, p. 11). This lack of convergence thinking and interdisciplinary collaboration is especially troubling given that flooding is as much a natural as a manmade problem with evolving complexities (Moser et al., 2012). Luckily, as pointed out in Chapter 1, a relatively small community of socio-hydrology researchers has started to recognize social processes as an intrinsic part of the hydrologic cycle, and acknowledged the complex interactions between social and hydrological drivers of flooding. However, as long as researchers receive their rewards (e.g. status, tenure) from the authorities above them, “they commonly come to see the world through the eyes of the elites” and overlook the value of interdisciplinary collaboration and public participation in the knowledge system (Fischer, 2000, p. 17).

3.2 Incentivizing non-expert engagement

As Chapter 1 has shown, the feedback (i.e. self-rated spatial awareness of flood risk) voluntarily provided by the public before and after viewing different flood models can help guide future flood modeling efforts by demonstrating a preference for visualizations with higher spatial resolution. Chapter 2 showed that the sketch maps provided by residents can reveal disparities in spatial knowledge of flood risk based on one’s area of residence and one’s educational attainment, which suggest the need for targeted outreach and communication campaigns to address the knowledge gaps of specific socio-demographic subgroups. These important findings can shape and nurture future collaborations between experts and non-experts, and would not have been possible without non-experts' contributions and participation. This is why it is especially important to consider the incentives that drive non-experts to participate in research projects.

Given that most public participants in participatory research and citizen science projects are volunteers, researchers have long questioned the motivation for members of the public to contribute to such projects and to do so in their full capacity:

> "Why is it that citizens who have no obvious incentive are nevertheless willing to spend large amounts of time creating the content of VGI (volunteered geographic information) sites? What kinds of people are more likely to participate, and what drives them to be accurate (or inaccurate)?" (Goodchild, 2007)

The lack of motivation for non-experts and practitioners to participate in research is evident in our focus group discussions, where the turnout for the three focus groups mentioned in Chapter 3 were suboptimal despite months of recruitment efforts through various channels. This may be due to a variety of factors such as low self-efficacy (i.e. one's appraisal of his/her ability to cope) and non-protective responses (e.g. denial of threats, wishful thinking) (Grothmann & Reusswig, 2006; Hung & Chen 2013). But the most worrisome potential cause for nonparticipation is that the social capital needed to motivate public participation has declined in recent decades due to factors such as economic anxieties and technologies (e.g. internet, television) (Bluhm & Heineman, 2006).

Social capital is defined as the “features of social organization such as networks, norm, and social trust that facilitate coordination and cooperation for mutual benefits” (Putnam, 1993, p. 35; Blanchard & Horan, 1998). In the absence of networks, norms, and trust among experts and non-experts, public participation may be minimal and the aforementioned benefits of public participation in flood risk communication and management may be undermined. Moreover, it has been argued that social capital such as trust and networks found at the regional and local levels are important determinants of collective actions, such as the development and adoption of preparedness measures to mitigate risk (Paton, 2003). An example of regional level collaborations aimed at building social capital in the form of networks among decision-makers is The National Academies of Sciences, Engineering, and Medicine’s Gulf Research Program, which actively promoted the collaboration among members of the public, private, and academic sectors in the Gulf of Mexico region in order to better understand the risk that oceanographic processes (i.e. Loop Current) pose to human and natural activities in the region (The National Academies, 2017). As another example, neighbors at the local level may build social capital by providing each other with information about fire insurance, or by helping each other clear dry brush around each other’s homes in order to collectively mitigate potential losses due to wildfires in their community. These two examples demonstrate that social capital can be accumulated at the regional level among decision-makers as well as at the local level among individuals, both of which can be critical in mitigating risks associated with natural hazards. Thus, it is imperative for collaborations on flood risk communication and management to be genuine and iterative, as these are preconditions for the development of trust and networks. These social capital can not only encourage sustained collaboration and improve professional relationships among experts and non-experts, but can also enhance the quality, credibility, and acceptance of scientific information as well as motivate collective risk mitigation behaviors (Innes & Booher, 2004; McNie, 2007; Koontz et al., 2004; Paton, 2003).

3.3 On developing sustainable collaboration

Related to the previous point, non-expert participants who volunteered their time must be provided with the necessary support and feedback in order to feel welcomed and continue in their participation. For example, researchers have found that citizen scientists consider training and constant communication with scientists as a reward and motivation for continued involvement (Rotman, 2012; Bonney et al., 2009). This is precisely why the focus groups in Chapter 3 intentionally included a hydrological modeling expert participant, whose purpose is not to intimidate the other participants, but to assist them in understanding and challenging the flood model estimates and flood visualizations that were presented.

In addition to training and feedback, another key to sustaining the collaboration between non-experts and experts is to ensure participant access to the products that grew out of the collaborative effort. This point was emphasized in our focus groups, where participants from all three focus groups advocated for a variety of strategies to increase the accessibility, usefulness, and visual impact of flood models. Examples of these strategies included the use of interactive tools designed to enable users to customize the level of detail, the type of information (i.e. layers), and the extent that they are viewing. Another example is the recommendation for flood information to be presented as animations or as “before and after” visualizations, portraying the flood impacts before and after the construction of new developments and flood defenses. The strategies that were suggested mostly involved the use of emerging information communication technologies (eICTs) such as geographic information systems (GIS), social media, and computer tablets to disseminate interactive flood visualizations, and previous studies “acknowledge the potential for eICTs to facilitate wider public participation in planning for disasters” (Cutts 2015, p. 149; Sheppard, 2005). Therefore, future collaborations between expert and non-expert should not only utilize eICTs as a way of soliciting data and input from non-expert participants as was done in Chapter 2, but should also leverage eICTs as a platform to disseminate and sustain the ongoing discussion of research findings among stakeholders (King, 2011; Cutts, 2015).

4. IMPLICATIONS FOR FLOOD RISK COMMUNICATION AND MANAGEMENT

Through genuine public engagement, the three participatory approaches (traditional household surveys, sketch mapping, focus group discussions) utilized in this dissertation generated findings that can advance flood risk communication and management as outlined in the social-cognitive preparation model (Paton, 2003). The social-cognitive preparation model consisted of three phases: (1) motivators, (2) intention formation, and (3) linking intentions and preparedness (Paton, 2003).

4.1 Motivators

Motivators are factors that motivate people to consider risk reduction measures and protective behaviors (Figure 4.1). Examples of motivators include one’s risk perception and awareness. We examined these motivators in Chapter 1 and Chapter 2, and found that motivation levels, in the forms of awareness and perception, varied across different socio-demographic and geographical subgroups within the population. This information is crucial in guiding the development of targeted risk communication activities. Because while concrete information on risk impacts may “improve memorability and construction of mental representations,” this information “has to concentrate on the most important target group (who may be) least informed about a hazard" (Dransch et al., 2010, p. 297). Aside from increasing awareness, perception, and motivational levels, these targeted risk communication activities are important because an adequate level of motivation is needed before one will progress to the next phase, intention formation. In addition, the focus group discussions on flood visualizations in Chapter 3 generated user-specific recommendations for increasing the realism and usability of flood visualizations, which previous research has shown to promote knowledge generation as well as awareness (Sheppard, 2005).

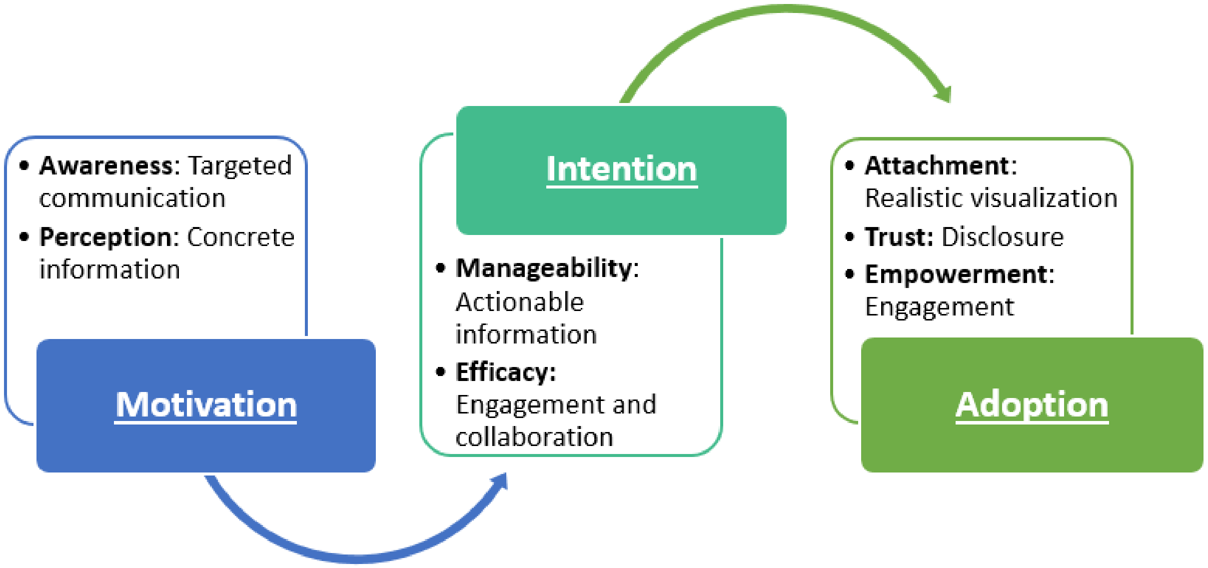


Figure 4.1: Contextualization of the social-cognitive preparation model (Paton, 2003) in flood risk communication and management

4.2 Intention formation

The factors within intention formation are related to the perceived manageability of the problem (outcome expectancy), as well as one's perceived capacity (self-efficacy) and available resources (response-efficacy) to mitigate damages (Figure 4.1). While the perceived unpredictability and uncontrollability of natural hazards may decrease outcome expectancy and self-efficacy, the genuine engagement and collaboration of experts and non-experts in the coproduction of flood visualizations with actionable information can not only decrease the sense of uncontrollability (Paton, 2003), but can also provide resources (i.e. information, social capital) needed to help individuals make favorable judgments about the effectiveness of their responses. Thus, the co-development of relatable flood visualizations that can convey actionable information to different stakeholders is not only a crucial part of advancing risk communication, but also has critical implications for building social capital and advancing risk management.

4.3 Linking Intentions and Preparation

The final phase in the social-cognitive preparation model is where individuals with adequate level of intentions, convert their intentions into actual preparation or mitigation measures (Figure 4.1). Paton (2003) noted that variables such as sense of attachment to a place, feeling of empowerment, and trust are all important in this process. This highlights the importance of genuine engagement as defined by the democratic process criteria in Chapter 3, which is not only key to building trust and support for the process and its outcomes (instrumental rationale), but can also empower stakeholders to contribute their knowledge to flood visualizations and decisions that can directly impact them (normative rationale), and coproduce realistic flood visualizations with experts in order to enhance residents' sense of community and depict model uncertainties in terms that are understandable and useful for users (substantive rationale) (Sheppard, 2005).

By contextualizing the research and findings of this dissertation along the three phases of the social-cognitive preparation model, we have demonstrated how risk communication is inevitably tied to risk management measures aimed at preventing and mitigating damages (Paton, 2003; Dransch et al., 2010). Thus, it is important to view the design of risk communication activities or the refinement of flood visualizations not as an end in itself. Rather, these activities are only means to encouraging the adoption of personal risk reduction measures, which can in turn increase community resilience.

5. FUTURE RESEARCH NEEDS

A principal contribution of this dissertation to the field of disaster studies and risk communication is to demonstrate how human perception and awareness of flood risk can be influenced and modified by a variety of social, geographical, hydrological, and informational factors. We have also shown that human perception and awareness can sway the feedback provided by stakeholders, which can potentially modify mitigation behaviors that can lead to greater community resilience from flood. Therefore, it is not only important to integrate stakeholders' feedback in future flood risk communication and management efforts, but to also be cognizant of the bias and uncertainty in non-experts' input especially in different social and political contexts. We have shown this in four ways.

First, in agreement with previous studies, we have shown in Chapter 1 and 2 that personal and contextual factors such as one's trust in government, place of residence, education, income, and home ownership status can influence one's spatial awareness of flood risk. Thus, it is particularly important to ensure that diverse stakeholders have equal opportunities to participate in the shaping of flood risk communication and management plans, in order to ensure that the solution is sound, equitable, and supported by the general population. While emerging information communication technologies such as PPGIS and virtual reality hold great promise in facilitating public engagement and involving people in the collaborative risk management process (Cutts, 2015; Sheppard, 2005), future studies should investigate ways in which these technologies should be implemented in order to safeguard their credibility and maximize their effectiveness. For example, other than identifying the visualization needs of different stakeholder groups, future research should identify the types of flood model parameters that different stakeholder groups are most concerned about, and their ability to provide plausible values for those parameters. As we strive to attract broad participation and support for the participatory management of flood risk, future research should also explore whether the different worldviews held by different non-expert groups in turn influence their willingness to engage, and the manner in which they engage with experts to coproduce flood risk communication and risk mitigation plans.

Second, despite this dissertation's focus on the different modes of non-expert engagement in flood risk assessment, it is important to note that the engagement of experts in flood risk assessment is equally important. Specifically, Chapter 1 has shown that highly detailed estimates of flood hazards provided by hydrological experts has greater potential of changing respondents' flood risk awareness. Although previous research has suggested that detailed and realistic visualizations can lead to more direct and robust knowledge construction (Sheppard, 2005), the mechanism in which respondents' flood knowledge is changed by these visualizations, whether this change is permanent, and how this change impacts one's willingness to sustain engagement with experts is unclear. Specifically, we suspect that there may be confounding factors such as one's previous experience with detailed flood information or one's prior perception of flood risk, which may serve to amplify or attenuate the impacts that realistic visualizations have on knowledge construction. This highlights the need for hydrological scientists and social scientists to investigate not only if, but how, do highly detailed estimates of flood hazards influence risk awareness, in an effort to improve risk communication and sustain collaborative partnerships with non-experts. Moreover, although the findings from the focus groups (Chapter 3) largely indicate their success in effectively engaging participants according to the democratic process criteria, more research focusing on the appropriate level of involvement by hydrological experts in focus group discussions is needed, given that different stakeholder groups (e.g. practitioners, homeowners, emergency planners, insurance agents) may have different initial attitudes, baseline knowledge, agendas, and incentives which drive their participation.

Third, much like the uncertainty inherent in hydrological models due to measurement errors or data scarcity, there is comparable (if not more) uncertainty in the information provided by different non-expert stakeholders which may be influenced by factors such as recall bias or perhaps even the same socio-demographic variables that have been shown to influence one's spatial awareness of flood risk. Thus, much like existing research on the communication of flood model uncertainty to different users, the dissemination of products arising from participatory research on flooding (e.g. Public Participation GIS) must similarly acknowledge and disclose the uncertainty inherent in such products. It is encouraging that findings from citizen science studies in the fields of astronomy and ecology have found that the accuracy of non-expert observations that are evaluated collectively by other non-experts and experts can be as good or even better than that of professional observations (Wiggins & Crowston, 2010). Similarly, studies on earthquake and damage data submitted as part of the U.S. Geological Survey's "Did You Feel It?" program have found that non-expert observations are robust and can be used to create intensity maps that "are made more quickly, provide more complete coverage and high resolution" (Wald et al., 2011, p. 688). However, previous research has also expressed concerns over potential biases and uncertainties that may be introduced by low response rates or external factors (e.g. loss of power or internet after major disaster) that may limit citizen participation (Wald et al., 2011; Brown et al., 2014). Thus, future research should address how to best account for and communicate the uncertainty inherent in PPGIS data to decision-makers, and how may this uncertainty impact the usefulness of flood products derived from participatory flood risk research activities.

6. CONCLUSION

As the problem of flooding poses an increasing threat due to a combination of social and natural forces, new approaches to flood risk communication and management are needed to complement traditional research approaches in hydrology and the social sciences. Despite the long tradition of narrow and specialized academic research, the establishment of the fields of socio-hydrology and citizen science provides a glimmer of hope.

Socio-hydrology and citizen science both have the potential to change how experts and non-experts fundamentally engage each other as they seek to reduce the impacts of flooding and build more resilient communities. While socio-hydrology encourages hydrological and social scientists to collaborate and analyze the interactions between social and physical processes within floodplains, citizen science and participatory research approaches enable scientists to engage non-experts in order to build social capital, and coproduce flood risk communication tools and management strategies. As in any public participation exercises or collaborations, there is the risk that experts may disagree with each other or with non-experts. Rather than viewing these disagreements as impediments to engagement or collaboration, these disagreements should be encouraged, as they can expose underlying substantive, normative, or instrumental concerns that are hampering flood risk communication and management. As shown in two of the many examples in this dissertation, the disagreements among residents over the extent of flood prone areas in their neighborhoods can reveal gaps in local awareness of flood risk, while the disagreements between focus group participants and experts can reveal stakeholder-specific depiction and content preferences that can advance the future development of flood visualizations. Given that no specific group of experts or stakeholders has complete knowledge of flood risk and flood vulnerability, the collaborative framework advocated by socio-hydrology and citizen science ensures that communication and management strategies will be inclusive of diverse perspectives, which may produce solutions to the wicked problem of flooding that is actionable, equitable, and supported by affected stakeholders.

This dissertation adopted three participatory approaches (traditional household surveys, cognitive mapping, focus group discussions) to inform the design of future flood risk communication and management activities. Although these approaches vary in the degree in which they engage stakeholders, they nonetheless provided researchers with different insights on local flood knowledge and concerns. Given that new modes of engagement are increasingly made possible by emerging information and communication technologies (e.g. GIS, social media, virtual reality), we have proposed a framework based on the democratic process criteria that is designed to foster public trust and confidence in the engagement process. While our findings suggest that these new tools and methods of engagement can have positive cognitive and affective impacts on individuals, it remains to be seen if these strategies can motivate behavioral changes as theorized or sustain the collaborations needed for the participatory management of flood risk.

Flooding has been called a wicked problem for a reason, primarily because the evolving complexities associated with the natural and human drivers of flooding make all-encompassing solutions elusive (Moser et al., 2012). As such, any efforts to manage flood risk must be adaptive and evolve with the changing sociopolitical context and/or natural condition. Moreover, these solutions must be inclusive of the concerns of various stakeholder groups and consider human a part of the hydrologic cycle. While it may be more “convenient” to disregard interdisciplinary collaborations or democratic interactions and continue the tradition of specialized research, decades of experience have shown that such an approach is not only ineffective, but may actually actively “undermine the capacity of societies to solve problems” by stifling creativity and alternative perspectives (Stehr, 2016, p. 44). Therefore, despite the uncertainties and challenges associated with participatory approaches of flood risk management, the human and economic toll associated with flooding is simply too great to persist in our old ways when new promising approaches are within reach.

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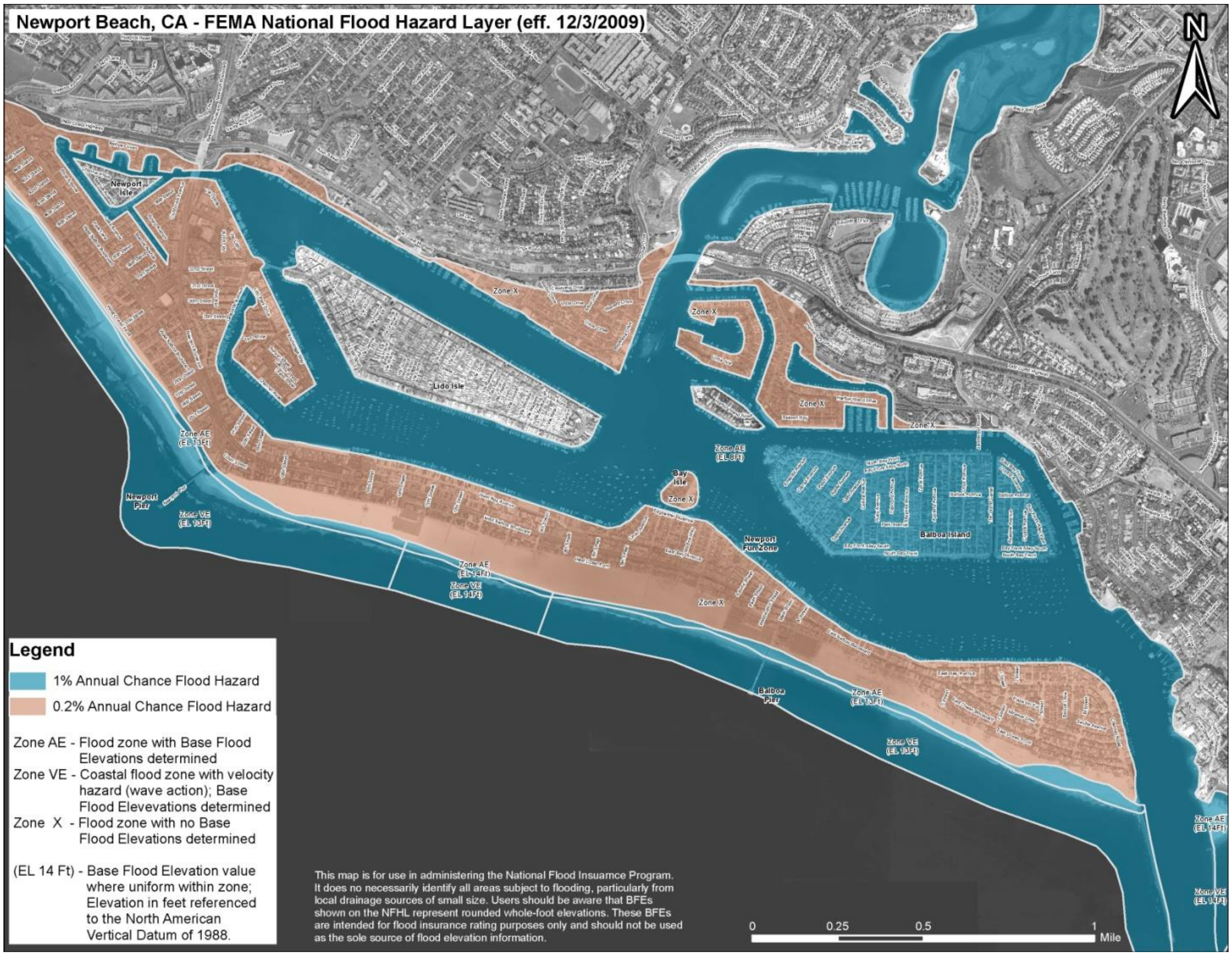
Appendix 1: Maps shown during the focus groups with detailed descriptions.



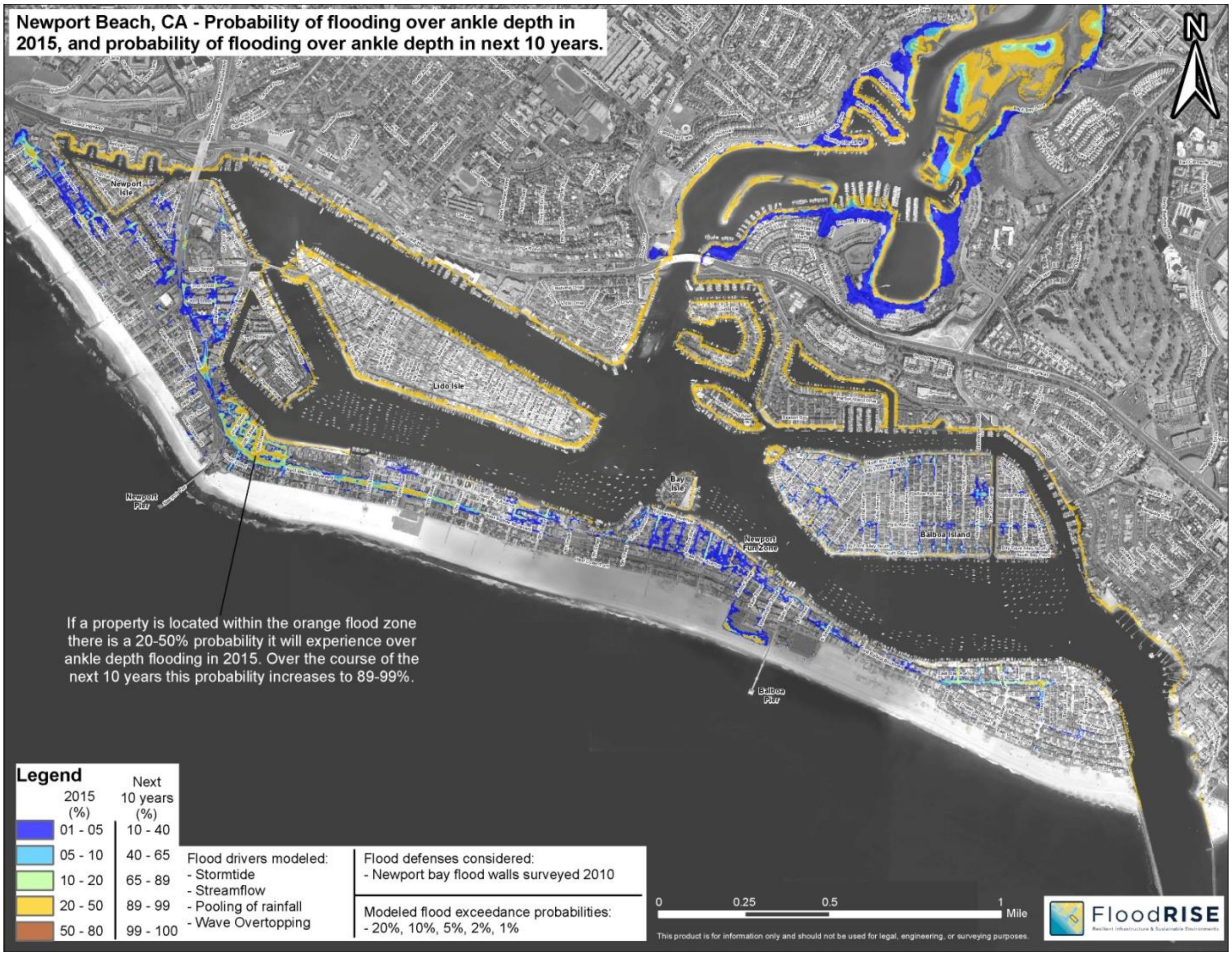
Newport Beach, CA - FEMA National Flood Hazard Layer (eff. 12/3/2009)

This map is for use in administering the National Flood Insuamce Program. It does no necessarily identify all areas subject to flooding, particularly from local drainage sources of small size. Users should be aware that BFEs shown on the NFHL represent rounded whole-foot elevations. These BFEs are intended for flood insurance rating purposes only and should not be used as the sole source of flood elevation information.

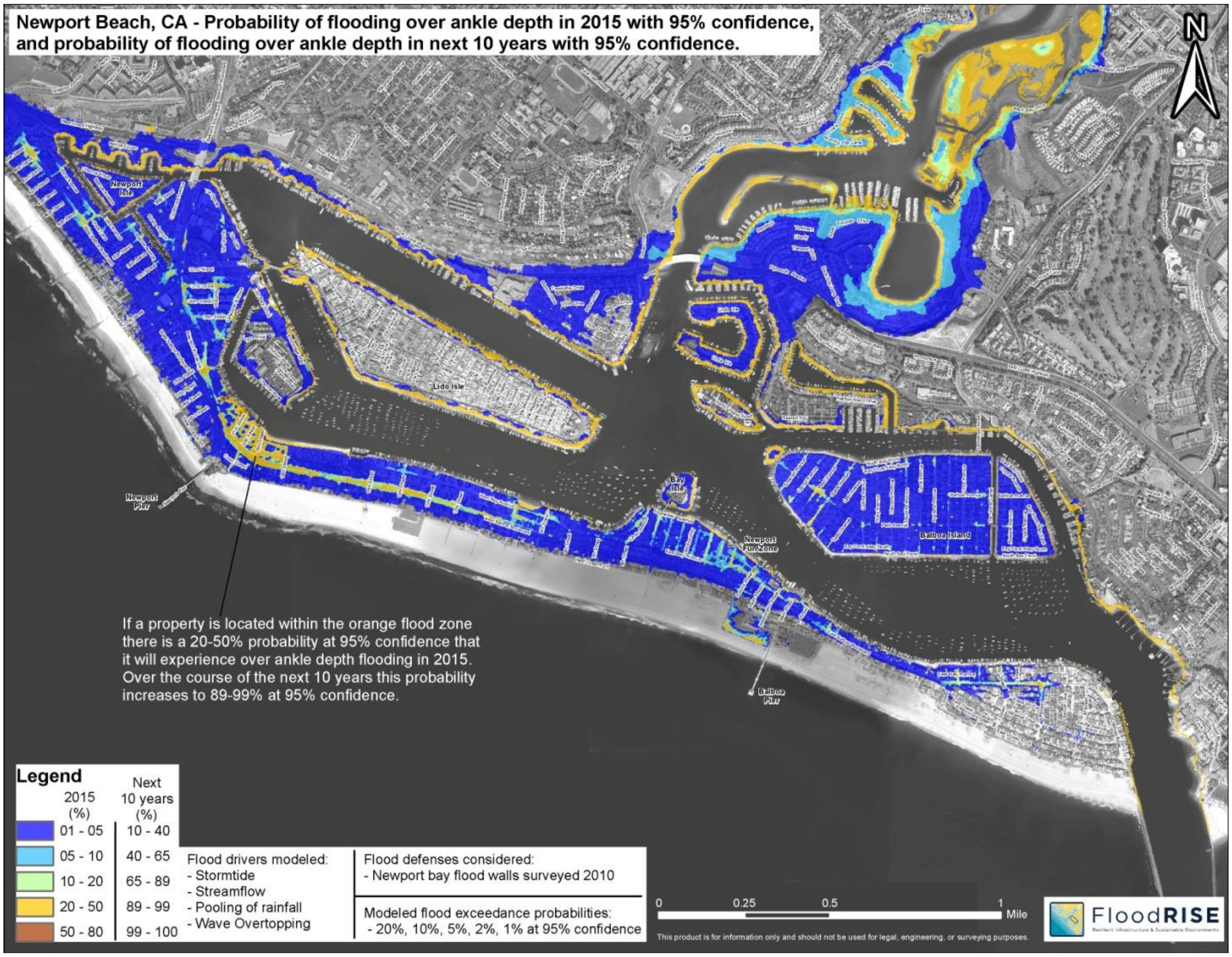
Map A. FEMA NFHL for Newport Beach, CA - This map shows the Federal Emergency Management Agency's (FEMA) National Flood Hazard Layer (NFHL) for the city of Newport Beach. It shows the 1% and 0.2% annual chance flood hazard zones and base flood elevations (BFE) for each flood zone.

Map B. FloodRISE 1% AEP depth in 2015 - This map shows the water depths resulting from flood events that have a 1% chance of occurring in 2015. The flood drivers considered during hydrodynamic analysis are stormtides, wave overtopping along the Balboa Peninsula, runoff and pooling from rainfall, and streamflow into the Newport Bay from the San Diego Creek, Bonita Canyon and the Delhi channels (not shown in map). The flood heights are related to body height as shown in the legend.

Map C. FloodRISE 1% AEP depth in 2050 - This maps predicts what the flood depths from 1% AEP flood events in 2050 will look like. To model the 1% AEP of sea level for this scenario, sea level rise predictions from the National Research Council for the southern California coast were aggregated with an analysis of sea level variance based on 91 years of stormtide measurements recorded at NOAA's Los Angeles tide gauge (ID: 9410660).



Map D. FloodRISE probability of flooding in 2015/over next 10 years - This map shows for each location its annual probability of flooding over ankle depth as well as the probability of flooding over the next 10 years. This map aggregates flood zones from a range of AEP scenarios from 20% to 1%. It complements the 1% AEP maps (B and C) by considering a larger variety of events that occur on average more frequently than the 1% AEP.



Map E. FloodRISE probability of flooding in 2015/over next 10 years with 95% confidence - This map is similar to map D, however it shows how uncertainty in the model data affects flood zone predictions. Uncertainty consideration is limited to model forcing parameters (tide elevations, wave runup elevations, and streamflow). While map D visualizes for each flood driver and AEP the median forcing parameters (e.g. 50th percentile wave runup elevation), in this map the 95th percentile for each forcing parameter is used. In other words, this map shows the upper level/limit flood zone for each exceedance probability.

Map F. FloodRISE roads accessible to vehicles in 2015 - This map shows the probability of streets being accessible to sedans and emergency vehicles under current climatic conditions (2015). The flood depth threshold adopted to discern road accessibility to sedans is 18 inches (1.5 ft), while for emergency vehicles a depth of 30 inches (2.5 ft) was used. While some road segments have a low probability of becoming inaccessible to sedans, all roads remain accessible to emergency vehicles since current flood conditions in the Newport Bay are not capable of generating flooding along streets over 2.5 ft in depth.

Appendix 2: Visualization stimulus and response spectrum in the Landscape Visualizations Theoretical Framework (Shepperd, 2005) (Reproduced with permission from the copyright owner)

Appendix 3: Key amplification steps within the Social Amplification of Risk Framework (Kasperson, 1988) and implications for flood risk communication and management

Filtering relevant information from flood models and suggest for their inclusion in flood visualizations
Decoding and understanding flood risk information shown in flood visualizations
Processing information based on individual experiences and understanding
Attaching social values to information to assess its policy and management implications
Interacting with peers to evaluate the credibility, accuracy, and trustworthiness of information
Formulating behavioral response in light of flood risk
Engaging in action to respond to flood risk