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The Influence of Hazard Maps and Trust of Flood Controls on Coastal Flood Spatial Awareness and Risk Perception

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Abstract

Understanding the impact of digital, interactive flood hazard maps and flood control systems on public flood risk perception could enhance risk communication and management. This study analyzed a survey of residents living near California's Newport Bay Estuary and found that self-rated nonspatial perceptions of dread or concern over future flood impacts were positively associated with spatial awareness of flood-prone areas. Trust in flood control systems was associated with greater spatial flood hazard awareness but weaker nonspatial dread or concern, suggesting residents who witnessed and trust flood control systems developed a confident sense of flood-prone areas and that this confidence reduced the overall nonspatial

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sense of flood dread and concern. Viewing a flood hazard map eliminated differences in spatial hazard awareness between subgroups that existed prior to viewing a map, and viewing a map with estimated flood depth and greater spatial differentiation was associated with higher levels of postmap spatial awareness.

Keywords
flooding, hazard maps, flood controls, communication, risk perception

Introduction

Affecting at least 20 million people worldwide annually, flooding has been recognized as the third most damaging natural hazard globally (Kellens, Terpstra, & De Maeyer, 2013; Loucks, 2015). As a result of climate change, the impacts of these events are expected to become much greater and costlier (Faulkner & Ball, 2007; Newell, Rakow, Yechiam, & Sambur, 2016). 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 (Di Baldassarre et al., 2015; Jongman, Koks, Husby, & Ward, 2014; Jongman, Ward, & Aerts, 2012; Morrow, Lazo, Rhome, & Feyen, 2015). One example of these vulnerable communities is the City of Newport Beach located in Southern California, where past studies suggest that the frequency of nuisance and extreme flooding is likely to increase due to ground subsidence and to a rise in sea level (Flick, Murray, Ewing, & Asce, 2003; Moftakhari et al., 2015; National Research Council., 2012; Tebaldi, Strauss, & Zervas, 2012). Consequently, high impact events that are currently of low probability, such as the so-called “century” extremes or the “100-year flood” (1% annual exceedance probability event), are expected to become an annual occurrence by 2050 in Southern California (Tebaldi et al., 2012).

Risk communication can enhance the public’s knowledge about risk, encourage changes in attitudes and behavior, and increase public confidence with risk management agencies (Wachinger, Renn, Begg, & Kuhlicke, 2013). Understanding factors associated with flood risk perception and the influence of flood hazard maps on risk perception could help (a) improve risk communication, (b) gauge people’s willingness to support government policies and take precautionary measures, and (c) support the development of more effective mitigation strategies (Kellens et al., 2013). Furthermore, digital, interactive flood hazard maps could be a valuable tool in enhancing risk communication. Although recent studies have examined the impact of risk map format, design, and delivery (Fuchs, Spachinger, Dorner, Rochman, & Serrhini, 2009; Hagemeier-Klose & Wagner, 2009; Kjellgren, 2013; Retchless, 2014), only two previous studies have directly assessed the influence of flood hazard maps on flood risk awareness. An early assessment by Handmer (1980) found that hazard maps were ineffective in influencing the public's perception of flood risk (Handmer, 1980), but a recent study by Retchless (2017) found that college students who viewed an interactive map of sea level rise increased their risk perceptions (Retchless, 2017).

This study expands our understanding of how viewing flood hazard maps affects the flood risk perceptions of coastal residents by analyzing results from a survey undertaken as part of the Flood Resilient Infrastructure and Sustainable Environments (FloodRISE) research project. Specifically, it contributes to flood risk assessment research and management in three ways. First, our study is the first to our knowledge to assess the associations between spatial flood hazard awareness and nonspatial dimensions of flood risk perception ("dread of expected floods" and "major flood impact concern") that lack geographic specificity. Second, we investigate whether trust in flood controls (e.g., seawalls, levees) creates a "flood control effect" for residents' self-rated spatial flood hazard awareness and nonspatial risk perception. Third, we use a pre–post study design to directly assess the impact of two interactive digital flood risk maps on self-rated spatial awareness of the distribution of local flood hazards: (a) two-dimensional hydrodynamic FloodRISE estimates of flood-prone areas depicting flood depth and street-level differentiation and (b) Federal Emergency Management Agency's (FEMA) National Flood Hazard Layer (NFHL) without flood depth information and with less spatial differentiation.

Literature Review

Risk Perception

Previous studies indicate personal hazard experience and trust in authorities or experts are the strongest predictors of risk perception of natural hazards, including floods, droughts, earthquakes, landslides, volcanic eruptions, and wild fires (Barberi, Davis, Isaia, Nave, & Ricci, 2008; Wachinger et al., 2013). The influence of individual factors including age, gender, and educational attainment on risk perception varies across studies, but in some cases, these factors mediate or amplify the relationship between experience, trust, and disaster preparedness (Burningham, Fielding, & Thrush, 2008; Jóhannesdóttir & Gísladóttir, 2010; Kellens, Zaalberg, Neutens, Vanneuville, & De Maeyer, 2011; Knocke & Kolivras, 2007). Although several studies suggest direct experience with a natural hazard has a strong and positive influence on risk perception (Damm, Eberhard, Sendzimir, & Patt, 2013; Grothmann & Reusswig, 2006; Heitz, Spaeter, Auzet, & Glatron, 2009; Ruin, Gaillard, & Lutoff, 2007), other research indicates that direct experience of a hazard among those who did not experience associated personal damage could result in decreased risk perception (Green, Tunstall, & Fordham, 1986; Halpern-Felsher et al., 2001; Scolobig, De Marchi, & Borga, 2012) and that memory of a previous hazard experience and associated adaptation behavior could vary by place of residence (Fuchs et al., 2017). Some evidence suggests risk perception is associated with contextual factors such as residential location and living in an at-risk area (Brilly & Polic, 2005; Duží, Vikhrov, Kelman, Stojanov, & Juřička, 2017; Heitz et al., 2009) and length of time at residence (Burningham et al., 2008).

Trust in authorities to manage hazards plays a strong role in risk perception, particularly when individual knowledge about a hazard is lacking (Siegrist & Cvetkovich, 2000). Citizens often lack knowledge to fully judge uncertainties and risk, and trust can reduce the complexity and burden of evaluating risk when they rely on the opinions and judgment of trusted experts instead of independently evaluating a hazard. Trust lowers flood risk perception and the amount of dread evoked by flood risk, and its effect extends to flood protection systems when citizens delegate the responsibility of building and monitoring control systems to risk managers (Terpstra, 2011; Viglione et al., 2014; Wachinger et al., 2013).

For instance, White (1945) coined the term "levee-effect" to describe how flood defense structures intended to reduce the frequency of flooding can change local floodplain conditions, instill a false sense of security among floodplain inhabitants, and leave residents in vulnerable areas relatively unconcerned about flood risk (White, 1945). 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 a barrier dune or other types of flood defense (Burton & Kates, 1964). Consistent with this hypothesis, residents living in areas enclosed by levees or areas certified as protected against the 100-year flood may have a false sense of security and a lower level of perceived flood risk (Ludy & Kondolf, 2012; McPherson & Saarinen, 1977; Pinter, 2005).

Furthermore, recent studies have used computer models to analyze the influence of hypothetical levees (structures that *could be* constructed) and found that too much trust in flood protections and short-lived collective memory of flood events could be associated with under perceiving flood risk, and that lack of trust in flood controls and longer memory of flood events could be associated with an overestimation of risk (Di Baldassarre, Kooy, Kemerink, & Brandimarte, 2013; Viglione et al., 2014). Related studies indicate that trust in flood protections is negatively associated with risk perception, flood preparedness, intent to purchase insurance, and the adoption of flood-mitigation measures (Grothmann & Reusswig, 2006; Hung, 2009). Trust is also informed by experience when flood defenses are visible because individuals can gather information about the quality of risk management by observing the performance of structures and can adjust trust in flood controls and risk perception based on observations (Terpstra, 2011).

Existing studies provide little consensus regarding how to measure the various dimensions of flood risk perception and most use multiple questions or items to measure its different aspects (Kellens et al., 2013). Risk perception is a process involving cognitive aspects (knowledge, expected likelihoods, and analytical reasoning) and affective aspects (feelings, perceived control, and emotional reactions); understanding both aspects is important given their complex interplay (Slovic, Finucane, Peters, & MacGregor, 2004). A variety of methods have been used to process and analyze risk perception questions including using only one question to measure perceived levels of flood risk (Burningham et al., 2008) or factor analysis to transform several items into one score (Kellens et al., 2011).

Questions regarding flood risk perception typically ask about risk in a general way, with low geographic specificity, for example, respondents' general nonspatial knowledge about factors associated with flooding or their level of awareness about flood risk (Heitz et al., 2009; Knocke & Kolivras, 2007) or whether their property or community is potentially at risk of flooding (Benight, Gruntfest, Hayden, & Barnes, 2007; Burningham et al., 2008; McEwen, Hall, Hunt, Dempsey, & Harrison, 2002). Although some studies have investigated perception of the distribution of flood-prone areas using cognitive mapping exercises (Brilly & Polic, 2005; Cheung et al., 2016; O'Neill, Brennan, Brereton, & Shahumyan, 2015; Pagneux, Gísladóttir, & Jónsdóttir, 2011; Ruin et al., 2007), this method requires each respondent to map his or her perceptions on a hard copy or digital map and tends to be resource and time intensive to collect and analyze.

The Impact of Hazard Maps on Flood Risk Perception

Hazard maps support flood risk management plans and public risk communication by depicting information on the geographic extent and/or depth of potential inundation for flood events of different probabilities (Meyer et al., 2012). They can provide a visual and vivid tool to represent complex and localized information, and to increase public knowledge and understanding of the potential geographic extent of a hazard's potential impact (Dransch, Rotzoll, & Poser, 2010). Digital, interactive maps are increasingly used in risk communication and offer a powerful platform for information presentation, analysis, and exploration. Maps that depict hazards at more local levels (e.g., neighborhoods or blocks) could promote greater personal engagement if flood risk information can be viewed relative to familiar features such as roadway networks and landmarks (Monmonier, 2008; Retchless, 2014). Flood hazard information could also be made more tangible and personally relevant if maps are accessible in an interactive format using a pan-and-zoom interface that encourages users to explore risks near specific locations that are personally meaningful such as home and common activity locations (Hagemeier-Klose & Wagner, 2009).

Unfortunately, we know little about whether and/or in what ways hazard maps raise public perception of flood risk as most previous studies have not directly evaluated their influence on public risk perception (Dransch et al., 2010). Previous studies have focused on map content and design (Fuchs et al., 2009; Kjellgren, 2013) or the public's ability to interpret and decode map content compared with experts or risk managers (Hagemeier-Klose & Wagner, 2009). The first study to our knowledge to directly assess the influence of flood hazard maps on flood risk awareness was conducted by Handmer (1980) as part of the Canadian Flood Damage Reduction program. It concluded that dissemination of hazard maps was ineffective in influencing the public's risk perception. Handmer used a pretest and posttest survey design in which each respondent's flood attitude was evaluated before and after flood hazard maps were distributed. He found that the flood attitude and awareness of the group that received maps was not significantly different than the control group that did not receive maps, and he attributed an overall local increase in risk perception to intensive media campaigns surrounding the maps. The only other existing study to our knowledge to directly assess the influence of flood hazard maps on risk perceptions was a survey of college students in Sarasota, Florida, conducted by Retchless (2017), which included an assessment of risk perceptions before and after using an interactive map of sea level rise. He found that risk perceptions increased postmap and that students who lived farther from affected areas and students who were initially doubtful or cautious about climate change experienced larger increases in risk perceptions (Retchless, 2017).

Study Objectives

Our study is the first to our knowledge to analyze the association between (a) a set of nonspatial measures of risk perception comparable with those found in the literature and (b) a spatial measure of flood hazard awareness, which asked each respondent to self-rate his or her level of awareness of where flooding could occur in his or her community. Introducing spatial awareness into the risk perception literature is important because (a) spatial knowledge of previous inundation events varies by sociodemographic and geographic factors (Cheung et al., 2016; O'Neill et al., 2015; Pagneux et al., 2011; Ruin et al., 2007); (b) awareness of the location of flooding during a disaster event could shape evacuation routes, actions, and decisions; and (c) understanding differences in spatial knowledge and how they relate to nonspatial dimensions of risk perception could help enhance the design and implementation of risk communications outreach and education.

We extend the "levee effect" hypothesis by introducing the term "flood control effect" to assess whether, consistent with previous studies, trust in flood controls (e.g., seawalls, levees) instills a sense of security and lowers nonspatial flood risk perception. We extend previous studies by examining how trust in flood controls influences spatial flood hazard awareness. We hypothesize that residents who indicate greater trust in flood controls are likely to have observed the performance of structures during previous flooding events, developed spatial knowledge of the distribution and operation of control systems and the location of vulnerable areas, and increased their overall confidence in which nearby areas are prone to flooding.

Last, given that digital, interactive maps are increasingly used in risk communication but only two previous studies have assessed the influence of flood hazard maps on flood risk awareness (Handmer, 1980; Retchless, 2017), we use a pre–post study design to directly assess the impact of two interactive digital flood risk maps on self-rated spatial awareness of the distribution of local flood hazards. In summary, this study seeks to extend our understanding of flood awareness and risk perception among coastal residents and support enhanced risk communication and management by addressing the following research objectives:

1. To assess associations between self-rated nonspatial risk perceptions that lack geographic specificity and spatial flood hazard awareness;
2. To investigate whether trust in flood control systems creates a "flood control effect" for spatial flood hazard awareness and nonspatial risk perception;
3. To assess the impact of two interactive digital flood risk maps on spatial awareness of flood-prone areas.

Method

Study Location

This study is part of the FloodRISE research project focused on promoting resilience to coastal flooding within the City of Newport Beach, California. The survey study area includes the constructed islands of Lido Isle and Balboa Island in Newport Harbor and the urban coastal lowlands of Balboa Peninsula. We divided the study area into the following four study subareas based on modeled estimates of the distribution of flood hazards: Upper Peninsula, Lido Isle, Lower Peninsula, and Balboa Island (Figure 1). Much of this area is below extreme high tide levels and is projected to be heavily affected by sea level rise (Gallien, Sanders, & Flick, 2014; Tebaldi et al., 2012). In fact, Moftakhari et al. (2015) found substantial increases 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 mid-term (Moftakhari et al., 2015).

About 20% of the study area's seawall is found in the upper portion of the Balboa Peninsula, about 47% is in the lower portion of the Balboa Peninsula, and about 32% is on Balboa Island. There is no seawall on Lido Isle given its higher elevation. Some of the oldest seawalls in the study area are located on Balboa Island, built in the 1920s and 1930s, and are estimated to have between 10 and 25 years of useful life left (City of Newport Beach, 2011). Moderate storm surges at high tide have occasionally overtopped the seawalls (most recently in December 2010) and the frequency of overtopping is expected to increase due to the rise in sea level (City of Newport Beach, 2011). Although seawalls are the primary type of flood control considered in this study (Figure 1), other flood controls in the study area include storm drains, pump stations to lift flood water from storm drains into the bay, and tide valves at the outlet of each storm drain, which are closed before high tides to prevent sea water from back-flooding onto streets. In addition, flood controls also include city workers who build temporary sand berms, stack up sand bags, and use trucks with pumps to keep water out of the streets as much as possible.

Participants

We used a stratified sample of parcels in each subarea to obtain an equal number of responses from peninsula and island subareas. We further stratified the sample within each of these subareas to ensure responses from each of the following flood hazard classifications (described below): those inside both the FEMA and FloodRISE affected areas, those outside the FEMA

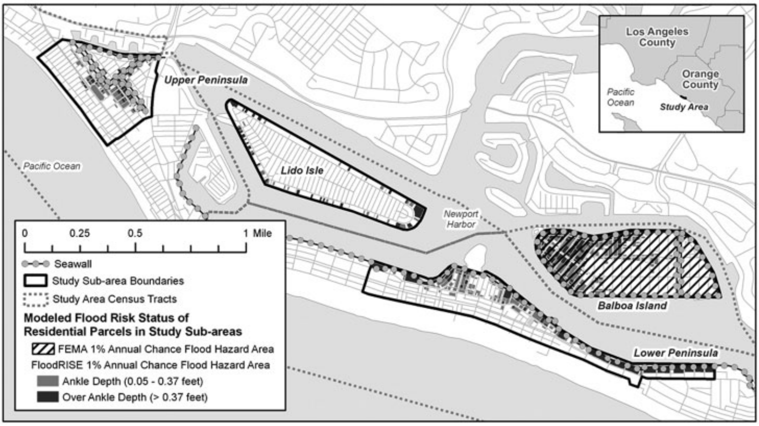

Figure 1. Study area boundaries and modeled flood hazard estimates.

affected area but within the FloodRISE affected area, those within the FEMA affected area but outside the FloodRISE affected area, and those outside of both the FEMA and FloodRISE affected areas. Although we initially sought a random sample across these four areas, we implemented quota sampling to obtain sufficient respondents in 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 that represented 8.84% of sampled households. Our final analysis sample included 201 survey participants who provided complete responses for key questions regarding their sociodemographic and geographic characteristics, as well as their attitudes toward local flood controls. Although this survey sample was comparable with the study area population in terms of gender, racial composition, and employment status, it included a higher percentage of homeowners and residents who were older, had higher income, and had higher educational attainment (Table 1).

Measures: Survey Data

The survey included two types of flood risk questions: nonspatial risk perception and spatial flood hazard awareness (Table 2). This distinction is important because most previous studies ask participants to generally rate the flood risk of their home or community without much spatial specificity (Kellens et al., 2013), but understanding self-rated awareness of how flood risk varies spatially could provide important insights for risk communication and

Table 1. Characteristics of Survey Sample and Study Area.

	Survey	Study area[a]
N[b]	201	15,623
Gender[b]		
Male	0.54	0.52
Female	0.44	0.48
Age[c]		
18-39 years	0.21	0.40
40-64 years	0.35	0.36
65 years or older	0.42	0.24
Race and Hispanic status[b]		
Hispanic	0.04	0.07
Non-Hispanic White	0.87	0.86
Non-Hispanic Black	0.00	0.01
Non-Hispanic Asian	0.01	0.03
Tenure[d]		
Own	0.62	0.49
Rent	0.35	0.51
Educational attainment[e]		
High school or equivalent	0.21	0.38
Bachelor's degree	0.40	0.38
Graduate degree	0.37	0.22
Employment status[c]		
Employed	0.72	0.72
Household income[b]		
Low below US$50,000	0.15	0.25
Middle US$50,000-US$99,999	0.25	0.26
High US$100,000-US$199,999	0.23	0.28
US$200,000 or higher	0.36	0.21

[a]2012-2014 American Community Survey, U.S. Census Bureau. See Figure 1 for corresponding census tract boundaries.
[b]Census data based on total population.
[c]Census data based on persons 18 years and older.
[d]Census data based on total occupied households.
[e]Census data based on persons 25 years and older.

emergency response. Consistent with previous studies, the nonspatial survey items comprised a series of scaled survey questions; we used counterbalancing and presented these items to each participant in a random order. These items asked respondents to provide information on the following dimensions of potential flood risk perception: (a) affect including worry, fear, or concern

Table 2. Flood Risk Survey Items.

Flood risk question type	Survey items	Dimension of risk perception measured
Nonspatial risk perception items[a]	I think about the risk of floods a great deal.	Affect (worry, fear, concern)
	I am concerned about the possibility of a major storm affecting my community.	Affect (worry, fear, concern)
	It is likely that a major flood will occur in my community in the next 10 years.	Affect (worry, fear, concern)
	A major flood is likely to cause major property damage to my community.	Awareness (consciousness)
	A major flood would be an extreme danger to people in my community.	Impact (consequences)
	My community is vulnerable to the risk of major floods.	Impact (consequences)
	People in my community have a great dread of major floods.	Likelihood (probability)
Spatial flood hazard awareness items		
Premap awareness	How would you rate your awareness of where flooding could occur in your community?[b]	Awareness (consciousness)
Postmap awareness[c]	*FEMA Map Subsample* Introduction: This map shows a potential flooding event near your home. The pink shade indicates areas of potential flooding. According to FEMA, on average, there is a 1% chance in any given year that these areas would experience a flood. Postmap viewing question: Now that you have viewed this map, how would you rate your awareness of where flooding could occur in your community?[b]	Awareness (consciousness)
	FloodRISE Map Subsample Introduction: This map shows a potential flooding event near your home. The blue shades indicate areas of potential flooding. According to the model developed by our research team, on average, there is a 1% chance in any given year that these areas would experience a flood. The blue shades indicate the depth of potential flooding based on the height of an average adult. Postmap viewing question: Now that you have viewed this map, how would you rate your awareness of where flooding could occur in your community?[b]	Awareness (consciousness)

Note. FEMA = Federal Emergency Management Agency; FloodRISE = Flood Resilient Infrastructure and Sustainable Environment.
[a]Ranked level of agreement with this statement from 1 (*strongly disagree*) to 7 (*strongly agree*). Items were presented to each respondent in a random order.
[b]Ranked level of awareness with this statement from 1 (*not aware*) to 7 (*strongly aware*).
[c]Respondents were randomly assigned to interactively view the FEMA or FloodRISE flood map.

of potential flooding, (b) likelihood or the probability of a major flood event, (c) their awareness or consciousness of flood risk, and (d) the impact or

Table 3. Confirmatory Factor Analysis of NonSpatial Flood Risk Perception Survey Items.

Risk perception factor	*M* (*SD*)	Cronbach's α	Survey items[a]	Standardized factor loading
Dread of expected floods	0.03 (2.28)	.74	I think about the risk of floods a great deal.	0.737
			I am concerned about the possibility of a major storm affecting my community.	0.710
			It is likely that a major flood will occur in my community in the next 10 years.	0.556
			People in my community have a great dread of major floods.	0.508
Major flood impact concern	0.05 (1.93)	.79	A major flood is likely to cause major property damage to my community.	0.808
			A major flood would be an extreme danger to people in my community.	0.776
			My community is vulnerable to the risk of major floods.	0.522

[a]Ranked level of agreement with this statement from 1 (*strongly disagree*) to 7 (*strongly agree*).

consequences of a major flood event (Kellens et al., 2013). As each of these nonspatial items measured different but related dimensions of risk perception, exploratory factor analysis was used to reduce these items into the following two composite variables, or factors, which were used as independent variables in the regression analysis: “dread of expected floods” and “major flood impact concern” (Table 3).

The spatial flood hazard awareness measure was derived from the following scaled question: “How would you rate your awareness of where flooding could occur in your community?” (Table 2). Participants were asked this spatial awareness survey item immediately after they were asked the nonspatial risk perception items and before they viewed a hazard map. Participants were asked this spatial awareness survey item again after viewing a flood hazard map. The level of correlation between the premap spatial awareness measure was low with both nonspatial measures: "dread of expected floods" (0.20) and "major flood impact concern" (0.19).

Our measure of trust in flood controls was derived for participants who responded "yes" to the question "Are you aware of any flood control structures (such as seawalls or berms) in place in your community?" These participants were asked to rank on a scale of 1 (*not secure*) to 7 (*very secure*) "How secure do you feel given flood control structure(s) in your community?" When analyzing the influence of trust in flood controls on nonspatial risk perception and spatial flood hazard awareness, we used the subsample of participants (152) who indicated they were aware of flood controls and were asked to rank their trust in these controls.

Measures: Spatial Data

The first estimate of flood hazards was the FEMA NFHL based on 2009 predictions of areas expected to flood from an event with a 1% annual chance (100-year flood). The FEMA NFHL for the Newport Beach site involved hydraulic analysis of ocean water levels due to storm surge, waves, and wave runup, followed by mapping of stillwater flood elevations through an equilibrium mapping approach along the coastline and urbanized embayment (Gallien, Schubert, & Sanders, 2011; National Research Council, 2009). FEMA flood hazard maps are used to determine whether a property is inside a Special Flood Hazard Area by lenders during real estate transactions, federal and state agencies, and the National Flood Insurance Program.

The second estimate of flood hazards was based on the 2014 street-level FloodRISE model of areas that could be affected by a flood event with a 1% annual chance (100-year flood). This model is a two-dimensional hydraulic model that relies on an unstructured grid of triangles, which was refined for accurate topographic representation of the study area's terrain and flood control features (seawalls). The model accounted for flow regimes that could result from abrupt changes in topography and infrastructure such as those caused by streets and seawalls. The model was previously validated for the modeling of storm tides and wave overtopping in the study area (Gallien et al., 2014; Gallien et al., 2011).

In addition, supplemental spatial data were assembled for each respondent's residential location using Geographic Information System (GIS) tools to understand how geographic factors such as distance from the closest water body, location within floodplain, proximity to seawalls, and subarea of residence influence respondent flood awareness and risk perception.

Figure 2. Screenshot of sample FEMA hazard map zoomed into Balboa Island.
Note. Based on FEMA's 2009 estimate of a 1% AEP flood event (100-year flood). FEMA = Federal Emergency Management Agency; AEP = Annual Exceedance Probability.

Survey Procedure

Sampled households received a prenotice letter that introduced the study, and survey teams visited sampled households during April, May, and June in 2014 to invite a head of household who was 18 years or older to participate. The survey collected sociodemographic and geographic information, which previous studies have indicated were associated with flood risk perception, such as residents' gender, age, previous flood experience, and proximity to and confidence in flood control systems (Grothmann & Reusswig, 2006; Kellens et al., 2013). Respondents were randomly assigned to view one of two flood hazard maps of the study area: a FEMA map of areas estimated to be affected by flooding, or a FloodRISE map of areas estimated to be affected by flooding (Figures 2 and 3). The maps were presented to respondents on a tablet device such that the entire study area was visible, and respondents could then choose to zoom within and pan across the study area to review the information in more detail. The FEMA map depicted affected areas in one color with less spatial differentiation, whereas the FloodRISE map depicted affected areas with a gradation of color representing different flood depths at the street-level scale (Table 2 provides the survey's introduction to the FEMA and FloodRISE maps).

Given the more spatially refined scale of the two-dimensional FloodRISE model depiction, and its ability to incorporate finer resolution topographic

Figure 3. Screenshot of sample FloodRISE hazard map zoomed into Balboa Island.
Note. Based on FloodRISE's 2014 estimate of a 1% AEP flood event (100-year flood).
FloodRISE = Flood Resilient Infrastructure and Sustainable Environment; AEP = Annual Exceedance Probability.

datasets and account for coastal flood controls, we hypothesized that it more realistically represents local conditions and better resonates with respondents' experiences. Although the FEMA map may be more familiar to residents (as this information is used by federal and state agencies and as part of real estate transactions), we hypothesized that this map was less impactful on resident perceptions than the FloodRISE map because it did not include estimated flood depth and generally depicted less spatial differentiation of flood-prone areas (Figures 2 and 3).

The first stage of analysis examined variation in spatial flood hazard awareness and nonspatial flood risk perception by sociodemographic and geographic factors using a two-tailed *t* test to examine whether the mean awareness or perception for each respondent subgroup was significantly different from the mean for all participants. To assess the influence of viewing a hazard map, we also examined the mean spatial flood hazard awareness for respondent subgroups before and after viewing a FEMA or FloodRISE map. The second stage of analysis used ordinary least squares multivariate regression to examine the relative influence of factors on respondent nonspatial flood risk perception and spatial flood hazard awareness (before and after viewing a flood hazard map). To assess how flood awareness and perception are related, we included the nonspatial flood risk perception factors ("dread of expected floods" and "major flood impact concern") as independent variables in the spatial flood hazard awareness models. As we included an independent variable for trust in flood controls, our regression models were restricted to the subsample of participants (152) who indicated they were aware of flood controls and were asked to rank their trust in these controls.

Results

Variation by Subgroup

Overall, the average self-rated spatial flood hazard awareness *before* viewing a flood hazard map was 5.16 on a scale of 7 (Table 4). Younger adults (18-39 years old), renters, residents in low-income households (<US$50,000), and very short-term residents (<2 years) had a mean rating that was significantly below the mean for all respondents before viewing the map, whereas older residents (65 years and older) and longer term residents (10-19 years) had a mean rating that was significantly above the mean for all respondents before viewing the map. In addition, respondents who lived on Balboa Island, at a relatively lower elevation, had a significantly higher mean spatial flood hazard awareness before viewing the map, whereas those who lived farthest from the seawall (>625 m) had a significantly lower mean self-rated flood hazard awareness before viewing the map.

The average self-rated spatial flood hazard awareness for all the respondents *after* viewing a flood hazard map increased by almost 1 point to 6.03, and viewing the map seems to have had an equalizing effect on spatial awareness. After respondents viewed the map, there were no longer significant differences in spatial awareness for the various sociodemographic and geographic subgroups that previously reported higher or lower spatial awareness (relative to the study area average) before viewing the maps. Younger, lower income, and very short-term residents had the greatest increase in spatial awareness after viewing the map. Although there was no significant difference in the spatial awareness of respondents who viewed the FEMA map compared with those who viewed the FloodRISE map before they viewed a hazard map, after viewing a map, respondents who viewed the FEMA map had a significantly lower mean spatial awareness compared with those who viewed the FloodRISE map based on a two-tailed t test (5.8 vs. 6.2), $t(199) = -2.17$, $p = .03$, results not shown.

We did not find significant differences in our bivariate analysis in the mean for either nonspatial risk perception factor ("dread of expected floods" and "major flood impact concern") for any of the sociodemographic subgroups compared with the mean for all respondents. However, residents who lived furthest from the seawall (>625 m) had a significantly lower "dread of expected floods" compared with all respondents.

Table 4. Bivariate Analysis of Factors Associated With Spatial Flood Hazard Awareness and NonSpatial Flood Risk Perception.

	Nonspatial risk perception factors[b]			Spatial flood hazard awareness[c]			
Characteristics[a]	Sample size	Dread of expected floods	Major flood impact concern	Sample size	Mean *before* viewing a map	Mean *after* viewing a map	Difference, *after* – *before*
n		154	154		201	201	
All	154	0.07	0.10	201	5.16	6.03	0.88
Map viewed							
FEMA map	66	0.10	0.11	88	5.16	5.82	0.66
Age							
18-39 years	21	0.09	−0.14	43	3.81***	5.63	1.81*
65 years or older	75	−0.41	−0.18	85	5.71*	6.05	0.34*
Home ownership tenure							
Rent	44	0.39	0.28	71	4.46**	5.85	1.38
Annual household income							
Less than US$50,000	16	0.25	−0.18	27	3.81***	5.74	1.93*
Time at residence (in years)							
Very short (<2 years)	23	0.67	0.17	40	3.95**	5.85	1.9**
Moderate (10-19 years)	39	0.05	0.38	47	5.72*	6.04	0.32
Residence study subarea							
Balboa Island	60	0.00	0.18	62	5.69*	6.24	0.55
Residence elevation							
Very low (<7 m)	33	0.25	−0.07	38	5.82*	6.37	0.55
Residence flood zone							
Within FEMA floodplain	78	0.08	0.15	81	5.72*	6.23	0.52
Distance from seawall							
Very far (>625 m)	32	−0.83*	−0.51	50	4.54*	5.90	1.36

Note. FEMA = Federal Emergency Management Agency.
[a]Only characteristics associated with significant results are shown (except for the map viewed).
[b]Factors generated based on factor analysis, see Table 2 for details.
[c]How would you rate your awareness of where flooding could occur in your community? (1 = *not aware* to 7 = *very aware*).
Significance indicates that the mean for a subcategory of participants was significantly different from the mean for all participants in the column based on a two-tailed t test: $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Regression Analysis

Regression models of factors associated with nonspatial perception measures explained a modest amount of the variation in the dependent variables (21%-22%; Table 5, Models 1 and 2). Years at current residence and trust in flood controls were associated with lower "dread of expected floods" and "major flood impact concern," whereas the number of previous flood information sources was associated with a higher dread and concern. In addition, female respondents and those with previous flood experience were associated with higher "major flood impact concern."

With regard to spatial flood hazard awareness before viewing a flood hazard map, the number of sources from which a respondent had previously received flood information was associated with higher spatial flood awareness before viewing the map (Models 3 and 4). In line with bivariate results, respondent age was positively associated with spatial awareness, but other influential sociodemographic and geographic factors from the bivariate results were not significant in these models. The two nonspatial flood risk perception factors ("dread of expected floods" and "major flood impact concern") were significantly associated with higher spatial flood hazard awareness.

Spatial flood hazard awareness after viewing a flood hazard map was significantly higher for respondents who viewed the FloodRISE map compared with respondents who viewed the FEMA map (Models 5 and 6). Although trust in flood controls was not significantly related to the nonspatial flood risk perception factors and spatial flood hazard awareness before viewing a hazard map, greater confidence in flood control systems was associated with greater spatial awareness after viewing a hazard map. Previous flood experience was significantly associated with higher spatial flood hazard awareness. Although the "dread of expected floods" risk perception factor was significantly associated with higher spatial flood hazard awareness (Model 5), the "major flood impact concern" risk perception factor was not significant in the model of spatial flood hazard awareness after viewing the map (Model 6). Overall, the models of spatial flood hazard awareness explained 7% to 22% of the variation of the dependent variables, which suggests unobserved factors influence spatial hazard awareness.

Discussion

Our results have implications for three areas of flood risk perception research and management.

Table 5. Regression Analysis of Factors Associated With Spatial Flood Hazard Awareness and NonSpatial Flood Risk Perception.

	Nonspatial risk perception factors[a]				Spatial flood hazard awareness[b]							
	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
	Dread of expected floods		Major flood impact concern		Mean *before* viewing a map		Mean *before* viewing a map		Mean *after* viewing a map		Mean *after* viewing a map	
Independent variables	Coefficient	Significance	Coefficient	Significance	Coefficient	Significance	Coefficient	Significance	Coefficient	Significance	Coefficient	Significance
Intercept	1.09		0.37		3.41	***	3.42	***	4.68	***	4.84	***
Flood hazard map reviewed												
FloodRISE map (1/0)									0.55	**	0.51	**
Sociodemographics												
Female (1/0)	0.49		0.72	*	−0.38		−0.49		0.15		0.15	
Age (years)	0.00		0.01		0.03	**	0.03	**	0.00		0.00	
Time at residence (years)	−0.03	**	−0.03	**								
Time at residence <2 years (1/0)					−0.67		−0.54		−0.16		−0.06	
Previous flood information or experience												
Number of flood information sources (*N*)	0.16	**	0.11	*	0.10	*	0.10	*	−0.02		0.00	
Previous flood experience (1/0)	0.63		0.59	*	−0.07		−0.09		0.44	*	0.47	*
Trust in flood controls												
Trust in flood controls[c]	−0.29	**	−0.24	**	0.07		0.08		0.17	***	0.15	**
Residential characteristics												
Far from seawall (>625 m)	−0.80		−0.61		−0.43		−0.40		0.18		0.11	
Nonspatial risk perception factors[a]												
Dread of expected floods					0.19	**			0.16	***		
Major flood impact concern							0.26	***			0.09	
Adjusted R^2	.22		.21		.20		.22		.13		.07	
N[d]	152		152		152		152		152		152	

[a]Factors generated based on factor analysis, see Table 2 for details.
[b]How would you rate your awareness of where flooding could occur in your community? (1 = *not aware* to 7 = *very aware*).
[c]How secure you feel given flood control structure(s) in your community? (1 = *not secure* to 7 = *very secure*).
[d]Based on the subsample who indicated they were aware of flood controls.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

First, we assessed the association between spatial flood hazard awareness and nonspatial flood risk perception. Our nonspatial perception measures were based on a series of general survey questions which, consistent with previous studies (Kellens et al., 2013), asked each respondent about general dimensions of his or her risk perception including affect, awareness, impact, and likelihood without assessing geographic specificity. We used factor analysis to generate two nonspatial measures from these seven questions: dread of floods and major flood impact concern. Our spatial flood hazard awareness measure was based on a survey question asking each respondent to rank his or her awareness of where flooding could occur in the community. Our study is the first to our knowledge to measure spatial dimensions of flood risk perception in this way, and results indicate differences between spatial and nonspatial dimensions of flood risk perception and awareness.

Consistent with previous research (Kellens et al., 2013), multivariate results indicate higher nonspatial flood risk perception was associated with prior flood knowledge either through previous personal experience with flooding or through governmental, media, or digital information sources. In contrast to previous studies, which found that length of residence was associated with greater flood risk awareness (Burningham et al., 2008; Pagneux et al., 2011; Ruin et al., 2007), we found that that years at current residence was associated with lower nonspatial perceptions after controlling for other factors. This could suggest that longer term residents may have grown accustomed to higher levels of flood risk over time, or that those with greater flood dread or concern moved elsewhere. Also, in contrast to previous studies, we did not find other sociodemographic factors (e.g., income, age, or educational attainment) to be significant determinants of nonspatial perceptions. Although we did not find differences by gender in the dread of expected flooding, being a female respondent was associated with higher major flood impacts concern. This suggests that women perceive such risks differently than do men, may be more risk averse, and are more likely to be concerned that a major coastal flood will cause substantial damage to property and life (Gustafson, 1998; Kellens et al., 2011; Nelson, 2015).

Our two nonspatial risk perception factors were positively associated with our spatial flood hazard awareness measure in our multivariate analysis. This suggests that respondents with greater dread and concern could be more observant and knowledgeable of nearby areas likely prone to flooding and have greater confidence in their awareness of the potential distribution of future flood impacts. Consistent with nonspatial perceptions, multivariate results indicate higher spatial flood hazard awareness (before viewing a flood hazard map) was associated with the number of flood information sources. In contrast with nonspatial perceptions, age was significantly and positively associated with spatial flood hazard awareness. Understanding factors associated with spatial flood hazard awareness is particularly important, because one's awareness can influence individual evacuation routes, actions, and decisions during a flood event. The differences we found in spatial awareness and nonspatial perceptions stress the importance of designing and implementing risk communications outreach and education more broadly in ways that address both the general, non-geographic sense of dread and concern of flood-prone communities, and the public's understanding of where flooding could potentially occur. For instance, outreach efforts could include interactive maps with street-level spatial differentiation of potential flood depth to visualize flood scenarios under a variety of conditions, educate the public on the location of higher ground and community shelters and resources, and communicate evacuation routes and procedures.

Second, our results inform flood risk perception research and management by asking whether, following the logic of the "levee effect" proposed by White (1945), a "flood control effect" exists for both spatial knowledge and nonspatial perceptions. Proponents of the "levee effect" assert that flood controls intended to reduce flooding frequency can instill a false sense of security and reduce concern over flood hazards in floodplains. Others have raised similar concerns that control structures such as seawalls, levees, dikes, and protective dunes could instill a false sense of safety (Burton & Kates, 1964; Ludy & Kondolf, 2012; McPherson & Saarinen, 1977; Pinter, 2005). Although it is beyond the scope of the current study to evaluate the effectiveness of flood control systems in the study area, the oldest seawalls in the study are nearly 100 years old, are estimated to have about 10 years of useful life left, and are not certified to protect against a 100-year flood (City of Newport Beach, 2011).

In terms of nonspatial perceptions, we found a "flood control effect" in that greater trust of flood controls was associated with lower "dread of expected floods" and "major flood impact concern." This pattern suggests that some residents may have a false sense of security instilled by controls in the region, and stresses the need for an expanded understanding of the influence of coastal flood controls on local risk perceptions as well as preparedness and behavior, especially because the coastal regions are becoming increasingly affected by high tide levels and nuisance flooding due to sea level rise (Gallien et al., 2014; Tebaldi et al., 2012). With regard to spatial flood hazard awareness, however, we found an opposite "flood control effect" in that greater trust in flood control systems was positively associated with self-rated awareness of where flooding could occur in the community after viewing flood maps. This may reflect that, consistent with previous literature (Terpstra, 2011), residents adjust their trust in flood controls based on observations of their performance.

Residents who have witnessed the protection provided by the seawall, drainage and pumping systems, and flood control crews could develop greater confidence in spatial awareness of areas prone to flooding. This confidence could, however, reduce overall, nonspatial sense of dread and concern for potential flooding because residents have delegated the responsibility of building and monitoring control systems to risk managers (Terpstra, 2011; Viglione et al., 2014; Wachinger et al., 2013).

Third, our results inform flood risk perception research and management by directly assessing the influence of digital, interactive flood hazard maps on the spatial flood hazard awareness of coastal residents. Only one previous study has used a similar pre–post study design and found that viewing multimedia, interactive flood risk scenarios was associated with increased flood risk perceptions related to sea level rise among college students in Sarasota, Florida (Retchless, 2017). In contrast, we compared the impact of interactively viewing two flood hazard maps: (a) FEMA's official map of Special Flood Hazard Areas, which is used in current risk management by federal and state agencies and insurance programs but does not depict estimated flood depth and provides little spatial differentiation in flood-prone areas, and (b) a more spatially refined FloodRISE map depicting flood-prone areas by potential flood depth at the street-level scale.

After viewing a map, respondents who previously experienced flooding and those who viewed the FloodRISE map had scores that were associated with higher levels of spatial flood hazard awareness. This suggests that the provision of a hazard map to coastal residents in an interactive digital format that allows panning and zooming seems to have an equalizing effect by raising the awareness of most respondents to the same level. Although further research is needed to better understand how the content and design of hazard maps can be refined to meet the needs of different stakeholders within flood-prone areas (Fuchs et al., 2009; Kjellgren, 2013; Meyer et al., 2012), our comparison of the impact of two hazard maps indicates that providing a map with flood depth estimates and greater spatial differentiation (i.e., the FloodRISE map) seems to be associated with heightened self-rated spatial flood hazard awareness. This finding builds on previous research supporting the development of interactive and customizable flood hazard mapping platforms to narrow differences in the risk perception across sociodemographic, cultural, and geographic groups and differences in expertise in map-use and risk assessment (Retchless, 2014; Roth, 2009). Such tools could improve risk communication and management by supporting interaction and feedback between flood dynamics, experts, and affected communities within a socio-hydrological framework (Sivapalan, Savenije, & Blöschl, 2012).

Limitations and Future Research

Although this research provides important insights into the influence that sociodemographic and geographic factors, trust in flood control systems, and flood maps have on spatial awareness and nonspatial risk perception, there are some limitations to our study. Our findings may not be generalizable to other coastal communities that may have different sociodemographic or physical characteristics given our respondents were drawn from a nonrandom sample of residents of a study area comprised of relatively affluent and older residents. In addition, the regression models account for a relatively low percentage of the variance in spatial awareness and nonspatial flood risk perception, which suggests that there may be other factors that have not been accounted for in our models. Furthermore, because our study design did not include a control for the pre–post assessment of the hazard maps, changes cannot be solely attributed to the impact of the maps because unobserved factors such as acquiescence bias may have influenced results. Although beyond the scope of the current study, additional research is needed to assess the accuracy of the flood risk perceptions of coastal residents in a process that allows for genuine and thoughtful feedback and interaction between expert and local knowledge of flood hazards (Cheung et al., 2016). Finally, further research is needed to more fully understand the influence of flood hazard map design (color, symbology, etc.), map interface design, and the level of participant map interaction (panning, zooming, etc.) on increased postmap perceptions levels (Retchless, 2017).

Conclusion

Understanding public flood risk perception and awareness is important for developing a more integrated understanding of flood risks within a sociohydrological framework. In this framework, the values, concerns, preferences, and actions of coastal residents are viewed as essential components in the coevolution and dynamics of coupled human-water systems. This integrated understanding can help to more effectively communicate technical expert estimates of risk within the social and cultural context of affected communities (Kellens et al., 2013; Sivapalan et al., 2012). Our findings provide important insights that could help design and implement risk communication outreach and educational strategies that effectively inform resident subgroups about flood risks in their community. These strategies must address the spatial and nonspatial dimensions of flood risk by considering not only variables that are associated with the general dread and concern over coastal flooding but also variables that influence one's knowledge of the geographical distribution of local flood hazards.

Authors' Note

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