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Flood risk perception in lands "protected" by 100-year levees

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Abstract Under the US National Flood Insurance Program, lands behind levees certified as protecting against the 100-year flood are considered to be out of the officially recognized "floodplain." However, such lands are still vulnerable to flooding that exceeds the design capacity of the levees—known as residual risk. In the Sacramento-San Joaquin Delta of California, we encounter the curious situation that lands below sea level are considered not "floodplain" and open to residential and commercial development because they are "protected" by levees. Residents are not informed that they are at risk from floods, because officially they are not in the floodplain. We surveyed residents of a recently constructed subdivision in Stockton, California, to assess their awareness of their risk of flooding. Median household income in the development was $80,000, 70% of respondents had a 4-year university degree or higher, and the development was ethnically mixed. Despite the levels of education and income, they did not understand the risk of being flooded. Given that literature shows informed individuals are more likely to take preventative measures than uninformed individuals, our results have important implications for flood policy. Climate-change-induced sea-level rise exacerbates the problems posed by increasing urbanization and aging infrastructure, increasing the threat of catastrophic flooding in the California Delta and in flood-prone areas worldwide.

Keywords Risk perception · Flood insurance · 100-year flood · Levee · Residual risk · Delta

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1 Introduction

On floodplains behind levees, new developments attract residents to lands perceived as "protected" from floods, but which are still vulnerable to inundation by floods exceeding the design flood magnitude. In effect, the levees "filter" small floods and change the perception of flood likelihood, thereby encouraging human settlement of marginal lands that might not otherwise be occupied (or at least as extensively). These human settlements are then vulnerable to destruction by infrequent, large events. The dynamics of such coupled human-natural systems have been well documented for barrier islands by McNamara and Werner (2008) and for back-swamp areas of New Orleans (Werner and McNamara 2007) and are applicable more generally to floodplains "protected" by levees.

Many residents of lands vulnerable to floods or other disasters underestimate their flood risk (Gardner and Stern 1996). Of particular interest are new developments on floodplains, because in these cases residents choose to move into newly constructed houses behind recently constructed (or in the United States (US), recertified) levees. How well do these individuals understand the true flood risk? This question has important public policy implications with respect to safety because informed individuals are more likely to take preventative measures than uninformed individuals. Further, where individuals can take measures to reduce risk, they can minimize consequences of a disaster such as loss of life and property damage. As such, if an individual *voluntarily* accepts a risk, he or she is presumed to have the option to avoid the risk (Raaijmakers et al. 2008). It follows that if an individual is unaware of a risk, the individual cannot make a fully informed decision about taking the risk.

Since the motivation to protect oneself comes from the perceived severity of the threat and the perceived probability of the occurrence or vulnerability (Grothmann and Reusswig 2006), misperceptions of flood risk have been found to result in larger losses than necessary (Sniedovich and Davis 1977). One's level of flood risk awareness directly influences his or her actions before and during a flood (Grothmann and Reusswig 2006; Burningham et al. 2008).

In the Sacramento-San Joaquin Delta of California, new developments have proliferated on flood-prone lands, many behind levees and below sea level. To understand public perceptions of flood risk in these developments requires that we first examine US federal flood policy, and how it encourages local land-use decisions to permit development in potentially unsafe areas. Despite a policy aimed at reducing flood losses, damages have risen since the policy's adoption, and flood risk is increasing.

Urbanization of floodplains has altered the natural hydrologic regime by constricting river channels and increasing impervious surfaces (where water may previously have infiltrated), both of which increase water surface elevations and increase the likelihood of a flood inundation of lands downstream. Additionally, more and more people have settled on floodplains behind levees (Kelley 1998; Burby 2001; Pinter 2005), which has increased the consequences of flooding due to levee failure or overtopping.

1.1 The US National Flood Insurance Program

The US National Flood Insurance Program (NFIP) was established by the Flood Insurance Act in 1968 to provide coverage to flood-prone properties, which private insurers would not cover. For its residents to receive insurance, participating communities were required to adopt land-use regulations to prevent further development in flood-prone lands, to prevent the problem from getting worse in the future. For the purposes of the insurance program, in 1973, the Senate Committee on Banking, Housing, and Urban Affairs adopted

the "100-year floodplain" as the regulatory threshold. The 100-year flood (i.e., with a return interval of 100 years as annual maximum) has a one percent probability of occurring in any given year, so this is often termed the "one-percent" approach.

The 100-year floodplain is delineated in an engineering study, usually by application of hydrologic and hydraulic models (Fig. 1). The 100-year floodplain is subject to both an insurance requirement and "community floodplain management." In the high-velocity "floodway," new development is prohibited. In the outer floodplain "fringe," new structures must be elevated above expected flood levels and must demonstrate that they will not raise the level of the flood by more than 0.3 m (1 ft). Under the NFIP, if a property is in a flood zone as determined by the Special Flood Hazard Area map, a federally backed mortgage requires the property owner to purchase a flood insurance policy, but properties owned outright are not required to have flood insurance. Properties outside the officially designated floodplain by virtue of a hydraulic structure (e.g., levee) are not required to purchase flood insurance, though there are arguments for mandatory purchase in these areas (H 1309, 2011).

Burby (2001) argued that the costs of construction and insurance should discourage development in floodplains if three conditions are met: *If* the government requires property owners to purchase flood insurance, *if* the government sets insurance rates such that they reflect actual flood damage costs, and *if* risk can be lowered through building regulations and avoiding development in floodplains, and *then* the costs of construction and insurance should discourage construction in floodplains. However, because houses behind levees are considered "out of the floodplain" and homeowners are not required to purchase insurance, NFIP may encourage construction of levees rather than discourage construction in areas that are still vulnerable to flooding, but at probabilities <1% likelihood per year.

The use of the 100-year flood as a standard has been widely criticized. The calculated 100-year flood commonly changes (it is usually redefined as larger) as new data become available (Mount 1995), and this larger 100-year flood would mean a more extensive 100-year floodplain. At least 25–30% of flood damage *claims* come from areas outside of the designated 100-year floodplain. (FEMA 2010, Loucks & Stedinger 2007). Additionally, the "100-year flood" is widely misunderstood. Many believe the floodplain will be safe from flooding for the next 99 years after a 100-year flood (Mount 1995). It is clear that the NFIP has had tremendous influence on land-use regulation and planning in local jurisdictions. In conversations with FEMA staff, we have been reminded that "It's just an insurance program." But in practice, the 100-year floodplain has become the default working definition of "floodplain" for land-use planning and flood-control projects in the United States.

1.2 Levees and residual risk

As the NFIP was being implemented, the question arose of whether floodplain lands protected by levees were still "floodplain." The decision was made that these lands were

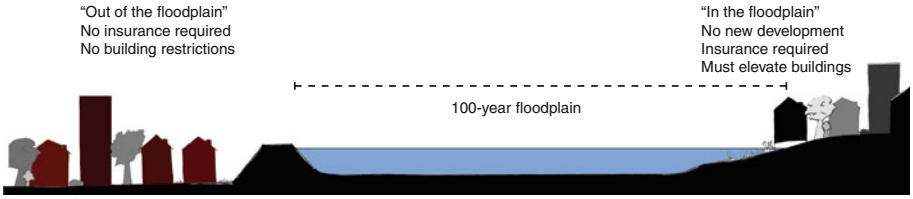

Fig. 1 How the National Flood Insurance Program works

outside the official floodplain, and thus residents would not be required to purchase flood insurance for federally backed mortgages (Montz and Tobin 2008), nor were they required to elevate houses or retrofit structures to be "flood proof." In fact, residents would not be informed that they were living in (or purchasing a house in) the floodplain, because according to the program rules, they were not. This element of the program has had unintended consequences, and may have led to greater development on flood-vulnerable lands than would have been the case in the absence of the program (Burby 2001).

A levee may "remove" the risk of a 100-year flood, but not the risk from floods larger than the 100-year flood, such as the 200-year, the 500-year, or even the 101-year flood (Carter 2005). Assuming the levees function as designed and protect against the 100-year flood, there is still a *residual risk* of being flooded by floods larger than the design 100-year flood. Over the life of a 30-year mortgage, this residual risk from larger floods adds up to 26% (Bell and Tobin 2007). Beyond this residual risk from larger floods, levees may fail from factors such as earthquakes, subsidence, sea-level rise, and human, organizational, and institutional factors (Mount and Twiss 2005; Bea et al. 2009).

How well do residents in floodplains now protected by 100-year levees (so not officially "in the floodplain") understand these risks? In the Netherlands, where extensive areas are habitable only because of levees and dikes, surveys found that residents perceived flood risk to be low, attributed to the belief that flood protection is government responsibility (Terpstra and Gutteling 2008). In Switzerland, residents in areas with expert-estimated 1% annual risk of floods perceived their risk to be low and were subsequently not prepared for disaster (Siegrist and Gutscher 2006). Property values in levee-protected lands in St. Louis County, Missouri, before the Great Mississippi floods in 1993 suggested that residents were unaware of the flood risk (Kousky 2010). However, our literature search encountered no previous study directly measuring the perception of risk by residents on lowlands behind accredited "100-year" levees. Four years after Hurricane Katrina flooded New Orleans, we surveyed risk perception in a suburban development in the Sacramento-San Joaquin Delta of California, which lies below sea level but is "protected" by a 100-year levee.

2 Factors influencing flood risk perception

The literature suggests that risk perception is unique to the individual, constructed by sensory experiences (Lee 1981), and influenced by knowledge, personal attributes, previous experience, and environmental conditions (Rohrmann 1994). Many have identified prior flood experience as one of the most influential factors in hazard perception (Burn 1999; Burningham et al. 2008; Siegrist and Gutscher 2006), as previous experience or familiarity with a similar event (to the one being assessed) allows an individual recall its occurrence and assign a future probability (Brilly and Polic 2005). Other factors that influence the public perception of a risk are the public's trust in expert knowledge and safety measures (including land-use decisions and levees), a misunderstanding of probabilities like the "100-year flood," and how such concepts are portrayed in the media.

In a 2007 position statement, the Association of State Floodplain Managers (ASFPM 2007) argued that thousands of floodplain residents believe they are safe because "they do not believe government would allow them to live behind a levee if it were not safe." Trust in flood control structures greatly influences risk perception (McPherson and Saarinen 1977), so much that in some cases, individuals living in a levee-enclosed area believed the structures reduce their risks to zero (Pinter 2005). When residents are told they are not "in the floodplain" it is not surprising that they underestimate their flood risk.

How media frames an issue affects how information is perceived, amplified, and attenuated by the public (Kasperson and Kasperson 1996). When certain events are reported disproportionately, the public's perception of the frequency of those events is biased (Combs and Slovic 1979). Because of media coverage, lower probability events may seem more common than they actually are, and higher probability events like floods may appear to occur less frequently than they do.

3 Study objectives

The objectives of this study were to determine whether residents of a recently constructed subdivision protected by a 100-year levee were aware of their risk of flooding, both residual risk of inundation by floods with return periods greater than the design flood, and from levee failure through seismic shaking or other mechanisms. We selected a subdivision of new houses (ranging in elevation from just above sea level to 1.8 m below), whose owners were well-educated professionals with higher incomes than average for the city and county. Thus, we could look for risk awareness in a population that was as likely to be aware as any, in a location whose flood risk would seem especially obvious by virtue of its position below sea level.

4 Materials and methods

4.1 Study area

The Sacramento-San Joaquin Delta has experienced rapid urbanization in recent decades, as urban sprawl has spilled over from the San Francisco Bay and Sacramento regions. Previously, inexpensive agricultural lands have been converted to subdivisions, with the result that San Joaquin County has been the fifth fastest growing county in the state, with more than 30,800 new housing units approved for development since the floods of 1997 on lands that can be considered flood-prone by virtue of meeting at least two of the following criteria: (1) they have flooded since 1862, (2) they are protected by certified "100-year" levees, and/or (3) they are no more than three meters above sea level (Shaw and Nichols 2005). The Spanos Park West development in north Stockton, San Joaquin County (Fig. 2), was constructed from 2000 to 2004. It is representative of much of the suburban floodplain development within the Delta, on lands ranging in elevation from just above sea level (+0.3 m) to 1.6 m below (Fig. 3a, b).

4.2 Site reconnaissance

We reviewed maps and conducted multiple site visits to validate map analyses, examine characteristics of housing, and to survey a topographic cross section from Bear Creek, across the levee, and on the adjacent lands in the development.

4.3 Survey instrument and selection

We administered a questionnaire containing 20 questions (both open and close-ended) designed to elicit specific information about a households' perceived level of flood risk in

Fig. 2 Location map, Sacramento-San Joaquin Delta and Spanos Park West

several categories—prior experience with floods, personal assessment of flood likelihood and damages, general flood knowledge, and behavior, including self-protective or preparatory measures. The survey extracted categorical data including ordinal, nominal, and binary. Approved by the UC Berkeley Committee for the Protection of Human Subjects, the survey was also reviewed and edited by more than 24 international professionals, academics, and practitioners via the listserve of the Natural Hazards Center in Boulder, Colorado.

We administered a survey to 500 households randomly selected from the 1,284 households in the subdivision. After subtracting vacant properties and foreclosures, we had a usable sample of 490 households, from which we received 114 usable responses (23% response rate, 9% of the entire development). Following the Tailored Design Method for

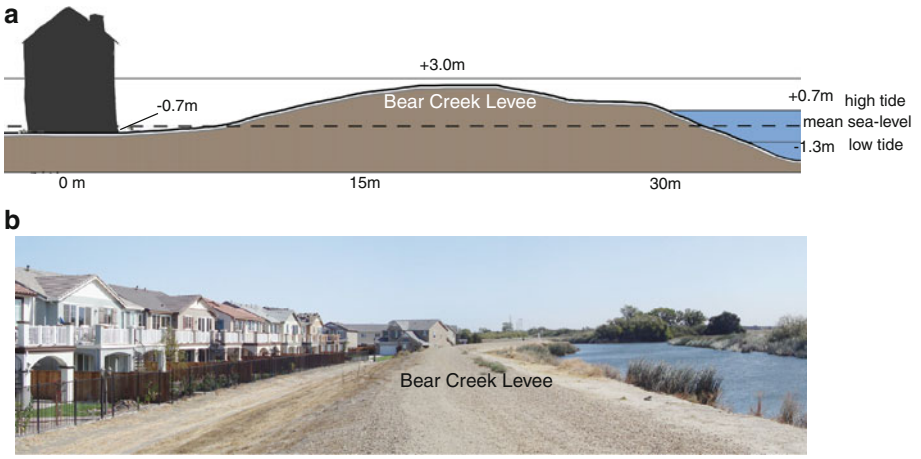

Fig. 3 **a–b** Cross section of Bear Creek levee at Spanos Park West

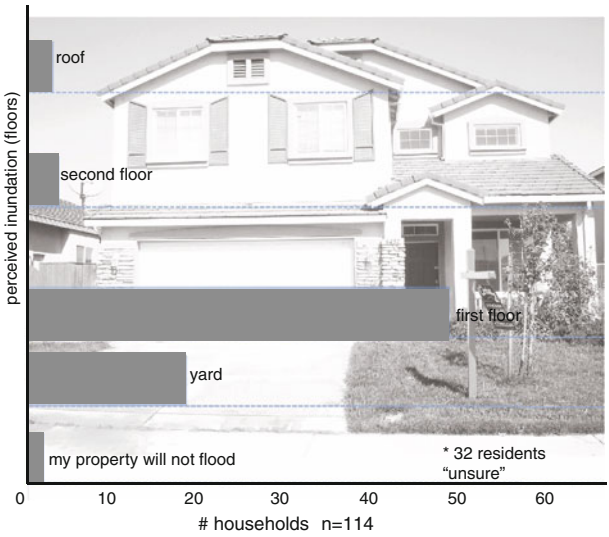

Fig. 4 Respondents' perceived inundation depth in the event of failure during a "100-year" flood

writing and administering surveys (Dillman 2000), we mailed 20 pre-test surveys with a letter introducing the study and revised any potentially confusing questions. Four weeks later, we mailed the revised survey instrument and letter of introduction to the full sample, reminded residents 11 days later with a post card, and finally re-mailed the surveys to addresses that had not responded after 5 weeks. We did not conduct a post-survey follow-up to check for non-response bias. To test for relationships between flood risk awareness and education level or income, we assigned numerical values (ranking) to some select qualitative (ordinal) data, and conducted a contingency table analysis. Because of the form of our variables, we could not compute a correlation matrix for all variables. However, our purpose was not to explore relations between risk perception and income/education, which have been documented elsewhere, rather to determine how well our sample population (of well-educated professionals) understood their true flood risk.

5 Results

5.1 Sample characteristics

Survey respondents were 46% female and 54% male. Ages ranged from 18 years to older than 65 with 67% between 35 and 54 years old. 73% of respondents reported speaking English as a first language. Mean respondent household size was 3.31 people, ranging from one person to more than six. Annual mean and median household income of respondents in Spanos Park West were roughly $80,000 and $90,000, respectively, higher than county-wide average of $63,739 (San Joaquin Council of Governments 2005a). 43% of respondent households in Spanos Park West earned $100,000 or greater annually.

The respondents in Spanos Park West were well-educated: 37% had a 4-year university degree, 27% post-graduate, and 10% had a professional degree. No respondent households reported an education level less than secondary school. Our sampled population was better educated than the rest of San Joaquin County, where only 17.3% have a bachelor's degree or higher (San Joaquin Council of Governments 2005b). The population in Spanos Park West was ethnically diverse, with 30% White, 23% Asian, 19% Hispanic, and 10% African American. While most respondents (69%) had lived in their *house* for 3–5 years, most had lived in Stockton for longer: 19% for 11–20 years, 39% for more than 20 years. 107 respondents owned their houses, six rented (and one did not respond to this question).

5.2 Survey responses to risk perception questions

When asked to assess their risk of flooding from "no risk," "low risk," "medium risk," to "high risk," 59% of respondents believed their risk was "low," 6% said "no risk," and only 35% said "medium" or "high" risk. When inquired about level of concern, 34% were "not at all concerned" about their property flooding and 47% were "somewhat concerned." Respondents were mixed in their levels of confidence that Bear Creek Levee would protect them during a flood: 39% were "confident" or "very confident," 42% were "somewhat confident" or "not at all confident" in the levee's protection, and 18% were unsure.

When asked to estimate the water depth and damage at their property in the event of a levee break (Fig. 4), ranging from "my property would not flood" to expecting flooding as high as "the roof," 18% of respondents anticipated water only reaching the yard, 45% stated water would reach the first floor, and another 28% did not know. Few selected the second floor or the roof. Comparing respondents' expectations to the actual flood depths at their houses from a levee break during a 100-year flood, 47% of respondents either underestimated the depth or were unsure how deep it would be. 46% estimated correctly and roughly 6% overestimated the depth. The main factor controlling actual flood depths will be location of the house within the subdivision, whose lands slopes westward from sea level to 1.6 m below sea level. The questionnaire included an opportunity for respondents to describe the damage they thought their property would sustain if a levee broke near their home. Not all respondents answered this question, but of those that did, most anticipated minimal damages: "water, mold, or mud damage," "Little if any—mostly exterior," and "Hardly any damage at all or maybe just flooding of the front lawn." A few anticipated greater losses and damage: "Major damage… If the levee broke, my first floor and everything in it would be completely destroyed beyond repair," "I would not live in it anymore," and "My home is only one level so I think it will be completely destroyed." As the development is below sea level, damage would in fact be significant, because the

inundation would occur suddenly as a wall of water, and the properties would not drain after passage of the flood peak.

When asked to assess their flood risk in comparison with other risks faced, such as illness, accidents, or other natural hazards, most respondents thought they were equally likely to experience a flood as a fire. However, the likelihood of a house catching fire over a 30-year mortgage period is 4% (Loucks and Stedinger 2007) compared to the 26% residual risk of flooding on lands behind 100-year levees. On a scale from "not at all likely" to "almost certainly," a combined 82% of respondents believed flooding was "not at all likely" or only "somewhat unlikely."

5.3 Prior flood experience, knowledge, and risk disclosure

2.6% of respondents reported having indirect prior experience with floods. None had personal experience with floods in their own house. Given reports in the literature that prior experience with floods is one of the most influential factors of risk awareness, this factor could contribute to underestimating the local flood threat.

When asked if they were familiar with the term, "100-year Flood," 34% of respondents said they were familiar with the term, 52% were unfamiliar, and 14% were somewhat familiar. However, only three respondents (2.6%) defined the term correctly. 31% stated they understood the term, but their responses indicated that they did not. The most common responses were some variation of, "A major flood comes every 100 years—it's a worst-case scenario," "According to history, every 100 years or so, major flooding has occurred in the area and through documented history, they can predict or hypothesize on what to expect and plan accordingly and hopefully correctly."

Six percent of respondents had been informed by their real estate agents that the subdivision was at risk of flooding, and only 12% reported any discussion of flooding with a real estate agent. Two respondents said they had asked their real estate agents specifically whether they were in a floodplain and were told, "no." Officially, this is correct, because the development is outside the FEMA-designated "floodplain" for the insurance program. One respondent who identified himself as a consultant in the planning and commercial development industry wrote: "The disclosure has been that even though there is a theoretical flood risk, the appropriate mechanism is the construction and maintenance of strong levees for which all homeowners contribute annually. Conversely, if such levees were not certified, then issuance of a building permit will not be possible in the first place."

60% of Spanos Park West survey respondents reported that they had not been informed of their risk and that they did not frequently hear about flood-related issues. In fact, 30% of households reported they never hear about flooding, 54% hear rarely, and only 15% of households hear about flood-related issues on a monthly basis. Some respondents requested more information and one resident commented additionally, "I contacted Stockton City Hall after hearing this information and was glibly told I had little to worry about." Of the 40% of households that had been informed of their flood risk, most found out through an insurance agency or local newspapers. Television also was a major source for flood information.

5.4 Behavior, insurance purchase, and preparation

20% of respondents had purchased a flood insurance policy. This is higher than the 1% national average for purchase outside of the official "floodplain" (Dixon et al. 2006). When asked whether or not their households had taken any measures to be "generally

prepared" for a flood, 13% of respondents answered "yes," citing discussing evacuation routes and storing valuables on the second floor. No residents reported keeping a boat despite extensive media coverage of rescues during Hurricane Katrina by boats.

At the end of the questionnaire, one respondent noted, "It is my understanding that my area is not in a flood zone. That the levees have been reinforced in the 1980s. If I felt or learned that a flood was eminent, I would take the steps to protect my property."

When asked whether respondents would evacuate or shelter at home if advised of a *voluntary* evacuation order, 79% responded they would evacuate, 17% that they would stay at home, citing a desire to protect their property, not knowing anywhere else to go, disability, or fear that the disaster would be a repeat of what happened in the Superdome in post-Katrina New Orleans. Others would avoid evacuating because they were still unconcerned about the risk. "Flooding is unlikely and if a flood occurs, it will be minimal," "FEMA set new standards and this should be safe," and, "I personally don't feel my home would flood, especially because of the height it was built off the street. As per the most recent home assessment, my home wasn't in the worst floodplain rating."

6 Discussion

One might expect that a population in which 75% of respondents have at least a four-year university degree would understand their risk. However, our study clearly shows that in a subdivision of houses selling for $200,000–$1,000,000 in August 2008 (Movoto Real Estate 2008), the mostly well-educated, professional residents were unaware of their true risk of flooding, believing that the "100-year" levee protected them from all flooding. Most had taken no precautions such as keeping a boat available for escape during a flood. In the Sacramento-San Joaquin Delta, floodwaters will be more lethal than those experienced by New Orleans residents during Hurricane Katrina, because the floods will likely occur during the winter, when water temperatures are typically below 10°C. Katrina floodwaters in New Orleans in August 2005 were around 30°C, warm enough that a person can survive over 12 h. Flood victims will survive less than an hour in waters below 10°C.

Previous studies have suggested that risk perception was correlated with education and income (Burningham et al. 2008). However, our population had a relatively narrow range: mostly well-educated professionals with high incomes, so it is not surprising that a contingency table analysis showed that flood risk perception was not related to educational level or annual income at $a = 0.05$.

Research to improve our understanding of how people think about risk can have an important role in informing policy (Slovic et al. 1982). It is likely that other flood-prone communities across the country are similarly unaware of their true risks and are comparably unprepared for floods.

Studies in the Netherlands (Terpstra and Gutteling 2008) and in Japan (Motoyoshi 2006) demonstrated that residents considered safety to be the responsibility of the government. Consistent with this attitude, our respondents may have assumed that because the government allowed them to live in a given area implied that the government considered that area safe. "We are not considered to be in a floodplain because the levees have been improved," wrote one resident. "We are in a FEMA Zone-X, [we are] protected by levees," wrote another.

This study is a first look into flood risk perception on lands protected by 100-year levees in the United States. It answers the important questions, *are these residents aware of their residual flood risk and are they prepared for a flood?* A more detailed look with a more

in-depth questionnaire (such as conducted by Terpstra and Gutteling 2008) might reveal which factors influence the perceived levels of risk in Spanos Park West and those factors which might influence future self-protective behavior. These results could then be used to target effective and appropriate measures for raising risk awareness and reducing risk.

In the meantime, it significant that those who are exposed are unaware of the threat, and policy makers could develop measures aimed at reducing risk given the current risk perception of their constituency. In what might be considered a partial recognition of the problems inherent in the use of the 100-year flood in land-use planning, the State of California has adopted laws requiring use of the 200-year flood as a basis for planning instead (Central Valley Flood Protection Act of 2008). However, in the Sacramento-San Joaquin Delta, where water surface elevations are driven more by sea level than by riverine hydrology, the difference between the 100- and 200-year water surface elevations is commonly on the order of centimeters or tens of centimeters, yet the residual risk for lands protected by a 200-year levee remains high.

The State of California also now requires annual flood risk notification to all residences in State and Federal "Levee Flood Protection Zones," though this notice is mailed after home purchase.

7 Conclusion

Residents in our studied subdivision in the Sacramento-San Joaquin Delta of California were unaware of the residual of flooding threat on levee-protected lands. Under federal flood insurance rules, these lands are not considered as "floodplain," despite being below sea level. Residents do not understand that they still face significant flood risk: both from the residual risk from floods exceeding the design flood, and from other threats to levee integrity in this seismically active region, an earthquake is likely to cause extensive levee failure (Mount and Twiss 2005). Thus, the residents are involuntarily exposed to risk.

Investment in "prevention, protection, and preparedness" has recently become an overarching strategy for reducing flood risk in the Netherlands and the European Union, and risk perception contributes to preparedness (European Commission on the Environment 2009).

While knowledge and acceptance of a risk does not guarantee a behavioral response, public policy to provide better information on flood risk to residents (Wenk 2006) would increase the likelihood that residents would take precautionary action (Rogers 1975).

Along rivers in long-settled landscapes, it is common to see buildings, walls, and pillars marked with high water marks of past floods, a visible reminder that the land is flood prone (Fig. 5). A similar approach could be used in these newly built, "memory-free" subdivisions by posting expected levels of inundation from floods exceeding the 100-year design flood or levee failure from other causes.

Other public education approaches should be developed to ensure people behind levees understand their true flood risk such as flood risk disclosure *prior* to any real estate transaction. Fridirici (2008) suggests integrating rally points or clear evacuation routes into neighborhoods as a likely way to raise awareness. In light of Palm's (1981) findings that natural hazard disclosure does not guarantee risk-avoidance behavior, policies that discourage development in hazardous areas might be considered as "preventative" measures by minimizing threat exposure to life and property. Or, as one respondent added to the open comment section of his questionnaire, "The correct way of addressing flood hazard is to never allow building in a risk prone area."

Fig. 5 High water marks from Elbe River, Sachsen, Germany

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