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Social Dimensions of Urban Flood Experience, Exposure, and Concern

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Research Impact Statement: Social vulnerability determines experience with and concern about future flooding, but not exposure to floods. Social and physical vulnerability need to be considered together in managing flood risk.

Abstract: With growing urban populations and climate change, urban flooding is an important global issue, even in dryland regions. Flood risk assessments are usually used to identify vulnerable locations and populations, flooding experience patterns, or levels of concern about flooding, but rarely are all of these approaches combined. Further, the social dynamics of flood concerns, exposure, and experience are underexplored. We combined geographic and survey data on household-level measures of flood experience, concern, and exposure in Utah's urbanizing Wasatch Front. We asked: 1) Are socially vulnerable groups more likely to be exposed to flood

risk? 2) How common are flooding experiences among urban residents, and how are these experiences related to sociodemographic characteristics and exposure? and 3) How concerned are urban residents about flooding, and does concern vary by exposure, flood experience, and sociodemographic characteristics? Although floodplain residents were more likely to be white and have higher incomes, respondents who were of a racial/ethnic minority, were older, had less education, and were living in floodplains were more likely to report flood experiences and concern about flooding. Flood risk management approaches need to address social as well as physical sources of vulnerability to floods and recognize social sources of variation in flood experiences and concern.

(**KEYWORDS**: flooding; urban areas; risk assessment; risk perceptions; social vulnerability; flood experience.)

INTRODUCTION

Urban flooding is a world-wide issue, with impacts increasing globally as cities and metropolitan areas expand and the global population grows increasingly urban (Seto *et al.*, 2011; Jongman *et al.*, 2012; Aerts *et al.*, 2014; Li *et al.*, 2015). Even in dryland regions, flooding is a serious risk and hazard and is expected to increase due to climate change (Garfin *et al.*, 2013). Addressing urban flood risks requires adaptive management approaches in response to rapid changes in urban land use, a changing climate, and shifting demographics within cities (Wilby and Keenan, 2012; Kundzewicz *et al.*, 2014). The challenge for flood risk research is to address the interactions between these many factors and to provide actionable information to water decision makers and managers.

Despite existing literature on social vulnerability to natural hazards, including floods, a major gap is our incomplete understanding of variation in flood concern, exposure, and experience within urban populations, particularly across sociodemographic groups. Despite increased attention to urban flood risk in the literature, the majority of this literature focuses on physical vulnerability and exposure rather than social vulnerability (Cho and Chang, 2017). The flood risk perception literature has focused on Europe (e.g., Botzen *et al.*, 2009; Wachinger and Renn, 2010; Wachinger *et al.*, 2013; Lujala *et al.*, 2015) and lacks adequate inclusion of sociodemographic factors, particularly race and ethnicity, which have long shaped the social dynamics of many cities, especially in the United States. Sociodemographic factors can have

strong influences on individuals' behaviors and perceptions, particularly in relation to water (Braden *et al.*, 2009; Larson *et al.*, 2009; Grafton *et al.*, 2011; Hale *et al.*, 2015, Flint *et al.* 2017), yet a recent synthesis report on risk perceptions did not mention race or ethnicity at all (Wachinger and Renn, 2010). When sociodemographic factors are included, they are usually used as control variables, rather than recognized as important sources of hazard vulnerability (Slimak and Dietz, 2006; Botzen *et al.*, 2009; Kellens *et al.*, 2013; Wachinger *et al.*, 2013). Importantly, we hypothesize that *exposure to* and *experience of* floods are related to aspects of social vulnerability, here defined as characteristics of people, individually and collectively, that influence their potential for loss and enable them to respond to and recover from hazards (Cutter *et al.*, 2003) in addition to physical aspects of flood exposure. While the role of floodplain exposure has been well studied (Lindell and Hwang, 2008; Botzen *et al.*, 2009), the social aspects of flood vulnerability are underexplored. Here we analyze variation in and interactions between flood experience, concern, and exposure across sociodemographic characteristics. Importantly, we control for risk tolerance, often used to explain differences in concern and risk perception across social groups, by measuring concern about multiple risks. A full accounting of how risks are experienced and perceived across sociodemographic groups is particularly important in hazards research given past cultural insensitivity associated with emergency response and unequal access to resources during disaster recovery across racial and ethnic lines (Fothergill *et al.*, 1999; Bolind and Kurtz, 2018). Flood risk management by public agencies is obligated to serve all members of a community and will not be successful if it is based only on experiences of the majority group and does not account for variation among different segments of the population.

A critical aspect of addressing differences across social groups is the potential for the nature of flood experiences to vary. The role of flood experience is central to many models of human-flood interactions (Viglione *et al.*, 2014; Di Baldassarre *et al.*, 2015), concern (Botzen *et al.*, 2009; Kellens *et al.*, 2013; Wachinger *et al.*, 2013), preparedness (Bradford *et al.*, 2012; Scolobig *et al.*, 2012), and strategies for risk communication (Bradford *et al.*, 2012). Yet the linkages between experience and concern are not consistent across studies and may differ across social groups. Most studies assess experience by asking if a survey respondent has had any experience with flooding (Botzen *et al.*, 2009; Lujala *et al.*, 2015), yet flood experiences can range from minor property damage to injury and death (Siegrist and Gutscher, 2008; Lawrence *et*

al., 2014). We hypothesize that the specifics of flood experiences are an important factor in determining the relationships between experience and concern and that these will vary across social groups.

Objective and Research Questions

The objective of this study was to assess the flooding experiences and risk concerns of residents living in northern Utah, a rapidly urbanizing, semi-arid, and flood-prone region, and to evaluate how those experiences and concerns varied by levels of social vulnerability and flood exposure. Risk concerns, a dimension of risk perceptions, are a fundamental link between physical and social dimensions of risk and hazard and are a function of the risk itself (Whyte, 1986; Slovic, 1987) and the person(s) considering that risk (Whyte, 1986; Slimak and Dietz, 2006). Risk perception has been linked to preparedness for and behavior during flood hazards (Riad *et al.*, 1999; Lindell and Hwang, 2008; Miceli *et al.*, 2008; Wachinger *et al.*, 2013) and to support for policy measures to mitigate risks (Glenk and Fischer, 2010). To better understand the social dynamics of flooding in urban landscapes, we evaluate relationships between social vulnerability (based on demographics associated with disadvantaged social groups), exposure (location vis-à-vis flood plain), self-reported flooding experience, and flood concern. Specifically, we address three research questions:

1) Are socially vulnerable groups more likely to be exposed to flood risk?

2) How common are flooding experiences among urban residents in Utah, and how are these experiences related to social vulnerability and exposure?

3) How concerned are urban Utah residents about flooding, and does concern vary by exposure, flood experience, and social vulnerability?

METHODS

Study Location

We conducted our study in the Wasatch Range Metropolitan Area (WRMA) in northern Utah, USA, comparing three valleys with different levels of urbanization: Salt Lake Valley, Cache Valley, and Heber Valley. Anglo-European immigrants settled in each of these valleys in the mid-19th century by harnessing local water resources to support irrigated agricultural production. Currently, the Salt Lake Valley is dominated by urban land uses and has the largest

population (over 1 million) of the three valleys. Cache Valley has remained a major agricultural production center but is rapidly urbanizing and has a population of roughly 113,000. Heber Valley has retained the most rural character of the three areas with a population of just over 23,000 in 2010, but it is becoming a growth center based on recreation (i.e., ski resorts) and natural amenities, and includes residential developments for commuters to the greater Salt Lake area and second homes. The WRMA climate is semi-arid with hot dry summers and cold, wet winters. Most of the precipitation falls as snow. All three valleys contain mountain-front communities with potential for significant flooding during the spring snowmelt season and occasional flooding from summer cloudburst storms. These conditions are likely to increase with predicted escalation in variability and extreme events due to climate change, rapid urbanization in these watersheds that exacerbates stream flashiness, and changes in (aging) reservoir management that balance risks associated with high water variability by erring on the side of keeping reservoirs as full as possible going into winter months. Each valley experienced damaging floods during springs of 2011 and 2017 as a result of large snowpacks and warm springs. Despite frequent, and occasionally major, flooding, the total damages from flooding in Utah over the past two decades are relatively small compared to other regions in the United States with larger populations and urban areas (https://www.ncdc.noaa.gov/stormevents/). However, this region has an even longer history of significant flooding, with major floods occurring in the 1940's, 1960's, and 1980's (Flores, 1983; Lindskov, 1984; Hale, 2016).

Although dryland regions are not often thought of as flood-prone, the Intermountain and Southwest regions of the U.S. are particularly vulnerable to flash flooding, with flood risks expected to increase in some sub-regions and seasons due to the hydrologic effects of climate change (Hamlet and Lettenmaier, 2007; Garfin *et al.*, 2013). Land use changes associated with rapid and concentrated urbanization in these regions, the proximity of many urban areas to public lands, and changing fire regimes are increasing the risks of even smaller flood episodes throughout the western U.S., as demonstrated by devastating fire and subsequent storm events in California in recent years. The WRMA study area is representative of growing urban areas in the western U.S.

Survey methodology

This research was part of a larger study of Utah residents' water perceptions, attitudes, concerns, and behaviors conducted in 2014. Data reported here come from a survey of households living in 23 neighborhoods (defined as census block groups) from 3 counties in northern Utah (Cache, Salt Lake, and Summit). Neighborhoods were purposively selected to be representative of diverse types of WRMA neighborhoods across a wide range of sociodemographic, built, and environmental characteristics (Jackson-Smith *et al.*, 2016a). According to FEMA's 100-year floodplain maps (http://hazards.fema.gov/gis/nfhl), none of these neighborhoods are protected by levees. Over 4,000 housing units were randomly sampled from county and city property tax rolls to participate in the survey, 180 households from within each of the 23 study neighborhoods. The 16-page, university IRB-approved survey included detailed questions about perceptions and attitudes related to a range of water issues (including flooding), measures of household water use and landscaping behaviors, support for various local or statewide water policy options, and demographic attributes of respondents (copies of the survey instrument are available at http://data.iutahepscor.org/mdf/Data/household_survey_instrument/). Surveys were administered using a drop off/pick up method (Steele *et al.*, 2001; Jackson-Smith *et al.*, 2016b) in which surveys were personally delivered to each household by field staff and, if a qualifying resident agreed to take the survey, left with the identified respondent for completion, after which the surveys were retrieved at an agreed upon date and time. Multiple visits were made to each sampled household until contact was made with a resident. If surveys were not retrieved after multiple attempts, prepaid return envelopes were left at the door for the respondent to use to return their survey. In a few cases where no contact was made or no access was available, a multi-wave mail survey design was implemented (Dillman *et al.*, 2014; Jackson-Smith *et al.*, 2016b).

From a total sample frame of 3,766 eligible (non-vacant) housing units, we received 2,337 responses from 23 neighborhoods in 3 counties with an overall response rate of 62% (Jackson-Smith *et al.*, 2016b). Because neighborhoods were purposively, not randomly, selected to reflect particular combinations and variations of social, built, and natural environments in the study communities, aggregate characteristics of respondents should not be treated as indicative of the general population in the study region. However, when compared to state-level census statistics, the respondents were demographically similar to residents in each of the study

neighborhoods and broadly representative of Utah's adult population, though whites, people over 35, and adults with 4-year college or graduate degrees were overrepresented (Endter-Wada *et al.*, 2015; Jackson-Smith *et al.*, 2016b, Table 1).

Measuring Respondent's Experiences and Concerns with Urban Flooding

We used a variety of questions to understand respondents' experiences with water in the urban environment. For this analysis, our central dependent variables were experiences with and concern about flooding. Descriptive statistics for dependent and independent variables are shown in Tables 1 and 2. To quantify concern, we asked respondents to rank their concern about several water-related issues, including flooding. We asked: "How concerned are you about flooding over the next 10 years?" Respondents were asked to rank their level of concern from 1 (not at all concerned) to 5 (very concerned). To quantify flood experiences, we asked respondents whether they were aware of any instances in the last 10 years in which their household had been impacted by flooding or stormwater. We specifically asked about six types of flood impacts: flooded basements, contaminated drinking water, contaminated streams, private property damage, damaged roads and infrastructure, or loss of life or injury due to flooding and/or stormwater.

To understand what characteristics of respondents were associated with flood concern and experiences, we also asked respondents about their background (descriptive statistics for independent variables shown in Table 1). To control for respondents who may have experienced flooding in previous residences, we analyzed variables related to questions about seasonal residence and whether respondents were originally from their valley of residence. Finally, we also collected a standard suite of demographic variables, including the respondent's age, gender, education, race/ethnicity, and religious preference, and the household's residential tenure status, presence of children, and household income.

Measuring Physical Exposure to Flood Risk

To evaluate exposure to flood risk, we determined for each respondent whether their household's residence was located within the 100-year floodplain using parcel information and the FEMA 100-year floodplain layer in ArcGIS. We also calculated the percentage of each neighborhood that was located within the 100-year floodplain using zonal statistics in ArcGIS.

Statistical Analysis

Models exploring the relationships between exposure, sociodemographics and other factors and reported flood experiences were developed for each type of flood experience (e.g., household basement flooding) as well as for a combined measure of flood experience (any household flood experience) using binary logistic regression. A chi-squared test was used to determine goodness of fit as significant difference from the null model. To explore differences in the distribution of populations within and outside of the 100-year floodplain, we used a test of equal proportions.

Tendencies to express concern (regardless of the issue) can vary across a population due to differences in risk tolerance. Therefore, we calculated a measure of *relative flood concern* to capture how a respondent rated concerns about flooding relative to other issues. Specifically, we computed a z-score for each individual respondent: ((Flood concern – mean of all concerns)/standard deviation of all concerns). These concerns included: water shortages, poor water quality, high cost of water, deteriorating water infrastructure, air pollution, traffic congestion, loss of open space, population growth, and climate change. This transformation provided a single measure that adjusted for the effect of variable risk tolerance across respondents. We fit a multiple linear regression model to determine how exposure, flood experiences, and sociodemographic characteristics were associated with relative flood concern. We conducted a model selection exercise, using Akaike's Information Criterion (AIC) to compare candidate models, to select theoretically-important and empirically-robust variables while ensuring model parsimony and avoiding multicollinearity between predictor variables. As a result, many more variables were explored than were ultimately selected for the final model. All analyses were conducted in R 3.2.2.

RESULTS

Exposure to flood risk

Overall, roughly half of our respondents lived in neighborhoods that overlap at least partially with a 100-year floodplain, and 3% of our respondents lived in parcels actually located within the FEMA 100-year floodplain map. Contrary to environmental justice literature expectations, our results suggest that socially vulnerable populations are not disproportionately exposed to flooding. Respondents who might be considered socially vulnerable in this region –

racial/ethnic minorities, Hispanics, lower income households, renters, and newer residents – were less likely to live in FEMA designated floodplains (Fig. 1). To confirm if these patterns were typical in the WRMA beyond our survey respondents, we also examined characteristics of residents reported in the 2010 Census of Population at the Census Block Group level (CBGs; the same geography we used to delineate our study neighborhoods). Of the 1406 CBGs along the entire Wasatch Range, 458 (33%) overlap with the 100-year floodplain. Block groups that overlap with the floodplain have a statistically significantly higher percentage of residents over 65 (9% vs 8%, $p=0.005$), higher percentage of residents with household incomes greater than $100,000 (25% vs 20%, $p<0.0001$), significantly lower poverty rate (9% vs 12%, $p<0.00001$), and a lower percentage of renter households (26% vs 31%, $p=0.0006$). However, there were no significant differences between floodplain block groups and other block groups in terms of race/ethnicity (percentage of non-Hispanic whites was 78% for both groups), or the percentage of the population over 25 with a bachelor's degree.

Reported Flood Experiences

Flooding impacts were reported by 44% of respondents (Table 2). The most commonly reported impacts were flooded basements, private property damage, and infrastructure or road damages (Table 2). The least commonly reported experiences with flooding were impacts on contaminated drinking water, contaminated streams, and injury or loss of life (Table 2).

Models of Reported Flood Experiences

Models predicting flood experiences were expressed highly significant goodness of fit overall and coefficients for sociodemographic variables were more consistently significant in models than exposure variables (Table 3). Associations with sociodemographic and exposure variables also varied across types of flood experiences. All models reported in Table 3 are significantly better than a null model. Estimates of predictive power (pseudo R^2 statistics) were low, but comparable with those in other flood concern studies (Botzen *et al.*, 2009).

Sociodemographic variables were significant predictors of reported flood experiences. Racial/ethnic minority and older respondents were more likely to report all types of flooding experiences. Some sociodemographic variables were significant only for certain types of flooding experiences. For example, respondents with less formal education were more likely to

277 report contaminated drinking water, while lower income households were more likely to report
278 experiences which resulted in injury and loss of life. Households with children were more likely
279 to report experiences with private property damage. Respondents affiliated with the Church of
280 Jesus Christ of Latter-day Saints (LDS) were more likely to report experiences with basement
281 flooding and less likely to report experiences with contaminated streams due to flooding
282 compared to non-LDS respondents. Controlling for the other variables in the model, tenancy
283 (owner/renter status) and gender was not significantly associated with reported experiences with
284 flooding impacts (Table 3).
285 Measures of exposure to floodplain risks were only partly related to reports of flooding
286 impacts at the household scale (Table 3). Respondents who lived in parcels in the 100-year
287 floodplain were more likely to report higher levels of flood impacts overall (the combined
288 measure) and private property damage in particular. The percent of a respondent's neighborhood
289 that was within the 100-year floodplain was also positively associated with household-level
290 reports of damaged roads and infrastructure (Table 3).
291
292 *Concern about flooding*
293 Across all survey respondents, the mean level concern about flooding in their community
294 over the next 10 years was 2.75 on a scale from 1 (not at all concerned) to 5 (very concerned),
295 indicating low to moderate concern. Mean concerns for other water and environmental issues
296 were generally higher, ranging from 3.5 to 4.3 (Fig. 2A). The distribution of concern about
297 flooding was approximately normal, with the most common response being 3, indicating modest
298 levels of concern (Table 2). A minority of respondents (16%) indicated that they were not at all
299 concerned about flooding, and 25% of respondents indicated that they were concerned or very
300 concerned (Fig. 2B). In contrast, concern for the other 9 types of community concerns listed in
301 the survey was much higher, with over 50% of respondents rating concern as 4 or 5 ("concerned"
302 or "very concerned") (Flint *et al.*, 2017). Eleven percent of respondents had a *relative* flood
303 concern score greater than zero, indicating that they were more concerned about flooding than
304 the other water, environmental and growth issues in the survey.
305
306 *Models of Flood Concern*

We estimated multivariate regression models to predict the relative flood concern z-score (ordinary least squares regression). The best model was significant overall but explained only 10% of variation (Table 4), as expected for risk perception models (Peacock *et al.*, 2005; Botzen *et al.*, 2009).

A broad range of previous flooding experiences were significantly related to predicting a respondent's *relative* level of concern about flooding (Table 4). As expected, relative concern was positively associated with having personally experienced basement flooding and injury or loss of life due to flooding. Surprisingly, relative concern was negatively associated with experience with any flood impact and contaminated drinking water. The percentage of a respondent's neighborhood that fell within the 100-year floodplain was positively associated with relative concern. Respondents' relative concern about flooding significantly increased if they were of a racial/ethnic minority, LDS, or had children living at home. Wealthier respondents had lower levels of relative concern. Residents originally from their valley of residence were less likely to be relatively concerned about flooding, which suggests that sensitivity to flooding may be higher for people moving from other places (Table 4).

DISCUSSION

The goal of our analysis was to identify the sociodemographic drivers of flood risk and to explore relationships between flood experiences, exposure to flood risk, and concern about future flooding. A key finding of our research is that physical exposure is important but provides an incomplete explanation of why experiences with flooding and risk perceptions vary within the population and geographically. We found that the links between flood experiences, exposure, and concerns are complex: while respondents from vulnerable groups were more like to report personal flooding experiences and concern about flood risk, they were less likely to be physically exposed to flood risk through residency in the floodplain. Our study highlights the critical role that social factors play in determining flood risks within urban systems and suggests a need to incorporate considerations of environmental justice in the development of effective flood risk management programs.

Are socially vulnerable groups more likely to be exposed to flood risk?

Our finding that people who live in the 100-year floodplain in Utah are more likely to be white and have higher incomes did not fit with expectations from the broader environmental justice literature but might reflect an amenity value associated with urban waterways within our study area. This pattern has been observed in other cities (Collins *et al.*, 2018). Our results contribute to a small but growing literature that has found more complex relationships between social vulnerability and exposure to flood risk. Studies in UK found that the presence of environmental justice concerns depended on the type of flooding – tidal compared to riverine (Walker and Burningham, 2011). In the United States, there are inconsistent patterns in the distribution of populations in floodplains both within cities (Maantay and Maroko, 2009) and across cities (Collins *et al.*, 2018). The lack of consistent patterns in flood risk exposure suggests that the disproportionate effects of flooding on minority racial and ethnic groups is not necessarily due to unequal exposure, but unequal vulnerability, as discussed above (Cutter *et al.*, 2003; Fielding and Burningham, 2005; Maantay and Maroko, 2009; Walker and Burningham, 2011; Collins *et al.*, 2018). This finding also has important implications for the interpretation of our results. The different effects of sociodemographic characteristics across regions indicate that local controls on social vulnerability are important. For example, the legacy effects of segregation on unequal flood risk and housing quality are important factors in the southeastern United States (Fothergill *et al.*, 1999), but the underlying causes of vulnerability in Utah, where the largest minority group is Latino/a, are likely to be quite different (Montgomery and Chakraborty, 2015). Understanding the sources of vulnerability can aid flood management organizations in targeting locally-appropriate response plans and can be used to understand how the results from generalized models (e.g., Di Baldassarre *et al.*, 2015) might vary across regions.

How common are flooding experiences among urban residents in Utah, and how are these experiences related to social vulnerability and exposure?

A key finding from our research is that experiences of flooding vary significantly within urban populations. Although groups typically considered more socially vulnerable were less likely to be exposed to flood risk through residency in the 100-year floodplain, they were more likely to report experience with flooding. Furthermore, the types of flood experiences varied across sociodemographic groups. This was the case even though floodplain exposure was also found to be positively associated with reports of flood experience. Our findings confirmed

previous research that found socially vulnerable populations – lower income, lower education, racial/ethnic minority, and elderly – to be more likely to report hazard experiences (Zahran *et al.*, 2008) and more likely to be concerned about flooding (Slimak and Dietz, 2006; Kellens *et al.*, 2013; Wachinger *et al.*, 2013). The strength of association between racial/ethnic minority status and flood experience was especially pronounced for reported loss of life or injury and exposure to contaminated streams, and weakest for property damage, highlighting that the balance of social and physical sources of vulnerability varies across specific flood risks. Furthermore, flood experiences may vary for different cultural groups as well as for vulnerable groups. The finding that racial/ethnic minority respondents were more likely to report contaminated streams as a result of flooding may reflect the distinct environmental ethic (and resultant increased sensitivity) that others have reported for Latinos in comparison with other racial and ethnic groups (Lynch, 1993; Heyd, 2004; Whittaker *et al.*, 2005; Larson *et al.*, 2011). Previous research has suggested that Latinos are particularly sensitive to local environmental issues, more so than non-Hispanic whites, but that this difference is less pronounced for more abstract environmental concerns (Whittaker *et al.*, 2005).

How concerned are urban Utah residents about flooding, and does concern vary by exposure, flood experience, and social vulnerability?

Social sources of vulnerability were manifested not only in reported flood experiences but also in concern about flooding. Increased concern about flooding for some groups was significant even after controlling for risk aversion through measurement of *relative* flood concern. In much of the previous research, it is unclear whether certain social groups have higher risk perceptions overall, or whether they are more concerned about the specific risk under study. The relationships between concern and race/ethnicity, income, children, and LDS religion were robust to the correction for risk aversion, suggesting that these factors are associated with increased concern about flooding specifically, not just differences in risk tolerance overall. These results highlight the importance of controlling for overall risk tolerance or aversion within a study population to understand predictors of the specific focal risk.

While previous work has used sociodemographic variables primarily as statistical controls to account for differences in risk tolerance across demographic groups (Slimak and Dietz, 2006; Kellens *et al.*, 2013), our results support the idea that social variables can play a

more central role in explaining risk perception through the mechanisms of trust, assets, and vulnerability (Cutter *et al.*, 2003; Terpstra, 2011; Wachinger *et al.*, 2013; Elrick-Barr *et al.*, 2015). For example, other researchers have found that trust in risk-managing institutions and government authorities is strongly and negatively associated with risk perceptions (Terpstra, 2011; Fatti and Patel, 2013; Kellens *et al.*, 2013; Wachinger *et al.*, 2013; Birkholz *et al.*, 2014). Although we did not measure trust directly in this study, vulnerable groups such as minorities, and those with lower income and less education are expected to have less trust in authority than white men (Finucane *et al.*, 2000). More broadly, minorities, and people with lower income and less education have fewer resources and lower levels of access to information and important political and economic networks to respond to threats to their well-being (Riad *et al.*, 1999; Cutter *et al.*, 2003; Peacock *et al.*, 2005; Larson *et al.*, 2011; Elrick-Barr *et al.*, 2015). Minorities tend to have higher risk perceptions than white men because they benefit less from many technologies and formal institutions, are more vulnerable to discrimination, and are more likely to see the world as a dangerous place (Finucane *et al.*, 2000; Kahan *et al.*, 2007). Importantly, the combination of our results about concern and exposure suggest that increased concern is not due to disproportionate exposure, in contrast to other studies of environmental risks (Laws *et al.*, 2015).

Integrating flood exposure, experience, and concern in urban systems

Previous research on the associations between flood experiences and concern have found mixed results, with some studies finding that experiences increase concern (Kellens *et al.*, 2013; Wachinger *et al.*, 2013; Lawrence *et al.*, 2014; Elrick-Barr *et al.*, 2015; Lujala *et al.*, 2015) and others finding the opposite or no effect (Gardner and Stern, 2002; Wachinger *et al.*, 2013). Although we found overall support for the idea that experiences were related to exposure and that concern was related to experience, the linkages between these aspects of flood risk were not the same across sociodemographic groups. Respondents from socially vulnerable groups were more likely to report experiences and express concern about flooding but were less likely to be exposed by living in floodplains. This result highlights the important role of a contextualized analysis of social vulnerability and suggests the need to incorporate practices into flood management that address social as well as physical sources of vulnerability – such as trust and access to resources. Previous modeling research on urban flooding has focused on feedbacks

between flood dynamics and the social system (Viglione *et al.*, 2014; Di Baldassarre *et al.*, 2015). Feedbacks from concerns to efforts to reduce physical exposure to flooding are likely important, capturing a major part of flood risk management. However, our research also highlights the importance of social vulnerability, which may be more difficult to address through local water management measures.

Our findings suggest several key areas for future work on flood risk. Especially given diversification in urban areas, understanding the effects of social vulnerability on the links between exposure, experience, and concern, as well as the underlying mechanisms is critical. Importantly, these relationships may vary substantially based on local or regional context. We also anticipate that the linkages between exposure, experience, and concern will vary across the type of flooding and the location of flooding. Our research focused on flooding from rivers and stormwater, but we were only able to measure flood exposure as a traditional floodplain. Future research would benefit from a more comprehensive definition of flood risk that takes into account the full range of natural and built sources of flooding– including rivers, groundwater, stormwater, and infrastructure failure.

Implications for flood risk management

Previous work has noted the difficulty of incorporating social science into flood risk management, which tends to focus on physical sources of flood risk, though contributions to broadening this perspective have been made (Brown and Damery, 2002; Botzen *et al.*, 2009; Birkholz *et al.*, 2014). Efforts to incorporate risk perceptions into flood management have focused on three issues: improving "accuracy" of community flood risk perceptions (Buchecker *et al.*, 2013), improving flood risk communications (Bradford *et al.*, 2012), and improving types of approaches used for flood risk management (Wachinger and Renn, 2010). Although more specific and directed one-way communications could be developed using the type of analysis presented here (Bradford *et al.*, 2012; Bodoque *et al.*, 2016;), e.g., by developing informational materials aimed at populations with low concern and high exposure, this approach does not take into account how systematic issues might affect flood risk management, such as lack of trust in authorities or access to resources. Instead, to accommodate the diverse experiences and concerns among sociodemographic groups, flood managers would benefit from developing better dialogue and problem-solving interaction mechanisms between communities and flood managers. It is

particularly important to develop strategies to engage with more vulnerable populations beyond simply delivering information, given that flood risk perceptions are often based more on emotional and affective rather than cognitive aspects (Wachinger *et al.*, 2013; Viglione *et al.*, 2014). Furthermore, our results highlight the importance of addressing the needs of vulnerable populations since they have disproportionate flooding experience and concerns, even if they are not disproportionately exposed.

Such public interaction approaches can improve flood risk management both in terms of improving management understanding of risks from the human dimensions perspective and in terms of increasing social capacity to deal with risks (Tapsell *et al.*, 2010). Dialogue can enable management actors to identify sources of vulnerability that may not be included in technological or biophysical risk assessments. By understanding the sources of risk and mechanisms by which populations are affected by flooding (e.g., drinking water contamination, property damage), flood management authorities can better target and diversify preparedness activities and emergency response to flood events, e.g., by ensuring that bottled water is available, especially for racial/ethnic minority and older residents. Indeed, it is likely that disproportionate access to resources may underlie some of the sociodemographic differences in flood experiences and concerns identified in this study. While flood management is unlikely to be able to address underlying societal structural issues, flood managers can use this information to ensure that access to resources directly related to the diverse nature of flooding hazards are available for all residents.

Flood management approaches that engage with communities may also increase the capacity of those communities to prepare for and respond to flood events. Lack of trust in authorities may be a key factor in the greater concern about flooding in racial/ethnic minority and lower income residents. As with access to resources, flood management cannot address underlying sources of distrust, but can increase trust specifically with respect to flood management authorities. Open dialogue, through workshops and other community-based participatory research approaches, has been shown to increase trust in management authorities (Tapsell *et al.*, 2010; Buchecker *et al.*, 2013). Our research suggests that for populations with greater social vulnerability and potentially lower trust of authorities (i.e., racial/ethnic minorities, female, lower income, and with lower education levels), these approaches could be particularly useful.

CONCLUSIONS

We set out to evaluate the relationships between flood exposure, reported flood experiences, and concern about future flooding in an urban region of northern Utah, which is typical of urbanizing environments especially in the water-scarce western U.S. We found significant associations in the expected directions, where experiences were significantly associated with exposure, and both experiences and exposure were linked to concern. However, nuances emerged when these results were examined through the lens of social vulnerability. In Utah, neighborhoods with floodplain exposure were disproportionately populated by the less socially vulnerable, yet respondents from vulnerable groups were more likely to report experiences with flooding and to be concerned about future flooding. These results highlight that social vulnerability is a key element in understanding both flood experiences and concerns, and suggest the need to examine more broadly the human aspects of flood experiences.

These results have important implications for socio-hydrology research and flood risk management. The significant variation in flood experiences and concern within diverse segments of urban populations identified here contrasts with the largely geographically-based and community-scale analysis of existing flood models (Viglione *et al.*, 2014; Di Baldassarre *et al.*, 2015). Incorporating this variation in flood risk analysis and using it to inform the interactional dynamics between urban residents and flood management agencies will be an important next step in modeling co-evolution of flood management strategies and coupled human-river systems. While the sources of social vulnerability to flooding are often beyond the scope of flood management, dialogue and participatory community-based strategies may be effective approaches to both identify unique considerations for preparedness and response across urban areas and to build trust and capacity within more vulnerable population segments.

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