Moving Up the Ladder in Rising Waters: Community Science in Infrastructure and Hazard Mitigation Planning as a Pathway to Community Control and Flood Disaster Resilience

CITIZEN SCIENCE:
THEORY AND PRACTICE

SPECIAL COLLECTION: DISASTER, INFRASTRUCTURE, AND PARTICIPATORY KNOWLEDGE

REVIEW AND SYNTHESIS PAPER

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ABSTRACT

Public participation is the democratic gateway to more just, inclusive, and resilient communities. However, infrastructure and hazard mitigation planning tends toward top-down, expert-driven processes that fail to meaningfully include communities most at risk of disasters. In this article, we critically examine the potential of citizen science in infrastructure and hazard mitigation planning with a focus on stormwater infrastructure and extreme wet-weather events, as floods are the most common disaster in the US. We review literature on various citizen science approaches, from crowdsourcing to community science, and offer a framework that situates them within Sherry Arnstein's foundational piece on public participation, a "Ladder of Citizen Participation." We discuss the opportunities different participatory methods offer for meaningful public involvement, knowledge generation, and ultimately community control and ownership of stormwater and flood infrastructure. We provide case study examples across the US of how public works departments, emergency management, and related organizations have engaged communities around hazard risks and flooding challenges, and offer recommendations for how these programs can be improved. We conclude that in order to produce data needed to mitigate flood disasters and increase trust and public interest in infrastructure needs, civic participation should be grounded in community science, utilizing a multimedia and technological platform. The methods applied and data generated can be leveraged toward public safety, and provide voice, agency, and power particularly to disenfranchised communities most at risk from current hazards and looming climate change impacts.

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INTRODUCTION

Changes in both seasonal rainfall and temperature across the United States have increased the frequency of flooding, particularly in urban areas (Mallakpour and Villarini 2015). Promoting flood disaster resilience to reduce exposure and damage calls for enhanced infrastructure and hazard mitigation planning aimed at improving the physical and social infrastructure that affects resilience. From stormwater systems to social steward groups, hazard mitigation planning should guide funding distribution for built structures and also should outline a process for collaborating with public works and communities alike for infrastructure planning, assessment, repair, and expansion (Hendricks et al. 2018). Infrastructure planning can be improved through public engagement in these decisions and through more and better data on infrastructure features and flood impacts. Citizen or community science, the latter a more socially inclusive version of the former, offers one public engagement approach that could increase the amount of localized and detailed data on both the real-time condition of and capacity of infrastructure and stormwater dynamics (Corburn 2005). Together these efforts would provide evidence and public momentum for capital improvement and spending guidance that can help to reduce urban flooding.

Infrastructure and hazard mitigation planning, though, remains mostly top-down and expert-driven, and is known for under-utilizing any type of participatory processes for planning, management, or data collection (Stallings and Qurantelli 1985; Berke, Smith, and Lyles 2012; Hendricks et al. 2018). This continuing lack of participation exists even as the future of flooding calls for more "community-based disaster risk reduction management" that begins with participatory generation of the knowledge base for risk assessments (World Bank 2013).

Community science provides a mechanism to increase flood resilience. Community science is a rapidly growing form of public participation, whereby individual people or groups of residents participate as novice scientists in research projects (Corburn 2005; Conrad and Hilchey 2011). Community science has the potential to serve as a community-based method for a number of tasks including monitoring, sampling, mapping, and plan making, not only for nature-based environmental topics, but for physical infrastructure and for extreme events. Community science, furthermore, shows promise in democratizing science, which fundamentally informs policy and decision-making for communities. The Environmental Protection Agency (EPA) even argues for citizen science to be a core tenet of environmental protection as it supports working across boundaries of policymakers, scientists, stakeholders, and the public to address grassroots environmental needs (EPA 2016).

Urban planning and built-environment fields aim to foster public participation in a variety of types of community decision-making, which also can encompass environmental, infrastructure, and disaster decisions. But as Sherry Arnstein (1969) first argued, how the public is engaged varies dramatically, and most often does not lead to citizen control of community decisions, especially for socially, politically, and economically marginalized groups. In fact, Arnstein differentiates between what she refers to as an empty ritual of participation and meaningful participation that exemplifies real power and influence over outcomes. We argue that if urban planning, engineering, and emergency management embraced the concept of community science and public participation more broadly, planners and related professions could empower residents in using community-driven research, analytics, organizing, and mobilization to advocate on their own behalf and to implement community-level programs that level the landscape before, during, and after flood disasters.

In this article, we give an overview of current infrastructure and hazard mitigation practice and how it might be enhanced by public participation in the form of community science with a particular focus on social and physical infrastructure geared toward flood disaster resilience. First, we outline social and physical infrastructure as the networks, systems, and processes that can provide built and human capital for flood resilience. We then introduce Arnstein's "Ladder of citizen participation" (1969) as a foundation to understanding the theoretical levels of participation. We discuss the potential of citizen science to achieve citizen control relative to other types of participatory approaches, and provide example programs and projects that have been implemented at the nexus of infrastructure and hazard mitigation planning across the US at various scales. Lastly, we end with ultimately how community science should be optimized for community control and flood disaster resilience.

STORMWATER INFRASTRUCTURE RESILIENCE

Resilience to flood events requires adaptive physical and social infrastructures to passively and actively mitigate, prepare for, respond to, and recover from stormwater that has the potential to build up and to breach homes and property. Stormwater infrastructure, whether physical or social, are systems, structures, facilities, and networks that are critical to supporting the capturing, conveyance, and management of stormwater. Larger-scale infrastructure, such as levees and dams, are designed specifically for more coastal area flooding and extreme events. Additionally, these systems might support flood monitoring, interventions, rescues, and response when waters escalate and pose a flood risk.

Smaller-scale stormwater infrastructure are systems designed to mitigate the buildup of stormwater runoff, thereby mitigating flood risks. At the neighborhood level, stormwater systems consist of minor systems or networks of pipes, ditches, curbs, and gutters that feed in stormwater runoff and convey it through a system to then be deposited into local waterbodies. Depending on the characteristics of any given storm event and the amount of stormwater runoff generated, these systems might also consist of on-site and off-site retention and detention ponds to pace the amount and flow of water moving through the system at any given time. Most modern stormwater systems in the US are MS4s or separated stormwater systems; however, combined systems that manage both stormwater and sewer still exist, particularly in older regions of the US along the mid-Atlantic and Northeastern corridors. Dams, levees, and dunes are considered major flood infrastructure systems and usually are designed to protect and mitigate at a larger scale. These systems usually line coastal areas and larger waterbodies and serve multiple communities at a time. However, these systems are also vulnerable to changing storm characteristics, and in the cases that storms stall over a geographic area and the water builds up beyond capacity, these larger systems have to release the load or pressure off the levees to prevent breakage and can still result in flooding. Most often, data on the current condition, capacity, and local dynamics of both our minor and major systems are not well kept, and the performance and level of service is unknown. In instances when these systems fail and flooding occurs, nonstructural systems may provide opportunities for flood resilience whereas these systems cannot. Thus, the combination of both minor and major structural systems with social infrastructure and systems becomes critical in hazard mitigation.

A LADDER OF COMMUNITY PARTICIPATION

Sherry Arnstein's "Ladder of citizen participation" (1969) influenced research, policy, and practice on public participation in many disciplines. The framework outlines citizen participation across eight ladder rungs within three broad domains she calls nonparticipation, tokenism, and citizen power. The bottom rungs of the ladder represent nonparticipation. Rungs three and four progress to levels of tokenism that allow participants to listen in and to voice their perspectives. Moving up the ladder, Arnstein argued that decision-making capacity begins to materialize as participants exercise more control over both the processes and the outcomes. This ladder framework is imperfect, but it illustrates how participants can leverage their power and control depending on the ways in which they were engaged.

Arnstein's ladder offers a framework to understand flood disaster resilience in light of best participatory planning practices. This is important because infrastructure and hazard mitigation planning has been shown to have less participation than other planning activities in a community (Pearce 2003; Berke et al. 2015). Scholars have argued for decades that greater public participation in hazard mitigation planning, and the integration of hazard planning with community planning, is crucial to gaining public support for resilience and to ensure the accuracy of the equity and risk assessments (Burby et al. 2009; Godschalk 2003; Godschalk et al. 1998; Mileti 1999; Pearce 2003). Boothroyd and Anderson (1983, p. 11) indicated nearly 40 years ago that public participation in hazard planning would "allow the integration of specialized technical and abstract knowledge with local concrete knowledge and feelings."

In light of the current US infrastructure crisis and a growing climate crisis, planning for these grand challenges with public participation is ever so critical. To understand how infrastructure and hazard mitigation planning could increase public participation, we align several of the common participatory methodologies alongside Arnstein's ladder of participation for reference (Figure 1).

Residents, if engaged through community science around infrastructure and hazard issues, have the opportunity to participate in the creation of knowledge and a grounded fact base from which decision-making around policy development, tax allocations, information sharing, program operation, etc. occurs. Community science represents the potential for redistribution of power dynamics in traditional top-down science similar to the redistribution of power that allows communities to have a voice in future government decision-making (Haklay 2013); Arstein also argued for a similar redistribution of power (1969, pg. 216). Considering the long history of volunteerism in disaster management (Whittaker, McLennan, and Handmer 2015; Qurantelli 1984), there are unrealized opportunities for more community science.

We argue that if used with the highest rungs of the ladder in mind, some of these participatory methodologies could

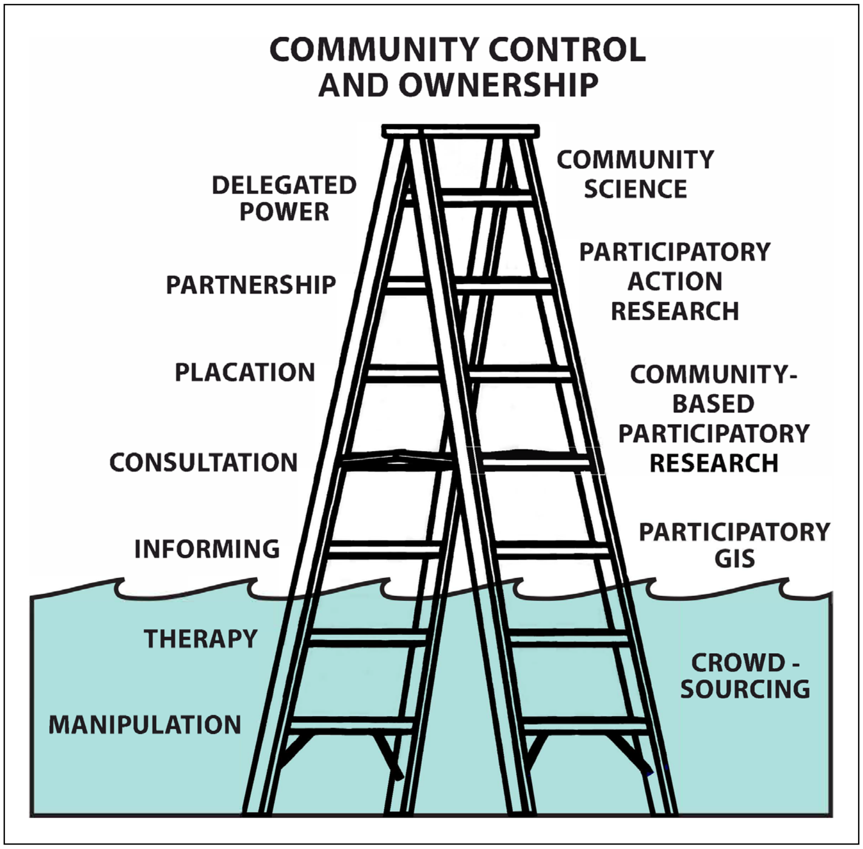

Figure 1 A ladder of citizen participation and the methods that fall within the rungs.

increase flood resilience planning, from risk assessment to developing recovery action plans through generating greater public engagement in hazard planning (McCall 2003). As we move through examples of citizen science used for flood infrastructure, we indicate how they relate to the location on the participatory ladder.

NONPARTICIPATION

Rungs entitled Manipulation (1) and Therapy (2), the bottom rungs of Arnstein's ladder, represent superficial engagement that remains largely patriarchal. These types of efforts are unidirectional and treat participants as if they don't possess knowledge of their own.

Traditional crowdsourcing and citizen science methods to gather additional data from the public reaches only the bottom of Arnstein's ladder. The Federal Crowdsourcing and Citizen Science Catalog listed 507 citizen science and crowdsourcing projects supported by federal agencies. The longest-running citizen science program related to hazards is the Cooperative Observer Program that began in 1890 to gather temperature, rainfall, and other weather information from volunteers across the US (https://www.weather.gov/coop/). But since then, less than four percent of the listed projects relate to disaster management (https://ccsinventory.wilsoncenter.org/). These programs improve data observation and reporting, which are important for improving risk assessment, but provide little to no opportunity for public participation in stormwater infrastructure and in decision-making for flood hazard mitigation.

Use of resident observations in the form of crowdsourcing have increased across all phases of disaster—mitigation, preparedness, response, and recovery—with the advent of Web 2.0 technologies and social media applications that allow for near-real-time information sharing. Heipke (2010, p. 551) defined crowdsourcing to include "data acquisition by large and diverse groups of people, who in many cases are not trained surveyors and who do not have special computer knowledge, using web technology." As residents gather supplies before a storm, prepare for evacuation, or conduct search and rescue, emergency management requires an influx of information to improve situational awareness of real-time conditions and needs including where flooding is occurring or where supplies should be sent. This swarm of resident activity is being leveraged through online crowdsourcing (Gustetic, Meszaros, and Safford 2015; Houston et al. 2015; Kawasaki et al. 2013). Granell and Ostermann (2016) found 59 disaster-related English-language articles since 2007 using crowdsourced data, of which Twitter (the micro-blogging social media platform) was the most common data source. For example, Liang et al. (2013) found that tweet density (from the social media application Twitter) could predict earthquake epicenters. Zou et al. (2018) found that tweet density also correlated to hurricane damage. In these efforts, researchers and practitioners attempt to use existing information from the public to support situational awareness, often without the public knowing they are participating in such activities. Importantly, those individuals generating data may be unaware of their participation in research (e.g., in the case of mining social media), and thus have no voice at all in the science.

Crisis mapping is a form of participatory GIS in which people provide real-time geospatial information about the impacts of natural and technological hazards (Brandusescu and Sieber 2018). The data produced is often faster and more detailed than traditional mapping techniques, and also encourages interaction between large groups of people online. Crowdmap, Open Street Map, and Humanitarian Open-Street Map are additional examples. Both residents in the affected areas and nonresidents can upload information to update these maps. In 2014, the United States Geological Survey (USGS) launched a participatory GIS application called "iCoast—Did the Coast Change?" to allow citizen scientists to identify storm-caused changes in coastlines by comparing before and after photographs, which is something computers are not yet advanced enough to do well. Citizen scientists who use iCoast help USGS improve predictions about coastal change and the vulnerability of communities to extreme storms. The Federal Emergency Management Agency (FEMA) has a mobile application that includes a "Disaster Reporter" function where citizens can upload and share photos, along with short text descriptions, for public display on a map. Citizens, first responders, emergency managers, and community response and recovery teams can both view and contribute information as events unfold (Everett and Fuller 2017). The National Oceanic and Atmospheric Administration's (NOAA's) mPING project employs citizen scientists to gather weather data. Since its launch in 2012, mPING has received more than 860,000 weather reports on weather events including rain, snow, ice, wind, tornadoes, floods, landslides, fog, and dust storms. The reports are used to improve forecasts related to road maintenance, aviation operations, and public warnings.

Crowdsourcing does not ask the data collectors to define the research questions or to determine the use of the knowledge generated. Without the trust of these communities, the data volunteered by the public will remain incomplete and potentially increase inequities if used to inform emergency decisions about where supplies should go (Cooper et al. 2017). Again, scientists define the problem, methodology, and use of the knowledge generated, and across all definitions and types of crowdsourcing, the initiator is almost always a company, institution, or organization—not the crowd or the general public (Estellés-Arolas and González-Ladrón-de-Guevara 2012). Crowdsourcing data collection techniques that support emergency preparedness and response, then, need to evolve with long-term plans for trust building, which have yet to be developed in most of these programs. At the lowest rungs of the participation ladder, the expansion of smartphone technology and the popularity of social media increases opportunities for crowdsourcing-based citizen involvement. Crowdsourcing data can provide crucial information about imminent risks, local damage, and response needs that experts could use immediately for planning practices, and as noted above, is the most common use of this form of citizen science in disasters (Villegas et al. 2018). Crowdsourcing is passive and self-selecting in terms of citizens choosing to provide information on a particular topic in a public forum (whether intended for research or not) and includes little or no additional effort on the part of residents. Distributed intelligence is similar in the way that citizens may volunteer to offer thoughts or insight on hazard scenarios and act as basic interpreters between the community and planners, emergency managers, first responders and anyone else involved in the work.

Crowdsourcing and volunteered geographic information, though, do not challenge the traditional command-and-control of emergency management. They also may be prone to bias that is inherent in use of these new technologies. Zou and colleagues (2018) showed that communities with smaller proportions of socially vulnerable populations used Twitter at higher rates during Hurricane Harvey. Thus, reliance on social media data as a data source may divert resources and attention away from those most in need. These disparities may result from the digital divide in which access to and use of smartphones and internet service is disproportionate across demographic groups (Fang et al. 2019; Scheerder, Van Deursen, and Van Dijk 2017; Van Deursen and Van Dijk 2019).

Additional recent efforts also engage the public for their labor, and thus are forms of nonparticipation. Public participation efforts are expanding into volunteer labor that helps maintain stormwater infrastructure. One such program is Adopt-A-Drain Houston, which encourages residents, schools, church groups, civic clubs, businesses, and the broader community to adopt a nearby storm drain (Sierra Club 2018). The adopters monitor and clean the drain of debris to reduce street flooding and protect property, homes, and people. The program asks adopters to clear 10 feet on each side of the drain four times a year to reduce the overall risk of flooding and especially when rain is predicted to support proper drainage of stormwater. The Cities of Service Prepared Together program similarly supports seven cities—four in California's Bay Area and three in New Jersey—as they engage citizen volunteers in initiatives that better prepare their cities for stormwater runoff and heat waves (Cities of Service 2017). Past project volunteers have adopted storm drains, similar to Houston's program, planted trees, and completed other pre-determined mitigation tasks.

These types of participatory activities are akin to Manipulation, rung 1**.** Not only do residents not have a voice in necessary updates, investments, or changes to aging stormwater systems or other mitigation actions, but are now asked to be responsible for upkeep. These efforts, then, often reflect an abdication of responsibility by government officials, masked as participation in community projects. The city, through volunteer participation, is reducing its responsibility for disaster impacts and their role in hazard mitigation.

TOKENISM

Arnstein classifies the middle rungs as tokenism: This includes (3) Informing and (4) Consultation. Participants hear and can be heard, but lack the opportunity to ensure their comments are acted on. Placation, rung (5), is tokenism as well because the public can advise, but are restricted in their ability to make decisions. While hazard mitigation planning is meant to "engage the whole community in thinking through the life cycle of a potential crisis, determining required capabilities, and establishing a framework for roles and responsibilities" (FEMA 1996, Introduction p. 1), the majority of current planning activities represent tokenism at best. Emergency and floodplain managers lead most hazard mitigation planning efforts, which limits the coordination of emergency plans with more comprehensive or community development planning efforts that are often more participatory (Berke et al. 2015). Furthermore, emergency and floodplain management continues a legacy of military training to enforce top-down, command- and-control style of public management (Neal and Phillips 1995). Officials assume that the technical nature of hazard risk assessments, response activities, and infrastructure tools are beyond the ability of the public to comprehend, or, conversely, that the public will irrationally panic if they know all the hazard risks (Pearce 2003; Mileti 1999). Thus, traditional hazard planning often ends with experts measuring risks independent of public input, deciding the appropriate response, and then simply informing the public of that decision (Holifield 2012; Sadd et al. 2011; Renn et al. 1991; Boyer-Villemaire et al. 2014). Berke, Smith, and Lyles (2012, p. 145) found that if any public participation was used in state hazard mitigation planning, for example, it was usually "posting of a draft copy of the plan to a website and soliciting comments and public notice of official meetings."

The advent of smartphones and GIS-enabled applications can foster greater participation if used to produce spatial narratives of local needs, conditions, and assets to improve response from local government (e.g., Wilson et al. 2015). Participatory GIS is growing in utility in urban planning fields as traditional public participation incorporates technology to gather more data and public opinions about the local community landscape (Cutts, White et al. 2011). Some new research shows that volunteers could be trained to collect data on their storm drains and other stormwater infrastructure to support further mitigation planning efforts. Participatory assessment techniques for stormwater infrastructure, for instance, is a method recently developed that mobilizes community members as citizen scientists to participate in the assessment of local stormwater infrastructure features (Hendricks et al. 2018). The assessment protocol includes criteria to evaluate the capability of different infrastructure components to reduce flooding in terms of stormwater runoff capture and conveyance; these include roadside vegetation, ditches and front slopes, culvert and cross-drain pipes, drain inlets, and pavement (Hendricks et al. 2018). This technique shows how participatory planning and provision of critical infrastructure can provide necessary data to improve existing conditions, exchange knowledge of risks between community members and local planners, and ultimately provide the fact basis to advocate for policies and programs that redistribute public resources toward hazard mitigation.

Damage assessment is another form of evaluation, particularly in the aftermath of disasters, when public participation can be leveraged. FEMA describes several ways that local officials and volunteers can conduct damage assessments (FEMA 2016). Trained volunteers have historically supported government officials in these assessments, but recent research is showing that inexperienced residents can also participate. Lue, Wilson, and Curtis (2014) found that inexperienced damage assessors could rate house damage similarly to experienced assessors, and that their scores met statistical standards for reliability in observers. They argued that citizens could participate in damage assessment and that their accuracy could be improved through tutorials and training. Resident participation in damage assessment allows community members to gather a fuller understanding of disaster impacts across the community, which would be useful for participation in long-term recovery planning processes.

Citizen science can provide ways to support participation in generating the knowledge base that will be used in recovery and future hazard mitigation planning decisions.

Many nongovernmental recovery organizations, for example, conduct recovery assessments of households, identifying unmet needs, while community-based organizations and governments alike call for residents to provide data on needs (Hendricks et al 2018; Meyer et al. 2018). These massive amounts of data on resident needs are rarely used systematically to either determine recovery strategies or monitor recovery progress to agree upon goals (Schwab 2014). Long-term recovery teams include numerous volunteers that spend time in the field working with affected homeowners (Hendricks amd Meyer 2021). These teams may not be well integrated into planning processes or used for recovery planning, even though they represent a wealth of community knowledge (Smith 2014).

The most common critique of these more participatory research strategies in any scientific area—specifically the highly technical infrastructure arena—is the validity of data collected by citizens. The claim that flood infrastructure is too technical for citizen participation is in our view based on weak assumptions about the certainty of expert data and the capacity and interest of residents. Flood modeling, for example, is itself an inaccurate enterprise, such that many, if not a majority of flood losses, occur outside expertly determined flood zones (Wing et al. 2020). Flood models often use few data points of water height to predict flooding over large geographic areas, which are more inaccurate in urban areas due to development changes than in other locations.

Knowledge creation through citizen science is critiqued for validity and reliability of the data, even as many planning processes call for integration of "local knowledge" of community processes including those related to hazards and disasters. Geertz (1983, p. 75) described local knowledge as being "practical, collective and strongly rooted in a particular place" and based on immediate experience. Preliminary evidence suggests that with appropriate techniques, protocols, and training, residents can collect valid and reliable data (Bonney et al. 2009a; Bonney et al. 2009b; Bonney et al. 2014). Co-learning and co-production by experts and local residents are strengths of community-driven research because they add localized data points to improve flood mapping (Coburn 2005). Furthermore, real-time data on stormwater infrastructure is largely absent, with assumptions of capacity and quality made based on assumptions around deterioration of the infrastructure from its original quality (Oti et al. 2019). Improving data validity through participatory methods will help experts learn about the experience of flooding and flood resilience outside of extreme events and outside of expertly designated floodplains.

Substantive data collection opportunities about infrastructure quality, damage assessments, and beyond are an improvement on the nonparticipation activities at the bottom of Arnstein's ladder and are a form of participatory GIS, but they still don't rise to the level of citizen power and control. These tokenistic activities have a notable amount of potential, but only if data and the information gathered are formally integrated in decision-making and are mobilized for action.

CITIZEN POWER

Public participants enter rung (6), Partnership, with planning officials when they can negotiate and compromise with officials. At the top of the ladder, (7) Delegated Power and (8) Citizen Control, participants have legitimate power and agency to make final decisions that are implemented in their communities.

Community-based participatory research (CBPR) (Israel et al. 1998), participatory action research (PAR) (Baum, MacDougall, and Smith, 2006), and feminist research (Acker, Barry, and Esseveld 1983; Reinharz and Davidman 1992) invoke a large step up the ladder from crowdsourcing or participatory GIS, but are rarely used in the US for infrastructure management and hazard mitigation. These forms of participatory research predate the phrase "community science" and imply similar levels of participation as the so-called new term "extreme citizen science" (Broeder 2018). Fundamentally, if we are regularly doing CBPR, PAR, and mechanisms of community science that truly foster co-production of knowledge and decision-making, we would not need to rename these processes as "extreme citizen science." Because "the process of PAR should be empowering and lead to people having increased control over their lives" (Baum, MacDougall, and Smith 2006, p. 854), these processes climb to the top of the ladder.

A key aspect of recovery planning is envisioning the renewed communities, making changes that increase resilience to future hazards, and achieving long-term goals. Participatory methods can also increase heritage conservation and preservation post disaster (Gibson, Hendricks, and Wells 2018) as decisions about repairing or demolishing damaged historic properties are often made quickly.

Importantly, there are methods to increase the validity and reliability of resident assessment of infrastructure. Research on validity and reliability of citizen science projects calls for increasing the number of participants to account for variability in the skills of citizen data collectors and outliers in data collection capacity (those producing poor data). This calls for greater participation relative to traditional planning approaches to public engagement.. Encouraging this participation is one of the most difficult aspects of any community science project. If large numbers of citizens are not possible, data quality is dramatically improved through training and intense interaction between scientists and community members. Again, this requires time for public training and the appropriate skillsets among planning staff that know how to conduct educational programming about complicated data issues.

Participatory community science also addresses the three types of disagreements in risk communication—factual disagreement, institutional ability to address risks, and value disagreement (Renn et al. 1991). Involvement in determining what data should be collected, when, how, and for what purposes helps communities share their experiences and learn about hazard risks; helps emergency management and community planners gain awareness of localized flood impacts and infrastructure failures; and may foster improved interest and investment in resilience initiatives. Together this could encourage factual and value agreement about the data. Mapping and identification of risk is an exercise in power dynamics, and which knowledge is allowed to be codified as true in risk assessments ranges depending on the level of participation in the science. CBPR, PAR, and feminist research all can conform to critical or constructionist approaches to science that honor the multiple realities experienced by various community members (Israel et al. 1998). These constructed realities differ based often on the social location (i.e., gender, race, class, etc.) of residents and their interactions in the community space. Community-engaged research approaches, then, can empower marginalized population groups, and are situated to the context and history of specific places and specific research questions (Wallerstein and Duran 2010). Also, more participatory methods particularly focus on the social context of research (Weber 2018; Israel et al. 1998), and could be applicable to planning around hazards rather than traditional individualistic risk assessments and risk communication models (Barzyk, Wilson, and Wilson 2015). Acknowledging that "knowledge is power" is a strength of community-driven methods in which the data generated can be used not only by experts, but by all participants focused on social change (Jacobs 2018; Osborne 2015; Chaskin 2013; Eisen 1994; Hall 1992).

A threat to community science for infrastructure relates to the second disagreement—the institutional ability to address risks. Participatory data must be used to pursue actual change in the infrastructures. For marginalized populations most at risk of flooding, this means their participation in this science will occur and trust will be fully developed only when the information generated is used to reverse years of disinvestment and to inform equity-oriented maintenance and investment decisions. Local governments will not want to undertake citizen science processes if they do not have the funds available or the political will to implement the changes the science suggests.

Again, this is how using Arnstein's ladder as theoretical framework for choices in community science methods helps. The most potent threats rest in Placation, Consultation, Informing, Therapy, and Manipulation—low rungs of the ladder that will break if we rest too heavily on them, making it impossible to climb any higher. Additionally, manipulation through crowdsourcing and participation limited to data collection that isn't given attribution or recognition, and isn't utilized in a decision-based way, can undermine participation efforts altogether and perpetuate mistrust between communities and emergency management personnel. These novel methods for producing more data do not automatically mean better measures of society, they also can change how we perceive reality or shape the reality they measure (Du Gay and Pryke 2002). Thus, using big data or many other citizen science methods "stake[s] out new terrains of objects, methods of knowing, and definitions of social life." (Boyd and Crawford 2012, p. 665).

CONCLUSION

COMMUNITY SCIENCE, DATA JUSTICE, AND RESILIENCE FOR ALL

Infrastructure and hazard mitigation practice, by way of capital improvement and emergency management, should include at minimum public participation in planning, and ideally public participation in knowledge creation and risk assessment. Arnstein's ladder is just one framework for meaningful public participation, but we argue that community science could provide, if used in ways that aim for the highest rungs, improvements in the knowledge base for risk assessments, greater trust in emergency management and planning officials, and better and more equitable decision-making for stormwater infrastructure. Haklay (2010, p. 107) noted that citizen science, by definition, "focuses on recording observations rather than highlighting community views or opinions." Thus, just including some form of citizen science does not automatically ensure participation or move a project up Arnstein's ladder. Some forms of community science, such as crowdsourcing, may actually represent nonparticipation, and may be used for manipulation of the public or therapy, as defined by Arnstein. Furthermore, early examples of citizen science, like traditional public meetings or public comment periods, which are the few techniques of participation used in hazard planning, are not "proactive in reaching out to stakeholders, especially those disadvantaged groups (e.g., low-wealth, racial and ethnic minorities) often underrepresented in government decision-making processes" (Berke et al. 2012, p. 145). Only when participation higher on Arnstein's ladder is included in community science projects can change be created. Many of the examples we discuss are only scientifically based, driven by scientific questions without linkages to action that would result from the data. This data must be used to pursue equity-based outcomes such as buy-outs and mitigation implementation. This means it requires transparency and participation action (via higher rungs on the Arnstein ladder) to ensure the data is used. If data is just collected or identified with no remediation or response action, then it will become a burden to residents through lost property value, health, damage, and beyond. CBPR, PAR, and feminist research offer citizen control over the research and, with PAR and feminist research, specific emphasis on action and decision-making from the research results. Without action and planning outcomes that are visible from participation in data collection, community science languishes as a new, highly technical, buzzword approach to manipulate and placate the public. As the US rolls out historic investments in infrastructure, and we transition to a more flood disaster–resilient future, community science that leads to community control and ownership is the smart, democratic, and just way forward.

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The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

Marccus Hendricks developed the concept and outline of the paper, as well as wrote a majority of the text. Michelle Meyer helped write the text, and reviewed and suggested revisions to the overall argument. Sacoby Wilson offered additional literature, examples for inclusion, and reviewed and revised the text.

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