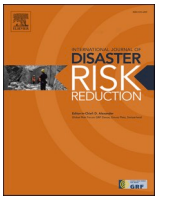
International Journal of Disaster Risk Reduction 113 (2024) 104843

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr



Co-design as participation: Creating meaningful pathways for collaboration in flood risk adaptation in Ohkay Owingeh Pueblo

Ria Mukerji [a,*], Yolanda C. Lin [a], Su Zhang [a,b,c], Mark Stone [f], Carolyn Hushman [d], Fernando Moreu [c], Lauren Vigil [e], Tyler Eshelman [b], Lindsey Rotche [a], Anistasia Baca [a], Marisa Nodine [d], Megan Faulkner [d], Chalon Johnson [d]

[a] Geography and Environmental Studies, University of New Mexico, Albuquerque, NM, United States
[b] Earth Data Analysis Center, Albuquerque, NM, United States
[c] Civil, Construction and Environmental Engineering, University of New Mexico, Albuquerque, NM, United States
[d] Department of Individual, Family, and Community Education, University of New Mexico, Albuquerque, NM, United States
[e] Highwater Mark LLC, Albuquerque, NM, United States
[f] Biological Systems Engineering, University of Nebraska-Lincoln, Lincoln, NE, United States

A B S T R A C T

Considering the detrimental effects caused by wildfires in New Mexico, there is a pressing need for the development of innovative hazard adaptation and mitigation strategies. Community-based approaches in hazard response have the potential to harness the power of co-design and the incorporation of traditional knowledge to help make conventional research and design process considerably less extractive. In this paper, we explore the elements of community based, bottom-up approaches that can support successful outcomes, in contrast to centralized top-down approaches. By offering a critical perspective of the idea that projects defined as bottom-up are inherently more effective than those that are top-down, we aim to amend a common participatory design framework, the double-diamond design method, and present a community-engaged framework on flood risk adaptation with the co-design of an environmental data dashboard to address this gap. This can be mitigated by employing a more human-centered design approach as a baseline, and further amending it to center community. We employed a series of workshops in Ohkay Owingeh Pueblo, in New Mexico, to integrate local knowledge. The goal of these workshops was to design an environmental data dashboard that would eventually serve as a point of information gathering and dissemination for the Pueblo. The workshops featured activities that worked to decolonize the process of co-design and put the Pueblo's needs at the center of the dashboard design process. The workshops allowed for participation in a variety of modalities – visual, verbal, auditory – giving community members space to lead and participate in many different formats.

1. Introduction

In context of disaster risk reduction, top-down design is often critiqued as not being inclusive to communities that researchers are working in, with many studies presenting bottom-up approaches as the solution [1–5]. While there exists a body of literature on projects that engage with bottom-up methods in a variety of ways, there is a lack of research that addresses the nuances of what kinds of bottom-up approaches are most effective. Simply categorizing a research endeavor as bottom-up does not necessarily make it so. There exists a lack of accountability and a need to avoid the simple illusion that the community is being included, even if the proposed goal is co-generating knowledge [6]. As a form of participatory design, knowledge co-generation works to involve communities, with one way being through incorporating indigenous and traditional knowledge. In that vein, there has been a recent push to decolonize common

* Corresponding author. University of New Mexico, United States.
E-mail addresses: rmukerji@unm.edu (R. Mukerji), ycl@unm.edu (Y.C. Lin), suzhang@unm.edu (S. Zhang), mark.stone@unl.edu (M. Stone), ckimble@unm.edu (C. Hushman), fmoreu@unm.edu (F. Moreu), laurenvigil@high-watermark.com (L. Vigil), teshelman@edac.unm.edu (T. Eshelman), rotchell@unm.edu (L. Rotche), abaca341@unm.edu (A. Baca), mnodine@unm.edu (M. Nodine), meganfaulkner@unm.edu (M. Faulkner), chalonj23@unm.edu (C. Johnson).

https://doi.org/10.1016/j.ijdrr.2024.104843
Received 18 August 2023; Received in revised form 15 May 2024; Accepted 17 September 2024
Available online 21 September 2024

methods of knowledge cogeneration, centering on acknowledging researcher positionality [7]. By doing so, researchers can present methods that ensure the success of bottom-up approaches to community participation and design. This paper will work to amend a common participatory design method in order to better include indigenous perspectives into the co-design process and to provide some context for what makes bottom-up approaches most effective.

Climate change is a broad issue that requires a multitude of actions and approaches to tackle effectively. Many approaches hinge on community participation and action and subsequently there has been an increase in interest in working with tribal communities [8–10]. This leads to a necessity to establish ethical community working practices. Much early academic work with indigenous communities centers the researchers, rather than the community, giving the research a distinctly extractive framing. This kind of research faces the risk of benefiting the researcher at the expense of the community. Public participation and participatory design are often touted as the most inclusive responses to climate change issues, including hazard response ([6], Mercer 2008, [7]). While participatory design sets out to include communities in solutions, oftentimes it creates an illusion of inclusion, rather than meaningfully including communities in the design process [6]. Typical methods utilized in participatory research include the double-diamond design method [11], design thinking [12], and human-centered design [13] approaches, all of which attempt to put people and collaboration first [7,14]. By amending the double-diamond design method, we can work to create more sustainable bottom-up approaches to participation.

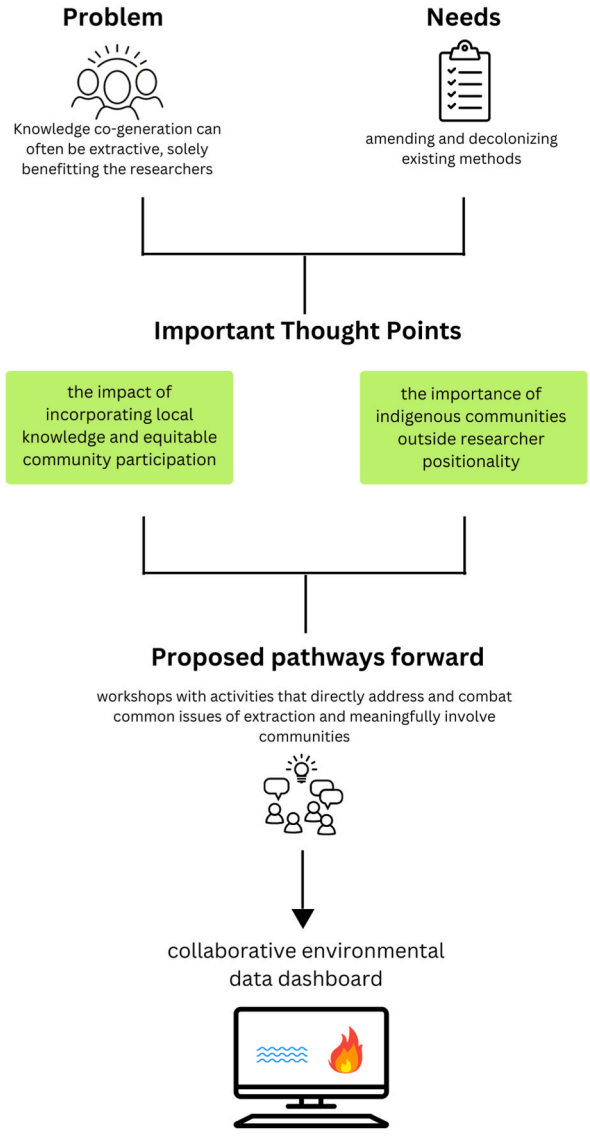


Fig. 1. Project Outline: How do we get to proposed pathways forward? The steps we need to take are outlined, with important considerations highlighted in green. The end goal is the co-creation of the environmental data dashboard.

1.1. Research questions and paper structure

This paper centers on the idea that success of bottom-up approaches can be better defined through the amendment of the double-diamond design method (see workflow in Fig. 1). We demonstrate this within the context of flood preparation and risk mitigation in indigenous communities. In addition, we discuss what kind of involvement constitutes a bottom-up approach. Using the frame of enhancing the participatory design process and more intentionally engaging with traditional knowledge, we designed a series of workshops to engage the community in the co-design process. The main research questions are: (1) does community engaged knowledge generation enhance the dashboard design process, (2) how can outside researchers work to decolonize projects (in the context of dashboard design) that engage with indigenous communities, and (3) how does risk perception affect proposed adaptation measures? Using two surveys (one after each workshop) and participant observations, we were able to better understand and assess answers to these questions. This paper is set up to follow the progression of the workshop design process and the workshops themselves. We begin with a literature review centered on participatory design, community participation and risk mitigation (Section 2). Section 3 introduces the research setting of Ohkay Owingeh and covers methods, outlining the design of the surveys and each workshop separately. The next section covers both the workshop and survey results (Section 4), while Section 5 discusses the impact of these workshops on our original research questions, placing emphasis on the need to center indigenous communities to perform successful participatory, bottom-up research.

2. Literature review: the components of participation

2.1. Integrating traditional ecological knowledge and participatory design

Participatory design offers a space to incorporate traditional and indigenous knowledge into the research process. Several scholars agree that at its philosophical beginning, participatory design essentially focuses on meaningful participation rather than performative design [13,15,16]. Most participatory design methods include some form of collaboration or codesign, where the varying parties come together [17] in attempt to break down disciplinary barriers. Active collaboration plays a crucial role in the process, especially in smaller-scale projects where it is more feasible and thus more widely embraced [18]. This is seen in several different participatory design approaches, including design thinking, human-centered design, and double-diamond design ([11,12]; Design Council 2015). While design thinking and human-centered design present many merits, we chose to focus our study on the double-diamond design method (See breakdown of all 3 methods in Table 1). The double-diamond design method is commonly defined as a graphical way of describing the design process, which has four main phases; discover, define, develop and deliver [11]. Design thinking is generally defined as an analytic and creative process that engages a person in opportunities to experiment, create and prototype models, gather feedback, and redesign [19]. Human-centered design is a problem-solving technique that puts people at the center of the design process [20].

While different, all these models bring the human aspects of design to the forefront of thinking. This project utilized aspects of the double-diamond design method, which was then amended to better fit the scope of this project. While the human-centered design and design thinking also center the democratization of the participatory design process [15], we focus our efforts through the double diamond design method because of its methodological approach to solutions. The double-diamond design method essentially divides the participatory design process into 4 stages – discover, define, develop, deliver (Fig. 4). The research (discover and define) and design (develop and deliver) phases are clearly defined and promote space for participatory research [11,21]. After each phase, findings are presented to the group for refinement and verification, helping to aid the co-design process.

The guiding principles of participatory design include emphasizing the importance of mutual respect for knowledge, opportunities to learn about other domains of knowledge, joint negotiation of project goals and tools to facilitate participation [22]. While this is the goal, oftentimes community collaborators are simply present to give input on design, rather than co-designers being present from the beginning of the project planning process, making the work much less participatory in practice. For design to truly be participatory, the work being done must involve all parties from the beginning and actually include the principles mentioned above.

There have been several attempts to better integrate community into participatory design in hazards research. One way is through the incorporation of community risk assessments into the participatory process [23]. Solutions that work from the bottom (the community) up (policy, government, etc.) are important ways to integrate community knowledge into the design process. These assessments work to foster more bottom-up approaches and simplify any technical aspects to increase public access by assessing trends in disaster response. Critics of this process point to the time and effort it takes to identify these trends and the skill required to do so [23].

Table 1
An overview differentiating the three main ideas this project draws inspiration from. We focus on the double-diamond process, but also require an understanding of how human-centered design and design thinking fit more broadly into the history of participatory design processes as a whole.

Term	Main idea	Citation
Double- diamond design	- A guide for understanding design problems and communicating solutions - Graphical way of showing a design process in 4 stages; discover, define, develop, deliver	[11]; Design Council 2015
Design thinking	- A design-based process aimed at non-designers to employ design-based thinking - Used most often in an education perspective to encourage interdisciplinary thinking and to democratize the participation process - theory based	[12,15]
Human-centered design	- Problem solving technique that aims to put real people at the center of design processes. - Focus on empathy, creativity and business or economic needs (of the group being studied)	Design Council 2015 [13,20]

To truly encourage collaboration, there cannot exist such a strong technical aspect nor can the project be set up in a way that one group is predisposed to be left out [24]. We attempt to fill this gap by utilizing examples in decolonizing co-design processes seen in other projects [7]. By learning from past workshops and personalizing them to an indigenous setting, we make an effort to produce a workshop plan that other studies may utilize in the future. Another way participation is addressed in hazards research is through the acknowledgement of power in how we respond and recover from natural hazard events. Gaillard et al. [25] offer a slightly different solution to the bottom-up approach by recognizing that bottom-up approaches often do not have the resources to succeed. They acknowledge the importance of integrating sustainable practices by integrating local and scientific knowledge and suggest that actions must happen from the top, but initiatives come from the bottom (Gaillard et al., 2008). One way that this project works to incorporate these ideals is to better understand how to decolonize the process of participatory design when working with indigenous groups and to incorporate traditional ecological knowledge (TEK).

Conventional participatory design methods often leave out traditional indigenous practices. Traditional ecological knowledge (TEK) can be invaluable when attempting to effectively carry out a participatory design session (Kimmerer 2011; [26]). TEK is generally accepted as a system of knowledge, heavily dependent on 'place' and indigenous epistemologies [27]. It sees its early roots in anthropology, with ancient epistemologies slowly gaining traction as a way to inform modern resource management [28]. Early TEK scholarship is largely conducted by non-indigenous scholars. Inclusion of native principles and methods is discussed and incorporated, but hinges on a bit more of a top-down approach, with involvement from local communities coming later in the design process. In more recent scholarship, there has been an emergence of scholars with indigenous backgrounds (Kimmerer 2011; [26,29]). Through this study we worked to include TEK principles in conjunction with participatory design methods to better understand hazard and risk perception and offer more sustainable solutions.

The double-diamond method has also been widely used in convergence research – research that relies heavily on interdisciplinary and transdisciplinary approaches to identify specific actions to solve hazards problems (Design Council 2015; [7,30]). Convergence research is generally inspired by the need to address a certain challenge or opportunity and can be inspired by a societal need. It lends itself to the conventional double-diamond design method because of its focus on problem driven research. While the double diamond method has been utilized widely in convergence research, Akama et al. [7] suggest that this process intentionally or not, carries legacies of euro-centric, industrialized origins. By emphasizing problem-solving and replicable methods, these processes detach knowledge, people, and relationality from the sites of the design's embodiment [7]. These sentiments are especially useful to this project, which takes place on the Ohkay Owingeh Pueblo in northern New Mexico. We work to minimize any 'othering' and to keep these principles in mind as we worked with the Pueblo and had members of the Pueblo on the team. By doing so, we aimed to create a replicable form of workshop and survey development that will be applicable in some form in other indigenous settings. It should be noted that not all indigenous or community spaces are the same, but the hope of the team is that this could be used as a frame for communities impacted by similar risks.

2.2. *Community participation and data portals*

Participatory methods can be better incorporated through the creation of data portals. Having a central repository of data is an effective way to better involve different stakeholders and community members in a co-design process [31]. Beyond this, data portals can serve as an ongoing facilitator of co-design as a process, allowing for collaboration for an extended period. One output produced by this study is a data portal that is co-designed with the Ohkay Owingeh community. A data portal is a web application that compiles data from a variety of sources and categorizes them under subsets or categories to make it simple for data query and analysis (Chad et al., 2018).

In the context of this study, a data portal provides users a way to access the data collected and visualize them in a multitude of formats such as graphs, charts, and maps that can assist with planning and emergency management. A data portal typically consists of

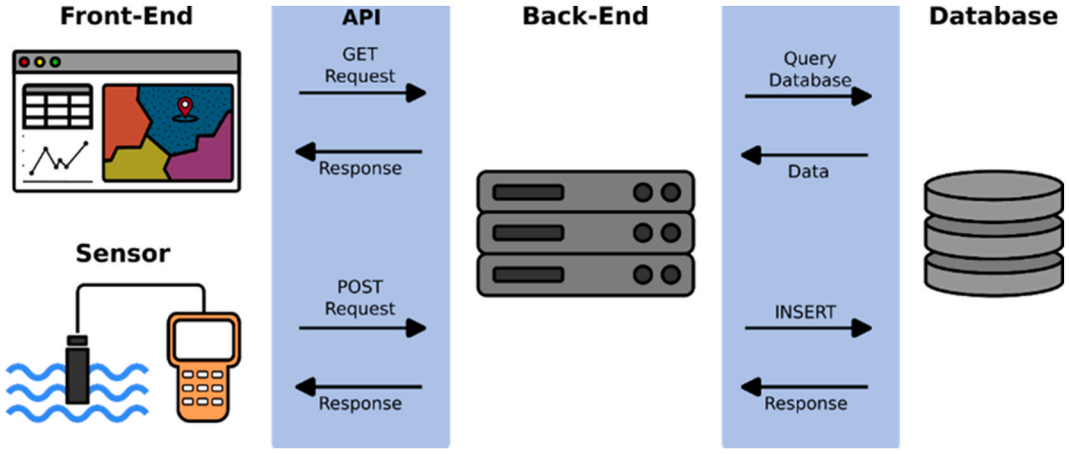


Fig. 2. A dashboard system architecture visualized by conceptualizing relevant literature. This figure shows the relationship between the different pieces of the system, from the database, to the information from the sensors to the front-end dashboard. In other words, how the sensor network data ends up in the data dashboard.

three primary components (Fig. 2), including a front-end, back-end, and a database (Chad et al., 2018). A front-end is a user-side component that provides the graphical user interface (GUI) of the data portal which users interact with, e.g., what a user would see when logging onto any website. A back-end is a server-side component which includes the web application and its web framework, the structure, the logic, and the application programming interfaces (APIs) needed for a functioning front-end. Additionally, the back end serves as an intermediary for interactions between the front-end and the database. A database is a collection of data that is organized by tables and their relationships, enabling query and manipulation by the back end. When a user accesses the data portal, a request is sent to the back end using predefined routes. Subsequently, the server interprets the request and queries the database to perform data retrieval (Chad et al., 2018). The database is then able to return any results from the query and the server will format the information and build the response to be returned to the front-end.

One of the major advantages of a data portal is that it can implement a system of user roles which limits the amount, type, and format of data that a user can access depending on the user's role in the community (Eboueya and Uden 2007). A general user, for example, has access to see information regarding current weather conditions and any imminent danger to the community. A planning user, who has a planner role, has access to additional information such as past precipitation data to determine a plan of action for an area of interest (AOI). In contrast, an emergency management user, who has a decision-making role, has exhaustive access to all information. Using this role-based access control ensures that each group of users is receiving the information most relevant to their community role. These aspects of the data portal were directly used to inform the final design.

As a secondary benefit, implementing a data portal allows authorized users to access the API to add data to the portal directly from a sensor unit (Sirisha and Kumari 2010). In order for a sensor to communicate with the data portal an insert request is made to the back-end, and once the request is authenticated, the back-end validates the format of the data and inserts the data into the database upon passing validation.

2.3. The merits of bottom-up approaches

Creating spaces for different stakeholders to effectively impact the decision-making process is one that requires a very specific form of participation that can be described as top-down or bottom-up approaches (Fig. 3). The top-down approach is common globally and is often used because it allows for already formulated proposals to be implemented by authority, so it is easier to focus control [2]. Criticisms of this approach stem from the fact that it relies on already formulated plans, not giving appropriate attention to the potential variance in sociocultural or environmental situations regionally [1]. Broad participation is limited since all decisions come in relation to the top, central plan. On the other hand, bottom-up approaches hinge on participation of the community, or least on those community members who are willing and able to participate, from the outset of the planning process [7]. The goal is that communities can help guide project development and implementation, but it is also important to note that there are several different types of participation. If communities are not active in their participation, it can cause this method to wane in effectiveness. Another important perspective in this study is the idea of global or regional effectiveness. This case focuses on Ohkay Owingeh, raising the question of replicability at a wider level – this case could serve as a regional (bottom) case study that can be used to help inform practices globally (top), serving as a different definition of top-down and bottom-up approaches [5].

2.4. Long-term risk mitigation

Flood mitigation reduces the overall risk of structures experiencing flood damage and reduces the severity of flood damage when it does occur. For this mitigation measure to be effective, policymakers and disaster researchers must think in the long-term (Kapucu et al., 2014). Long-term risk mitigation is a critical part of flood preparedness. Early warning systems, active memory, traditional knowledge: these things are only useful if they can be applied in the long-term ([32]; Hawlbachs 1995; [33]). One way to ensure long-term risk mitigation is to integrate flood knowledge into education and include risk communication in any long-term recovery and planning efforts.

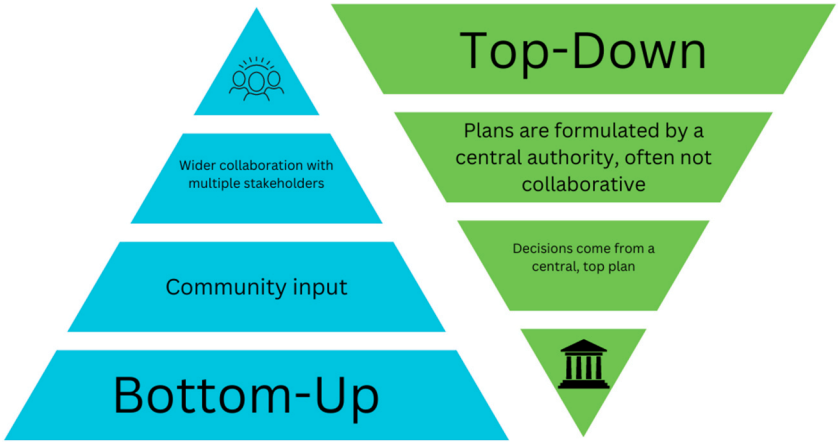


Fig. 3. The differing top-down and bottom-up approaches to collaboration. Both attempt to assist communities, however they differ in their centralization of power.

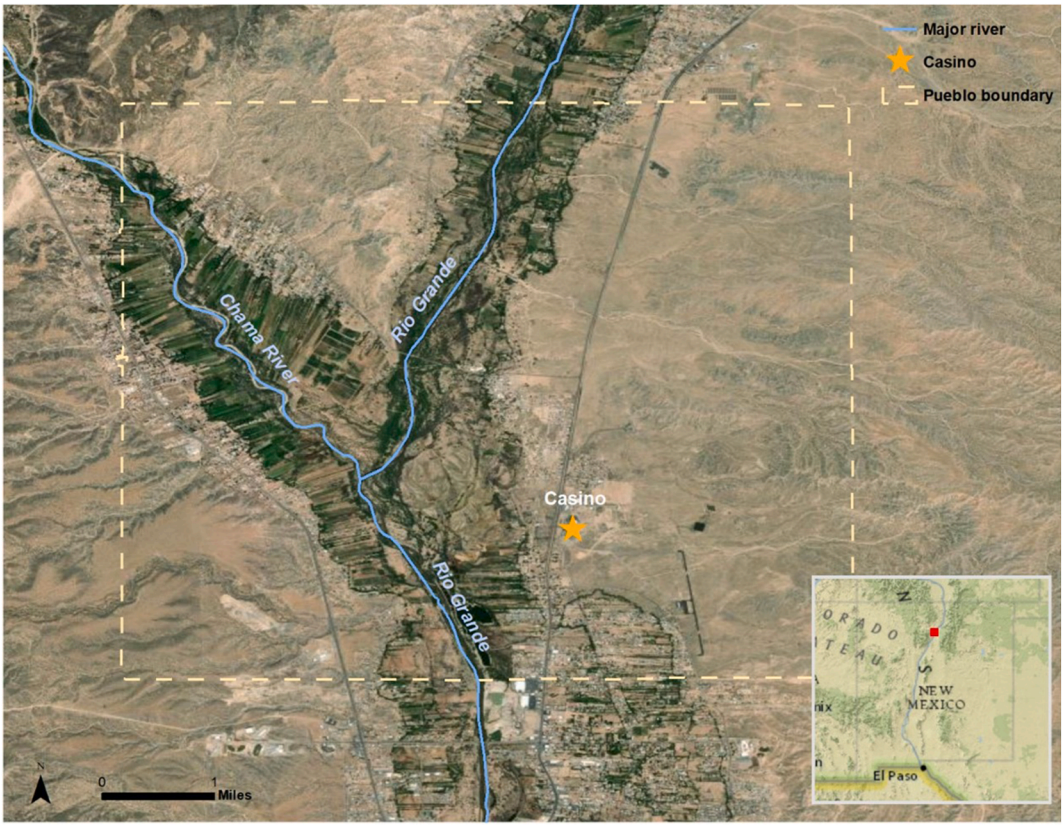


Fig. 4. Map of the study area, Ohkay Owingeh Pueblo. The dashed lines indicate the Pueblo boundary, and the blue lines show the Chama and Rio Grande rivers (with their confluence in the center of the Pueblo). The Ohkay Hotel Casino is marked with a yellow star as it is the largest economic driver for the Pueblo. Due to Pueblo privacy, homes are not shown.

Flood Early Warning Systems (FEWS) play a large role in disaster risk reduction schemes as cost-effective methods to mitigate flood disaster damage [34]. The linkages between the hydrological and social aspects of early warning systems are increasingly being considered as key aspects for successful flood mitigation. The behavior of the public and first responders during flood situations is heavily influenced by many behavioral traits such as perceived benefits and risk awareness. This centering on social vulnerability is a move away from traditional FEWS studies, which largely focus on one aspect of the issue, such as forecasting or social vulnerability as separate parts, rather than as a whole (United Nations 2006). In their 2016 study, Lopez et al. found that a high social preparedness contributes to mitigation of flood losses and that one of the most effective modes to promote social preparedness was through memory-raising campaigns [34]. This idea of social memory is critical in the implementation of FEWS. In the case of the Ohkay Owingeh, it is critical to view FEWS as a comprehensive solution, as more than simply the ability to forecast or model future floods.

Perception is key when it comes to being prepared for a hazard event. Early warning systems and models can function perfectly, but if trust in the system and a perception of imminent danger is not present, then the system cannot be an effective warning system. In context of this research, we are interested in how communities are interpreting risk from their own perception. In other words, how have perceptions of risk within the Pueblo changed since an uptick in localized flooding. A frequent assertion made in the risk management literature is that understandings of risk perception should inform risk communication strategies [35]. Proponents of long-term risk mitigation argue that the outcomes of risk perception research can help to "better prescribe risk management and communication strategies, and thereby lessen the societal costs of major disasters [36]." Risk communication and risk perception go hand in hand. From a response perspective, it is of utmost importance to have a grasp of what the perceptions of risk are in the community that is experiencing a disaster.

Models and early warning systems may show the objective components of risk, but communication among various stakeholders, such as government officials, communities and on the ground workers can help scientists understand where more subjective components of risk can play an important role. Risk awareness is critical, as individuals need to know if they are in an area of potential flood risk. Information sharing and education can play a role in increasing that awareness ([37]; King 2000). The awareness of the risk decreases when there is little information provided [38], while a more acute awareness results from an increase in information access. Moreover, experiencing a flood by itself increases a person's awareness [39]. In Ohkay Owingeh, flooding may occur with large gaps between large-scale incidents, creating a need for education between different flood events (See Box 1 for further background on flooding in Ohkay Owingeh). Most importantly, it is critical to engage those who do have knowledge of past floods in the creation

process of flood adaptation and mitigation measures (Monteil et al., 2020). We attempt to fill some of the gaps in this literature by including specific questions about how those on the Pueblo perceive their own risk in the Workshop 1 and 2 surveys. With this information we are able to gain a better understanding of what the Pueblo needs in terms of response.

3. Methods

In recent decades, occurrence of wildfires in the southwestern United States has tripled [41]. In the last 15 years, each of the states in the intermountain west have experienced major fires ([42]; Williams et al., 2013). Factors like early snowmelt, increased temperatures (Williams et al., 2013), and land management practices contribute to this trend. Severity of these fires have also increased leading to increased erosion and debris flow [43]. In New Mexico, strong winds exacerbate fire spread and high-intensity summer storms create a flash flooding risk across the intermountain west [42]. Watersheds are especially susceptible to geomorphic change and flooding after wildfires. This rings especially true in New Mexico, where several severe wildfires have changed the lives and landscapes of the New Mexico Tribal Pueblo Communities over the last 20 years.

The main goal of this study was to amend the double-diamond design method to collaboratively create an environmental data dashboard with the Ohkay Owingeh Pueblo. To do so, we amended the 'discover' and 'define' phases of the double-diamond design method to include researcher accountability, more robust co-design opportunities, acknowledgements of researcher positionality and worked to incorporate local knowledge through two workshops. We worked to understand the relationship between tribal employees and members of Ohkay Owingeh (map in Fig. 4), including individuals employed by the Pueblo and who worked in the hazard mitigation space, and the research team, largely based at the University of New Mexico. The long-term goals of the present study are to create a community of practice that will be able to share ideas and build resilience in tribal communities. One smaller aim was to help Pueblo members better be heard in the process of a large multi-phase project working with a variety of different researchers, including geographers, psychologists, engineers, and computer scientists. It was clear from early in the design process that this was a major issue in the beginning stages of the project (See Box 2 for context of the larger project), and we sought a different approach to make the process less extractive and more collaborative.

This study amended the double-diamond design method and introduced a new way to co-design an environmental data dashboard. Traditionally, hazard research and the development of adaptation measures was largely carried out by the physical science disciplines (Gaillard et al., 2007; [44]), with engineering solutions and structural adjustments the most utilized ([45]; Wisner et al., 2004). This approach to response does not require a significant amount of interaction with the general population and in fact, critical knowledge that may have been held within those in the public, was ignored. Following a shift in the dominant paradigm in the 1970's, a more participatory approach became more commonplace ([44], Gaillard 2007, [46]).

For the design of the workshop, we took the double-diamond design method and amended both the define and develop phases to include processes that center the community and decoloniality (Fig. 5). During the develop phase, we collaborated with the Pueblo and aimed to co-produce knowledge during a workshop that was hosted by the research team. The main goal of the team was to host a workshop to co-design a dashboard that would display knowledge collected from rainwater sensors and the distribution of a survey following each workshop. The purpose of the workshops was to design the dashboard in a way to be both the most useful and the most

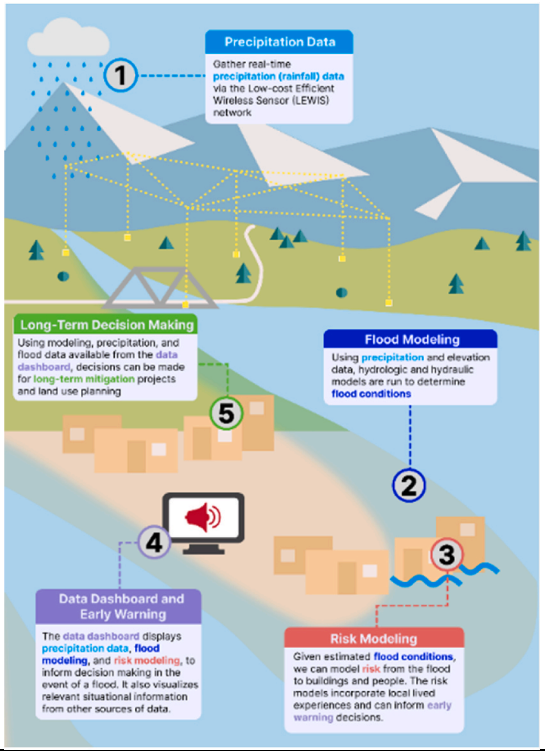
Box 1
Ohkay Owingeh Pueblo – Growing with Nature

This study focuses specifically on Ohkay Owingeh Pueblo (Fig. 1), a Tewa-speaking sovereign nation in northern New Mexico. Ohkay Owingeh sits near the town of Espanola, between Santa Fe and Taos, bordering both the Rio Grande and the Rio Chama. The surrounding mountains have experienced a number of severe fires in the last 20 years, including the 2000 Cerro Grande Fire, the 2003 Encebado Fire and the 2011 Los Conchas Fire. These fires have all caused large-scale flood impacts during the summer monsoon in areas similar to Ohkay Owingeh in northern New Mexico. Ohkay Owingeh has two distinct types of development. The original pueblo, or the old town, which is located higher up above the floodplain, and its newer, more modern construction, which largely lies on the floodplain, are in line with the river. According to members, the original Pueblo experiences less flood impacts because of its strategic location, but much of the new construction does see flood damage, including the Ohkay Hotel Casino, one of the largest economic assets of the Pueblo. The nexus of wildfire and flood serves as the setting for this project.

In the last 30 years Ohkay Owingeh has experienced three major flood events (Bohannan Huston Inc. 2020). The first storm, occurring in April 1998 saw flooding near the casino and homes south of the casino resulting in the eventual construction of two retention ponds to mitigate future impacts. In 2013, flooding occurred again near the Casino and to properties adjacent to State Highway 68. The retention pond built in the aftermath of the 1998 flood failed, flooding the Casino area, overtopping Highway 68 and creating a host of accessibility issues because of the roads, properties and bridges that flooded [40]. The 2016 flood was concentrated on the Pueblo Center area with one apartment complex taking on most of the damage as a result of retention ponds overtopping (Bohannan Huston Inc. 2020). While Ohkay Owingeh has also seen several nearby wildfires in this time period, it is important to note that these particular floods were not the direct result of wildfire.

Box 2
A Piece of a Larger Puzzle – Greater Preparedness and Resilience to Post-Wildfire Flooding in Native American Communities Using Low-Cost Efficient Wireless Intelligent Sensors (LEWIS)

This study on the co-design of flood adaptation measures is part of a study at the University of New Mexico supported by the National Science Foundation (NSF) through the CIVIC Innovation Challenge (NSF Awards # 2043618 and #2133334). As part of the overall study (Fig. 2), the research team worked to design low-cost sensors to track rainfall data in locations chosen by Ohkay Owingeh. The goal of this self-built, customized, and distributed sensor network is to inform Pueblo communities of trends and thresholds in landscapes that can help to prevent wildfires and provide critical information to early warning systems when wildfires and floods occur (Malek et al., 2023). At the outset of this portion of the overall project, one of the major concerns from the Pueblo was that they felt they were not being adequately included in the sensor application process. To better involve Pueblo members and leadership in the project process from that point forward, we worked to engage members in the design of an environmental data dashboard to house the data from the sensors and other general flood hazard information. This was done through the hosting of two workshops (May and August 2022, respectively) where Pueblo members were asked to participate in a series of activities to aid in dashboard design. The data dashboard workshop and associated activities that this paper focuses on were part of the dissemination of the sensor information, to understand how the data collected by the sensors could be useful to Ohkay Owingeh. The study team situates this work within the context of traditional ecological knowledge, community engaged and convergence research and the evolution of early warning systems. The image shows the relationship between the different parts of the broader project (the sensors, modeling and workshops components).



accessible to the community members on the Pueblo.

The data portal for this project was initially created to establish a draft to assist with the discussion among community members and the project team about how the data portal front-end would be designed. Instead of making community members to come up with front-end ideas from scratch (i.e., without any starting design or product), using something that already exists can help with the discussion by allowing them to voice their opinions on the design of the data portal and identify the elements that they like, dislike, and would like to change in following developments. The relationship between the data portal and the sensors is important in that the portal acts as a database for the rainfall information collected from the sensor, allowing community members access to this information. When participatory design is used to drive the development of the data portal, a collaborative working relationship can be

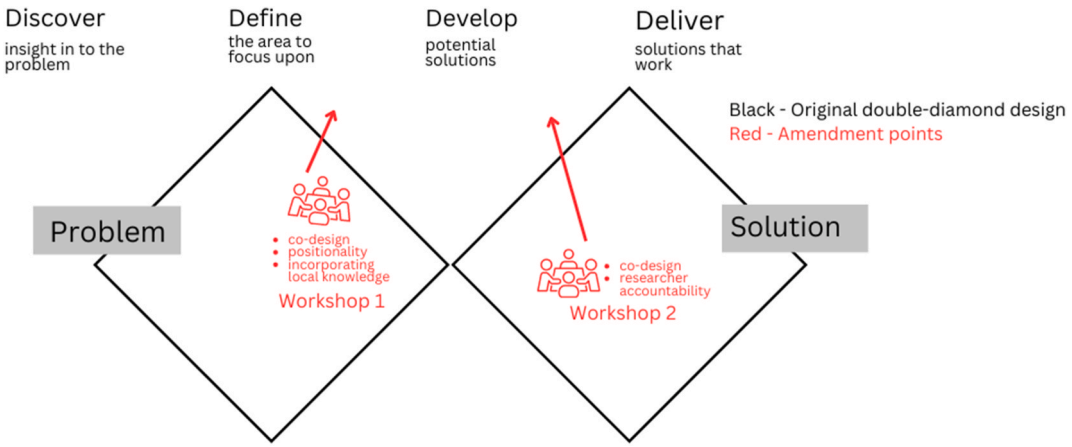


Fig. 5. The more common double-diamond design method. Researchers move through all 4 steps with the community but means of collaboration are not outlined (in black). Generally, the discover, define, develop and deliver phases are carried out under the leadership of the researchers. In the research team's amendment, the define and develop phases and conducted with heavy input of the community and certain aspects, like positionality and researcher and accountability are put at the forefront of the process (seen in red).

established between the community members and the project team, and ultimately, creating a data portal that becomes not only more personal but also more meaningful to the community. The workshops were designed as 2-h meetings with different activities (Fig. 6), with community members ranging from different fields of hazard management on the Pueblo. The first workshop occurred in May 2022 and consisted of community members from the different research teams, as well as Pueblo leadership, including a member of the Tribal Council. The second workshop occurred in August 2022 and consisted of the same Tribal members as the first, in addition to pueblo community members who have a direct role in disaster response; this included the Director of Planning and several civic servants, including firefighters and police officers. Two-thirds of the attendants of the first workshop also attended the second workshop, with the attendance of Workshop 2 significantly higher than Workshop 1.

3.1. Survey design

Survey questions were designed by the research team and went through the Institutional Review Board approval process at the University of New Mexico (UNM IRB #11321). The survey was distributed in two parts, the Workshop 1 survey, distributed before

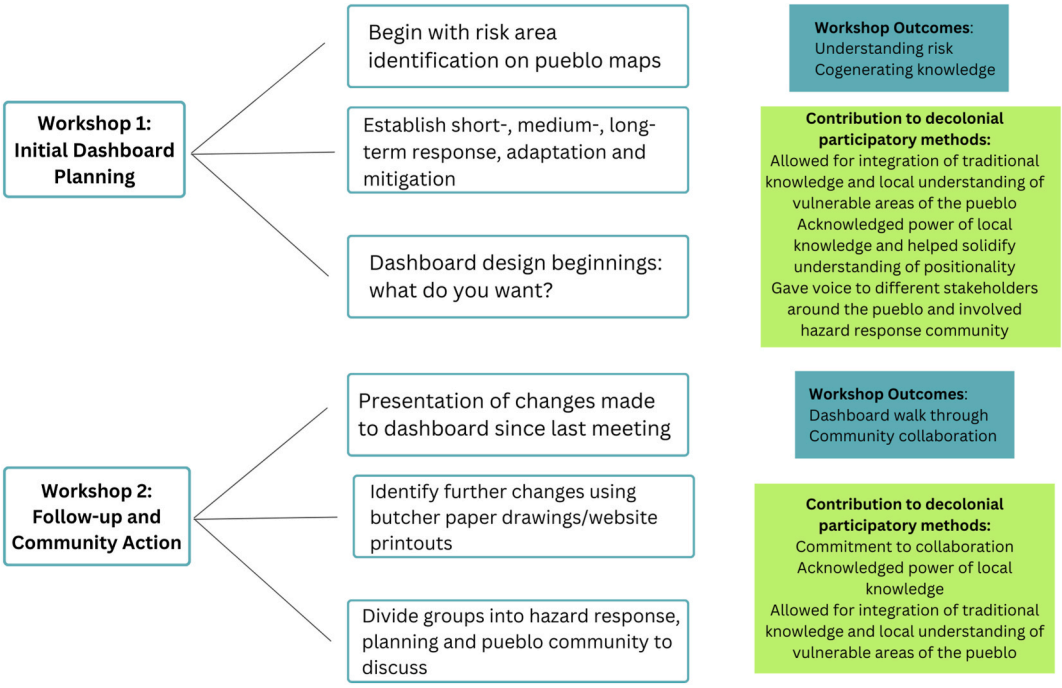


Fig. 6. Workshop Design Flow – Both workshops consisted of activities that contributed to the decolonization of participatory methods.

commencing the first workshop and the Workshop 2 survey distributed after the second workshop. They were distributed to community members by hand immediately following the respective workshop and time was built into both workshops to allow for the survey to be completed immediately. The purpose of the survey was to gauge community members perceptions towards hazards threats to Ohkay Owingeh and on their feelings towards the study as a whole. It was our desire to include a range of different members of the community. While our first workshop was largely homogeneous, with Pueblo employees from the same department making up our whole workshop, the second workshop was more diverse, with the addition of Pueblo members from various departments in a variety of different leadership and work roles. However, both workshops did largely include people who were both members of the tribe and employees of the Pueblo. To help determine the success of the participatory pieces of the study, we asked several questions that centered on how involved workshop community members have felt throughout the duration of the study (See Table 2 for further sample questions and answer types).

Workshop 1 questions began with more general questions regarding hazard and risk perception in Ohkay Owingeh and progressed to what community members wanted to see showcased on the data dashboard and how they felt about the design process more generally. The survey was fourteen questions, with a mix of multiple choice and fill in the blank style questions. We had seven participants in the first workshop, all Tribal employees of Ohkay Owingeh. The Workshop 2 survey began similarly with questions on hazard and risk perception (to see if anything had changed throughout the course of both workshops) and then centered on questions first about the effectiveness of the prior workshop and then on the environmental data dashboard and how community member input had been integrated. We had twelve participants in the second workshop, ranging from those who worked in planning to those involved in hazard response (police, fire department). All attendees of the second workshop worked with the community in some capacity.

3.2. *Workshop 1: initial dashboard planning*

The first workshop took place in May 2022 and began with a discussion of modeling and participatory design and then transitioned to background on the hydrology models, given by one of the engineering team members. We then discussed the steps in choosing this methodology to the community members to remain transparent – how did we choose the methods we are using and how can we be most useful to the Ohkay Owingeh community. An overview of the three W's (who am I, who are you, who are we) follows. The 3 W's are outlined as a way to decolonize the participatory co-design process [7] and is used to help aid researchers acknowledge their positionality and to help community members gain a sense of trust in the project [46].

During the workshop, community members were asked to participate in two activities. The first activity centered on understanding where risk was most acute. For the first part of this activity, they were shown a large map of the Pueblo and given smaller maps with overlays of 10-, 50- and 100-year flood inundation data (Fig. 7). Community members were then asked to identify places within the Pueblo that were at particular risk to flooding, had high cultural value or a high economic value. They were asked to identify important neighborhoods and any important landmarks in the Pueblo. The maps that were used had a plastic overlay screen for community members to draw on. They were able to circle the areas of highest concern right on the map.

For the second part of the first activity, community members were asked to identify the appropriate response for those areas that were identified as important. Once the response was written down on a sticky note, the next step was to categorize the response as recovery, mitigation or adaptation (Fig. 8) using poster board and sticky notes. Recovery centered on immediate response following a disaster event, mitigation focused on shorter term changes that could be made to help cut overall losses, while adaptation focuses on long term change to better prepare communities to deal with hazard and disaster events.

The second part's goal was to cogenerate knowledge on both what areas were of highest importance to those on the Pueblo and on how best to design the dashboard that would show the information from the sensors that the engineering team installed. We attempted to continue to use our decolonization practices by emphasizing that the dashboard was for the Pueblo. How can we (the researchers) help you achieve your goal? How can this show information that will be useful to you?

The second activity for this workshop included passing out large pieces of butcher paper to the different groups of community members. They were then tasked with drawing out what they felt the dashboard might look like and include. They were encouraged to include cosmetic details, such as color scheme, as well as larger functional ideas, such as the potential inclusion of an eventual early warning system (an idea received from the activity). The ideas formed in this portion of the meeting were taken to the website design team to incorporate into the design of the dashboard site and were shared in the next workshop, 3 months later.

Table 2
Sample survey questions. Multiple choice answer choices were yes, somewhat, no & I don't know. The survey was a two-page printout that was passed out to attendees at the beginning and end of the workshop.

Sample Survey Questions	
Question	**Answer Type**
Ohkay Owingeh is adequately prepared to respond to flood threat	Multiple Choice: Yes, Somewhat, No, I don't know
I feel that I play an important role in reducing the risk of environmental hazards	Multiple Choice:Yes, Somewhat, No, I don't know
I have adequate ways and opportunities to share my input, questions, and concerns with the CIVIC team	Multiple Choice:Yes, Somewhat, No, I don't know
Thus far, I have felt included in sensor and dashboard decisions.	Multiple Choice:Yes, Somewhat, No, I don't know
What is your role and how do you engage with hazards/hazard response?	Free Response
In your opinion, what is the greatest natural hazard threat to Ohkay Owingeh?	Free Response

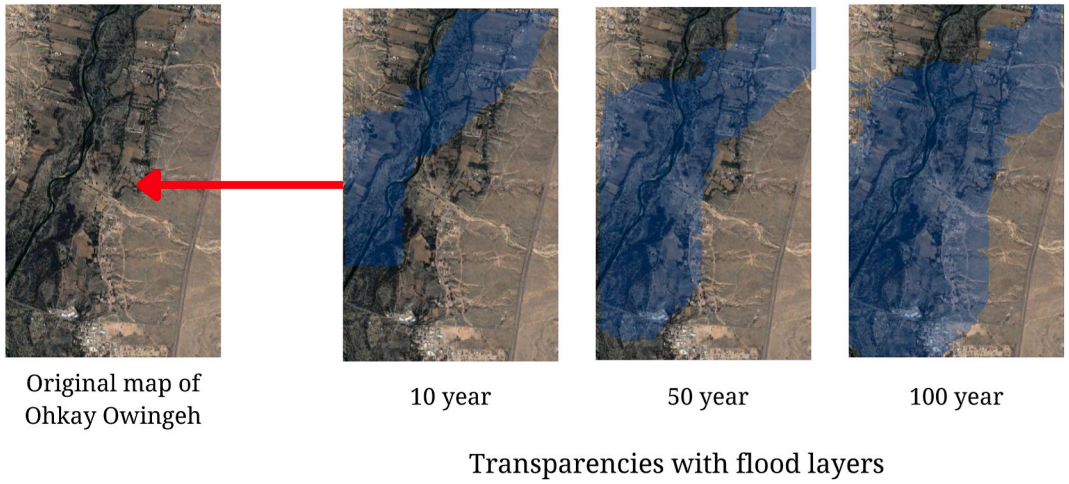


Fig. 7. A single map with 3 different flood layers was given to community members, recreated here. This activity was meant to encourage participation in a way that engaged community members directly with the subject matter.

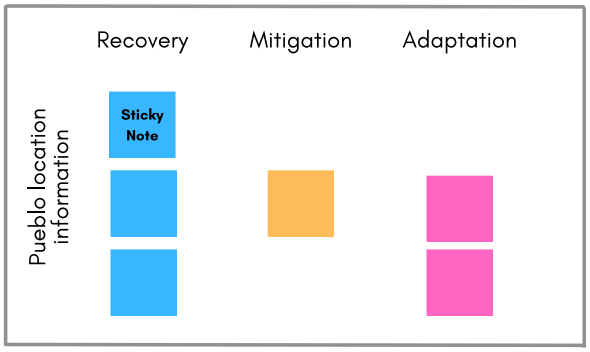


Fig. 8. Representation of Activity 2: Community members were asked to choose locations of importance in the Pueblo and give example of probable responses.

3.3. Workshop 2: follow-up and community action

The second workshop, hosted in August 2022, three months after the first, was meant to serve as a follow up to the initial workshop and status report from the dashboard. The main goals included presenting what the dashboard team had been able to integrate from the information gathered from the first meeting and to determine what still needed to be added. The workshop was set up in the same way as the previous one – a 2-h meeting broken up into different activities. The team began with background on the project, since the group was larger during the second workshop. We reviewed the role of the sensors and how the rainfall data collected would be integrated into the models in the future. We also reemphasized the importance of the knowledge cogeneration process and had the research team check in with their positionality, by reviewing the three W's.

On the day of, the workshop began with an informal lunch that included research team members and community members from the Pueblo who were participating in the workshop. We were able to begin with an informal period of getting to know one another and a member of the Tribal Council opened the meal and meeting with a traditional blessing. The activity portion of the workshop began with the dashboard team first giving a presentation and walk-through of the dashboard. They walked through the login process and how the dashboard would look for three distinct roles (which were decided upon in the last workshop); policy makers and community planners, disaster response personnel and the general Pueblo community. The team also made sure to make clear where the data and locations from the sensors could be found. After the dashboard demonstration, community members were divided into three groups to match the roles in the dashboard. Each group was given large print outs of each website page and encouraged to mark them up with any changes. Community members were prompted to make suggestions big or small, ranging from color or font changes on the website to changing any content that was currently showing up on the site. The focus was more directed on the feedback solicited during Workshop 2 than in Workshop 1. Following time to work on the large print outs, groups were then given butcher paper to draw out any additional changes to the website. Last, a follow-up survey was distributed, regarding risk perception towards flood events and the dashboard to gauge whether there were any changes from the previous workshop.

3.4. Methods for analysis

The methodology for this project consisted of two parts: the workshop development and execution, and the survey. The survey's purpose was two-fold; to serve as an instrument to understand risk perception from the perspective of the Pueblo community as a way to understand perceptions around the workshops themselves. The reasoning for separate surveys after each workshop was to be able to capture feedback from Workshop 1 before commencing Workshop 2. To do this we made a point to analyze survey results following Workshop 1. This was done to make sure suggestions for the data dashboard were accurately captured and implemented prior to Workshop 2. These were captured in a Microsoft Excel sheet and passed on to the computer programming team. For the questions concerning risk perception, a thematic analysis was used to group perceptions by recurring themes. This was done by inputting results into a Microsoft Excel sheet and manually coding common themes.

4. Results

4.1. Workshop results

The main result of both workshops was the creation of the environmental data dashboard. Using the feedback we received after Workshop 1, the team was able to incorporate the knowledge that attendees felt was important to the success of the dashboard prior to finalizing the platform. The materials from the workshops were integral to the success of the dashboard. The inundation maps, the sticky note activity and the butcher paper activity items were collected to use for any future updates that may be needed on the dashboard. The amendment to the double-diamond design method is seen in the setup of the workshops to allow space for meaningful co-design in the 'discover' and 'define' phases of the workshops (see Fig. 7). Workshop 2 (12 attendees) had more attendees than Workshop 1 (7 attendees), with attendees recruited through connections the research team had with Pueblo staff from working with Ohkay Owingeh on prior projects. Staff helped reach out to Tribal Council and Pueblo staff who work in the context of hazard response (fire fighters, police officers, environmental planners, etc.).

4.2. Survey results

A survey was distributed following both workshops. The Workshop 1 survey had two parts: the first section asked questions about risk perception on the Pueblo to gauge where community knowledge was on flood risk, while the second part consisted of three short answer questions that gauged satisfaction with the workshop. The Workshop 2 survey had an almost identical part one, with the questions on risk and perception remaining the same, but with three added questions on attendees' thoughts on the dashboard prototype used during the workshop. Part two diverged and asked questions about if those who had attended the previous workshop felt that their suggestions had been captured and incorporated effectively (See Table 3).

The Workshop 1 survey had 7 respondents, while the Workshop 2 survey had 12 (Workshop 2 had more attendees than Workshop 1). When questioned about what they thought the greatest natural hazard threat to Ohkay Owingeh was, 15 out of 19 total respondents said that flooding was, with the majority of respondents also saying that Ohkay Owingeh was 'somewhat' prepared to respond to flood threats (See Fig. 9 for survey response). When asked about the threat of wildfire, respondents similarly felt that Ohkay Owingeh was 'somewhat'' prepared to respond to wildfire, but also felt that wildfire was a lower threat than flooding.

Following Workshop 1, when asked if the workshop was inclusive and if they felt that they had adequate ways to share their input, all attendees responded 'yes'. In this vein, when asked if their input was adequately incorporated into the dashboard prototype shown during Workshop 2, all those who attended Workshop 1 and also filled out the Workshop 2 survey responded 'yes' or 'somewhat'.

Attendees to the workshops were all in some way affiliated or employed by the Pueblo. People came from a mix of different departments that dealt with hazard response in some capacity, in addition to members of the Tribal Council. The survey results as a whole indicated that there was satisfaction with both the Workshops and the end resulting dashboard. Respondents indicated that they would like a few more dashboard changes at the end of Workshop 2, which were passed on to the computer programming team to incorporate into the final product. Several people mentioned that they felt more included in this workshop than they had felt during other parts of the project, with many citing the ability to draw on the maps (from workshop 1) as important to feeling included in the development

Table 3
Both surveys contained basic risk and perception questions as Part 1, but differed in Part 2. At the end of Workshop 1, the team was most interested in understanding the basics of what the Pueblo community wanted to see in the dashboard prototype and if attendees found the workshop inclusive and helpful. Following the second workshop, the team was most interested in understanding what attendees thought about how their feedback was incorporated and if they felt the process was meaningfully inclusive.

Part 2 Survey Questions	
Workshop 1 Survey	Workshop 2 Survey
What is your role and how do you engage with hazards/hazard response?	If you were at the previous workshop, do you feel like your input was effectively integrated into the dashboard? If you were not at the previous workshop, please skip.
In your opinion, what is the greatest natural hazard threat to Ohkay Owingeh?	At this point, is there anything that you would add to the dashboard?
If you could change one thing about hazard response in Ohkay Owingeh what would it be?	The data dashboard is user friendly
How do you envision an environmental data dashboard being helpful to the community?	I think that the dashboard will be used by the community.
Do you see the environmental data dashboard as being useful in risk communication to the larger Pueblo community?	

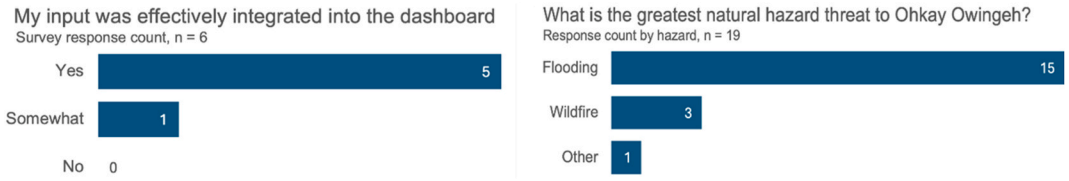


Fig. 9. Survey responses for 2 sample questions. Workshop 2 had a larger attendance than Workshop 1, hence the lower survey response count for sample question 1 (left). In sample question 2 (right), flood threat is perceived as the greatest threat to the Pueblo.

process. Moreover, respondents stated that they appreciated the ability to give input on what the dashboard would ultimately include. This feedback helped us, as researchers, understand the difference between feeling included versus actual, tangible inclusion. This difference was evidenced by survey responses which stated that they felt the activities were inclusive. The goal for the dashboard was for it to be a reflection of community needs, with the input of various tribal employees. One of the most repeated answers on the survey was the call for a general information site that the public could access before needing to login with Pueblo credentials. Survey respondents asserted that this would better engage community members that are not as comfortable with technology and would be a better way both to communicate information in a time of emergency and to encourage education on flood risk prior to emergency hazard events.

5. Discussion

This paper focuses on the concept that the effectiveness of bottom-up approaches can be enhanced by refining the double-diamond design method. We illustrate this within the framework of flood preparedness and risk mitigation in indigenous communities. Both the workshops and the surveys worked together to help the research team and Pueblo co-design the best version of the environmental data dashboard possible. Through the amendment of the double-diamond design method, this study set out to answer 3 questions: (1) does community engaged knowledge generation enhance the dashboard design process, (2) how can outside researchers work to decolonize projects that engage with indigenous communities, and (3) how does risk perception affect proposed adaptation measures?

5.1. Does community engaged knowledge generation enhance the dashboard design process?

The results from the survey are in line with what was expected from amending the more common double-diamond design method with more inclusive options. During the ‘discover’ and ‘define’ phases of the project (as laid out by the traditional double-diamond design method), community members were given ample opportunity to make their desires known through the activities during the first workshop. By including workshop activities that naturally integrated the wants and needs of Pueblo members, we were able to utilize their insight in the initial design stages of the data dashboard. Our spatial data team was able to use the design drawings of the dashboard that were made during the workshop in their own website design process. Following the initial workshop, the amended ‘develop’ phase was able to integrate this information for further review at the second workshop. During the second workshop, we were able to delve further into the develop phase by soliciting more feedback from the community members present. Since the second workshop had a larger and more diverse set of participants then the first, we had the opportunity to include an even broader range of knowledge to the dashboard and were able to shift some of the focus of the dashboard from solely displaying the sensor information to also serving as a place to learn information about flood risk in general on the Pueblo.

Community engaged knowledge was critical in the design of the dashboard for Ohkay Owingeh. The design process followed a traditional bottom-up approach but diverged in how the research team incorporated activities throughout the workshops. In addition, it is important to think about some of the nuances of what encompasses bottom-up approaches to participation. The literature states that if communities are not active in their participation, bottom-up approaches wane in effectiveness, taking away any agency that may have been gained [5,18]. Here, much of the agency in decision-making was given to the Pueblo employees, making room to incorporate important indigenous and local knowledge. Through using activities that facilitated the involvement of the local community in the knowledge generation process, the dashboard is more useful to the community at large, and participation is active throughout the process. One of the most interesting outcomes from Workshop 1 was the emergence of how important colors could be in establishing trust with the community. More than 1 group made a point to assert that the dashboard website colors should match the colors typical of the Pueblo to indicate seasonality. We were able to amend the double-diamond design method in a way that makes use of the original phases, but better and more clearly integrates the knowledge generated together at the workshops. Because the community had a hand in what is being displayed, they are more engaged with the content and feel more like it shows their own perceptions of what is in important to the Pueblo. The data will eventually also be stored on the Pueblo rather than on UNM servers, giving the Pueblo even more control over what they do with the dashboard.

5.2. How can outside researchers work to decolonize projects that engage with indigenous communities?

Specific methods and practices were integrated into the design process to ensure that the dashboard workshop and the engagement with local community members was not extractive. Human centered design put focus on people [20], but for this study it was important to do this in a way that not only centered people but considered the needs of Pueblo first and foremost. Most of the existing literature attempts to bring in the community, but this project strayed by centering focus on researcher positionality as key to achieving meaningful participatory design. Most of the existing literature attempts to bring in the community, but this project strayed

by centering focus on researcher positionality as key to achieving meaningful participatory design, as suggested by Akama et al. [7]. At the beginning of the meeting, the research team took time to describe this intention of making the process less extractive and outwardly acknowledged their positionality and role in the project at the outset. This initial understanding of the reciprocal relationship is important, as it helps to establish some form of trust between the Pueblo members and the research team. Additionally, it helps to eliminate some of the illusion of inclusion since it shows a commitment to collaboration on the part of the researchers. Beginning the project with definite and purposeful respect is a sure way to help to establish that trust. This addresses the root of what is necessary to conduct successful bottom-up research. Many studies show the benefits of bottom-up approaches over top-down ones [1–5], but there is a lack of studies which demonstrate what it is that makes bottom-up approaches more successful. Putting decolonization at the forefront of the workshops and ensuring that knowledge is generated together, with Pueblo members taking the lead is an important way to ensure that bottom-up approaches are being made inclusive.

In addition, all the Workshop 2 survey respondents noted that they felt included in the dashboard design process, suggesting that the researchers were successful in ensuring a reciprocal relationship for the project. The increase in attendance between the two workshops indicated that Pueblo members did feel included and heard throughout the process and that the knowledge cogeneration process was successful. Prior to this, it was noted that there had been some initial hesitance at how included community members and employees would feel through the workshop process. Respondents also did not hesitate to indicate where changes were desired after viewing the dashboard for the first time, indicating that some level of trust had in fact developed between the researchers and Pueblo members, further speaking to the benefits of a reciprocal relationship. The second workshop included several Pueblo members who had not been involved in the project from the beginning, as had those that the research team had been in contact with up to that point. The results from the second survey indicated that those new members also felt included in the project, indicating that that level of trust was able to be established during the time of the workshop, presumably by the researchers. This is in line with Akama et al.'s suggestion that trust and positionality are critical to establishing successful reciprocal relationships (2019).

5.3. How does risk perception affect proposed adaptation measures?

To put the workshop in the context of the larger project, we need to ask what the importance of community input is when we talk about sensors and the importance of sensors when we talk about modelling. Sensors provide the data points and those are directly used in the models. We can better calibrate and improve our models as precipitation and flood events happen. On one hand, sensors help inform communities to make better decisions, but community input also helps sensors in their effectiveness. The perception of risk is what the relationship between sensors, modelling and community input is tied to. As stated in the literature, this relationship is critical to effective short-and long-term risk mitigation. As shown in the literature (Hawlbachs 1995 [34]; United Nations 2006), this interrelated relationship is critical to effective short-and long-term risk mitigation.

In the survey results, all of respondents answered that Ohkay Owingeh was adequately prepared to deal with flood risk, while 95 % of community members answered yes when polled on whether or not they felt that flood and fire risk were a major threat to the Pueblo. This indicates that there is certainly a strong perception and recognition of risk, but that the community falters when thinking about its ability to respond. Having a strong perception of risk in a community encourages people to get involved [34]. We can see some of this in the increase in community members in our follow-up workshop as opposed to our original one. This adds to the idea that effective bottom-up research is rooted in avoiding the illusion of including communities in the research process, as touched up on by Gaillard and Mercer [25]. Community members being aware of risk and being aware of research projects is separate from people actually striving to participate in workshops. The increase in attendance shows that this is a critical part of the equation.

The workshops were a success in many ways, with Pueblo members giving substantial input on the design of the dashboard. The most repeated feedback from the community in the survey responses and verbally during the workshop was to provide more general information about flood risk to the Ohkay Owingeh Pueblo, which can be accomplished through the data dashboard. Future flood risk was also outlined as a major perk of the dashboard and several civil servants who work in the realm of hazard response (police officers, firefighters, sheriffs) expressed interest in using the dashboard as a way to both inform Pueblo members about general flood risk and communicate information in times of need (ie. As an early warning system or to assist with evacuation). While this did not fall within the scope of the current project, we hope that the data dashboard can serve as a jumping off point for the hazards response team on the Pueblo to work from and aid in long term adaptation in Ohkay Owingeh.

The importance of risk perception and community awareness can be seen in the activities that community members completed during the workshop. In the 'Understand Risk Activity' from the first workshop, community members were asked to identify areas that were most at risk and think critically about adaptation, response and mitigation measures that could help to reduce some of the vulnerability and risk in those chosen places. The places that were highlighted in the activity were locations that the community had chosen and felt some sort of connection to, whether it be economic, cultural, or personal. In turn, when thinking about ways to alleviate some of the risk to those areas, workshop community members had to think together about short-, medium-, and long-term strategies to prepare these areas, generating knowledge together with their community and the help of the research team. This kind of community generation of knowledge is invaluable and a necessary way to address hazard risk in areas where community is an important part of the hierarchical structure. It takes human-centered design principles and allows the perspectives and perceptions of the Pueblo to be at the forefront.

6. Limitations

While this study strived to collaborate with the community in a meaningful and productive way throughout, certain limitations do exist. Most importantly, it is important to be critically aware of the research team's positionality. As a group of researchers at a large

research university with only one member of the Pueblo on our research team, it was necessary to be very careful about generalizing and not falling into a cycle of perpetuating coloniality. While efforts were made to prevent any obvious 'othering' in some ways this felt inevitable. The need to differentiate the roles of researcher and Pueblo member felt like a potential form of 'othering' in itself. In addition, this was a singular study on one Pueblo over a limited amount of time. We would encourage further hosting of workshops in similar situations on other Pueblos and/or reservations for a more thorough study.

One of the repeated suggestions noted on the survey for things the Pueblo would want displayed on the data dashboard is the creation and implementation of a flood early warning system. While the data dashboard would be able to host such a tool, the creation of a flood early warning system is outside the scope of this project, though it would be a potential avenue for future work with the Pueblo.

The issue of elite capture also arises, as we spoke with members of the Pueblo who also worked for the Pueblo in some capacity. The people we talked to were engaged in flood response or more aware of flood risk than the average Pueblo member, and future work may shift focus to general members of the Pueblo as well. This also touches on the subtleties of who is at the center of a bottom-up design approach. While we were able to incorporate much of what workshop attendees desired (a community-driven, co-designed effort), it is important to note that most of our workshop attendees were employees of the Pueblo (as well as tribal members). If the critique of top-down design is that it is unduly focused on centralization and government input, we must acknowledge that our workshop members were, in fact, employees and government workers. However, the nuances of power relations cannot be ignored. While they may have been part of the central system of power on the Pueblo, the fact that Pueblo members were making decisions and had a meaningful, guiding role in the workshops cannot be ignored in the continual battle to combat lasting colonial methods.

7. Conclusion

This study aimed to amend the double-diamond design method to be more inclusive of indigenous perspectives and to decolonize the design process. By addressing researcher positionality early on, we were able to minimize exploitative practices and effectively incorporate the perspectives of the community members who participated in the workshops. In its original iteration, double-diamond design requires the input of several involved parties but does not outline effective ways to do so beyond outlining the four working stages; discover, define, develop, and deliver. By dividing these steps into two parts, 'discover' and 'define' during Workshop 1 and 'develop' and 'deliver' during Workshop 2, we were able to more effectively find ways to integrate the knowledge developed with the Pueblo. With our amendment to the double-diamond design method, we can fill a gap in the literature that allows for more impactful and meaningful participatory design when working with specific communities.

Other researchers looking to incorporate processes to decolonize knowledge cogeneration practices when working with tribes can look to the activities outlined in this project, especially when it comes to acknowledging researcher positionality. Activities can be changed to more readily fit any community that work is being conducted in. In addition, our survey helped demonstrate that risk perception can work hand in hand with participatory design methods to better allow communities to think about hazard response in the longer term. Rather than vaguely assert that our method is a bottom-up approach, we outline the specifics to underscore that this approach is dependent on meaningful knowledge cogeneration and decolonization in the form of recognizing researcher positionality, as a way to demonstrate that top-down approaches miss these opportunities and nuances. This project has shown that risk perception can work as a tool to inform adaptation measures and the knowledge cogeneration in itself is an effective mode of collaboration. Moreso, it has given us a chance to explore the nuances of bottom-up design and better understand methodologies to make bottom-up approaches more inclusive.

CRediT authorship contribution statement

Ria Mukerji: Conceptualization, Formal analysis, Methodology, Writing – original draft. **Yolanda C. Lin:** Conceptualization, Funding acquisition, Methodology, Writing – review & editing. **Su Zhang:** Conceptualization, Funding acquisition, Software, Writing – review & editing. **Mark Stone:** Conceptualization, Formal analysis, Funding acquisition. **Carolyn Hushman:** Funding acquisition, Methodology. **Fernando Moreu:** Funding acquisition. **Lauren Vigil:** Investigation, Methodology. **Tyler Eshelman:** Software, Visualization, Writing – original draft. **Lindsey Rotche:** Formal analysis, Visualization. **Anistasia Baca:** Investigation. **Marisa Nodine:** Methodology. **Megan Faulkner:** Methodology. **Chalon Johnson:** Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

The authors would like to thank the employees and members of the Ohkay Owingeh Pueblo, without whose welcome and partnership this project would not have been possible. We would especially like to thank Christy Ladd and Sybil Cota. This project was funded by National Science Foundation Awards #2043618 and #2133334 as part of the CIVIC Innovation Challenge program.

References

[1] A.O. Isidiho, M.S.B. Sabran, Evaluating the top-bottom and bottom-up community development approaches: mixed method approach as alternative for rural uneducated communities in developing countries, Mediterr. J. Soc. Sci. (2016), https://doi.org/10.5901/mjss.2016.v7n4p266.

[2] R.S. Oktari, R. Syamsidik, H. Sofyan Idroes, K. Munadi, City resilience towards coastal hazards: an integrated bottom-up and top-down assessment, Water 12 (10) (2020) 2823, https://doi.org/10.3390/w12102823.

[3] T. Thaler, S. Seebauer, Bottomup citizen initiatives in natural hazard management: why they appear and what they can do? Environ. Sci. Pol. 94 (2019) 101–111, https://doi.org/10.1016/j.envsci.2018.12.012.

[4] T. Thaler, M.-S. Attems, S. Fuchs, Bottom-up innovations in natural hazard risk management in Austria, Int. J. Disaster Risk Reduc. 67 (2022) 102689, https://doi.org/10.1016/j.ijdrr.2021.102689.

[5] J. Manous, E.Z. Stakhiv, Climate risk-informed decision analysis (CRIDA): 'top-down' vs 'bottom-up' decision making for planning water resources infrastructure, Water Pol. 23 (S1) (2021) 54–76, https://doi.org/10.2166/wp.2021.243.

[6] R. Few, K. Brown, E.L. Tompkins, Public participation and climate change adaptation: avoiding the illusion of inclusion, Clim. Pol. 7 (1) (2007) 46–59.

[7] Y. Akama, P. Hagen, D. Whaanga-Schollum, Problematizing replicable design to practice respectful, reciprocal, and relational Co-designing with indigenous people, Des. Cult. 11 (1) (2019) 59–84, https://doi.org/10.1080/17547075.2019.1571306.

[8] J.K. Maldonado, B. Colombi, R. Pandya, Climate Change and Indigenous Peoples in the United States, Springer International Pu, 2016, https://doi.org/10.1007/978-3-319-05266-3.

[9] K.P. Whyte, Justice forward: tribes, climate adaptation and responsibility, in: Climate Change and Indigenous Peoples in the United States: Impacts, Experiences and Actions, Springer International Publishing, Cham, 2013, pp. 9–22, https://doi.org/10.1007/978-3-319-05266-3_2.

[10] P. Priyadarshini, P.C. Abhilash, Promoting tribal communities and indigenous knowledge as potential solutions for the sustainable development of India, Environmental Development 32 (2019) 100459, https://doi.org/10.1016/j.envdev.2019.100459.

[11] Daniel Gustafsson, Analyzing the Double Diamond Design Process through Research & Implementation, Aalta University, 2019. Master's Thesis, http://urn.fi/URN:NBN:fi:aalto-201907144349.

[12] H. Chon, J. Sim, From design thinking to design knowing: an educational perspective, Art Des. Commun. High Educ. 18 (2) (2019) 187–200, https://doi.org/10.1386/adch_00006_1.

[13] A.L. Fleury, H.S. Almeida, M.M. de Carvalho, An overview of the literature on design thinking: trends and contribution, Int. J. Eng. Educ. 32 (2016) 1704.

[14] A. Escobar, Transiciones: a space for research and design for transitions to the pluriverse, Design Philosophy Papers 13 (1) (2015) 13–23. https://doi-org.libproxy.unm.edu/10.1080/14487136.2015.1085690.

[15] E. Björgvinsson, P. Ehn, P.-A. Hillgren, Design things and design thinking: contemporary participatory design challenges, Des. Issues 28 (3) (2012) 101–116.

[16] P. Dalsgaard, Participatory design in large-scale public projects: challenges and opportunities, Des. Issues 28 (3) (2012) 34–47.

[17] S. Bødker, M. Kyng, Participatory design that matters—facing the big issues, ACM Trans. Comput. Hum. Interact. 25 (1) (2018), 4:1-4:31.

[18] S. Bødker, S. Pekkala, Introduction the Debate Section: A Short Review to the Past and Present of Participatory Design, vol. 22, 2010.

[19] R. Razzouk, V. Shute, What is design thinking and why is it important? Rev. Educ. Res. 82 (3) (2012) 330–348, https://doi.org/10.3102/0034654312457429.

[20] R. Jacobson, Information Design, MIT Press, 2000.

[21] Jonathan West, Gianpaolo Fusari, Elizabeth Raby, Ralf Alwani, Gabriele Meldaikyte, Anna Wojdecka, Matthews, Book section, developing the double diamond process for implementation, in: Dierdre Barron, Kurt Seemann (Eds.), Design4Health, Melbourne. Proceedings of the Fourth International Conference on Design4Health 2017, 2018, pp. 310–312, 4 - 7 Dec 2017, Melbourne, Victoria, Australia, https://researchonline.rca.ac.uk/id/eprint/3603.

[22] J. Simonsen, T. Robertson (Eds.), Routledge International Handbook of Participatory Design, first ed., Routledge, New York London, 2013. ISBN: 9780203108543.

[23] M.K. van Aalst, T. Cannon, I. Burton, Community level adaptation to climate change: the potential role of participatory community risk assessment, Global Environ. Change 18 (1) (2008) 165–179, https://doi.org/10.1016/j.gloenvcha.2007.06.002.

[24] C. Dorsner, Social exclusion and participation in community development projects: evidence from Senegal, Soc. Pol. Adm. 38 (4) (2004) 366–382, https://doi.org/10.1111/j.1467-9515.2004.00396.x.

[25] J.C. Gaillard, J. Mercer, From knowledge to action: bridging gaps in disaster risk reduction, Prog. Hum. Geogr. 37 (1) (2013) 93–114, https://doi.org/10.1177/0309132512446717.

[26] G.A. Cajete, Indigenous science, climate change, and indigenous community building: a framework of foundational perspectives for indigenous community resilience and revitalization, Sustainability 12 (22) (2020) 9569, https://doi.org/10.3390/su12229569.

[27] G.A. Cajete Tewa, American Indian epistemologies, N. Dir. Student Serv. (109) (2005) 69–78, https://doi.org/10.1002/ss.155, 2005.

[28] F. Berkes, J. Colding, C. Folke, Rediscovery of traditional ecological knowledge as adaptive management, Ecol. Appl. 10 (5) (2000) 1251–1262, https://doi.org/10.1890/1051-0761(2000)010[1251:ROTEKA]2.0.CO;2.

[29] Gregory Cajete, Philosophy of native science, in: Anne Waters (Ed.), American Indian Thought: Philosophical Essays, 57, Blackwell Publishing Ltd, Oxford, UK, 2004, p. 45.

[30] L. Peek, J. Tobin, R.M. Adams, H. Wu, M.C. Mathews, A framework for convergence research in the hazards and disaster field: the natural hazards engineering research infrastructure CONVERGE facility, Frontiers in Built Environment 6 (2020) 110, https://doi.org/10.3389/fbuil.2020.00110.

[31] S. Metzger, E. Ayres, D. Durden, C. Florian, R. Lee, C. Lunch, H. Luo, N. Pingintha-Durden, J.A. Roberti, M. SanClements, C. Sturtevant, K. Xu, R.C. Zulueta, From neon field sites to data portal: a community resource for surface–atmosphere research comes online, Bull. Am. Meteorol. Soc. 100 (11) (2019) 2305–2325, https://doi.org/10.1175/BAMS-D-17-0307.1.

[32] M.-A. Baudoin, S. Henly-Shepard, N. Fernando, A. Sitati, Early warning systems and livelihood resilience: exploring opportunities for community participation. https://collections.unu.edu/view/UNU:3174, 2014. (Accessed 28 July 2023).

[33] J. Cools, D. Innocenti, S. O'Brien, Lessons from flood early warning systems, Environ. Sci. Pol. 58 (2016) 117–122, https://doi.org/10.1016/j.envsci.2016.01.006.

[34] M. Lopez, G. Di Baldassarre, J. Seibert, Impact of social preparedness on flood early warning systems, Water Resour. Res. 53 (1) (2017) 522–534, https://doi.org/10.1002/2016WR019387.

[35] S. Birkholz, M. Muro, P. Jeffrey, H.M. Smith, Rethinking the relationship between flood risk perception and flood management, Sci. Total Environ. 478 (2014) 12–20, https://doi.org/10.1016/j.scitotenv.2014.01.061.

[36] W.J. Burns, P. Slovic, Risk perception and behaviors: anticipating and responding to crises, Risk Anal. 32 (4) (2012) 579–582, https://doi.org/10.1111/j.1539-6924.2012.01791.x.

[37] R. Raaijmakers, J. Krywkow, A. van der Veen, Flood risk perceptions and spatial multi-criteria analysis: an exploratory research for hazard mitigation, Nat. Hazards 46 (3) (2008) 307–322, https://doi.org/10.1007/s11069-007-9189-z.

[38] X. Shen, Flood risk perception and communication within risk management in different cultural contexts. https://bonndoc.ulb.uni-bonn.de/xmlui/handle/20.500.11811/3979, 2009. (Accessed 28 July 2023).

[39] A. Scolobig, B. De Marchi, M. Borga, The missing link between flood risk awareness and preparedness: findings from case studies in an Alpine Region, Nat. Hazards 63 (2) (2012) 499–520, https://doi.org/10.1007/s11069-012-0161-1.

[40] Department of Planning and Zoning, Comprehensive management plan for county of Rio arriba. http://www.rio-arriba.org/pdf/departments_and_divisions/comprehensive_plan.pdf, 2014.

[41] E. Fleishman, J. Belnap, N. Cobb, C.A.F. Enquist, K. Ford, G. MacDonald, M. Pellant, T. Schoennagel, L.M. Schmit, M. Schwartz, S. van Drunick, A.L. Westerling, A. Keyser, R. Lucas, J. Sabo, Natural ecosystems, in: G. Garfin, A. Jardine, R. Merideth, M. Black, S. LeRoy (Eds.), *Assessment Of Climate Change In the Southwest United States: A Report Prepared For the National Climate Assessment*, NCA Regional Input Reports, Island Press/Center for Resource Economics, Washington, DC, 2013, pp. 148–167, https://doi.org/10.5822/978-1-61091-484-0_8.

[42] M.F. Wehner, J.R. Arnold, T. Knutson, K.E. Kunkel, A.N. LeGrande, Chapter 8: droughts, floods, and wildfires. https://ntrs.nasa.gov/citations/20180001310, 2017.
[43] S.L. Stephens, J.K. Agee, P.Z. Fulé, M.P. North, W.H. Romme, T.W. Swetnam, M.G. Turner, Managing forests and fire in changing climates, Science 342 (6154) (2013) 41–42, https://doi.org/10.1126/science.124029.
[44] J. Mercer, D. Dominey-Howes, I. Kelman, K. Lloyd, The potential for combining indigenous and western knowledge in reducing vulnerability to environmental hazards in small island developing states, Environ. Hazards 7 (4) (2007) 245–256, https://doi.org/10.1016/j.envhaz.2006.11.001.
[45] Gilbert F. White, Human Adjustment to Floods: A Geographical Approach to the Flood Problems in the United States" PhD, University of Chicago, Dissertation, 1945.
[46] K. Haynes, J. Barclay, N. Pidgeon, The issue of trust and its influence on risk communication during a volcanic crisis, Bull. Volcanol. 70 (5) (2008) 605–621, https://doi.org/10.1007/s00445-007-0156-z.