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The Science Application for Risk Reduction (SAFRR) Scenario Retrospective 2006–21

ShakeOut

ARkStorm

Tsunami Scenario

HayWired

Scientific Investigations Report 2023–5011

U.S. Department of the Interior
U.S. Geological Survey

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Abbreviations

ABAG	Association of Bay Area Governments
ALERT	actionable, longitudinal, education, relevant, thorough
AWWA	American Water Works Association
BCSH	California Business, Consumer Services, and Housing Agency
Cal OES	California Office of Emergency Services
Caltrans	California Department of Transportation
CalWARN	California Water/Wastewater Agency Response Network
CERT	Community Emergency Response Team
CGS	California Geological Survey
CTPWG	California Tsunami Policy Working Group
DHS	Department of Homeland Security
DRR	disaster risk reduction
DWR	California Department of Water Resources
EBMUD	East Bay Municipal Utility District
FEMA	Federal Emergency Management Agency
JVSV	Joint Venture Silicon Valley
LADWP	Los Angeles Department of Water and Power
LHMP	local hazard mitigation plan
MHDP	Multi-Hazards Demonstration Project
NOAA	National Oceanic and Atmospheric Administration
NTHMP	National Tsunami Hazard Mitigation Program
OFR	Open-File Report
PEER	Pacific Earthquake Engineering Center
RQ1	Research Question 1
RQ2	Research Question 2
RQ3	Research Question 3
SAFRR	Science Application for Risk Reduction
SCEC	Southern California Earthquake Center
TIS	Tsunami Information Statements
USGS	United States Geological Survey

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By Nora Smithhisler and Nina Burkardt

Abstract

The U.S. Geological Survey Science Application for Risk Reduction (SAFRR) Project has created four major hazard scenarios—ShakeOut, ARkStorm, Tsunami Scenario, and HayWired—with multidisciplinary teams of scientists, academics, and practitioners. By presenting a clear and highly detailed narrative of potential damage from earthquakes, tsunamis, and winter storms, the scenarios are intended to foster science-based preparedness strategies and disaster risk reduction innovations.

This evaluation explores the presence of these scenarios in cultures of preparedness and their role in disaster risk reduction, and reports barriers and enablers to creating and using these scenarios. To do this, the evaluation team developed a mixed-methods study that includes background research for each scenario, qualitative interviews, data collection of media and academic engagement, and examples of SAFRR scenario use in hazard planning. The data collection led to the development of a hazard scenario evaluation tool that combines theories from multiple disciplines to create a best practice set of categories that aid in scenario use and efficacy. The evaluation tool categories—actionable, longitudinal, educational, relevant, and thorough—are organized as a series of checklists that are used to determine how the scenario planners prioritized different aspects of the scenarios to achieve their goals. The tool could also be used to aid scenario planning for other regional disaster risk reduction scenarios of a similar scope.

Findings from this evaluation include detailed narratives of scenario use over time, demonstrating that the scenarios have continued to be useful in hazard planning and preparedness across the globe. Examples of use include using the scenarios to advocate for resilient building and development policy, to promote hazard response exercises, and as source data for the development of new hazard models and science. The scenarios themselves are innovative, both in the hazard science created for scenario development and in their branding and public engagement as U.S. Geological Survey products. This SAFFR retrospective is a descriptive evaluation and does not formally address the effects of the scenarios. Nevertheless, this report does include evidence of scenario affects as discovered through qualitative interviews and research, which is presented to explore how the SAFRR scenarios have been received by cultures of preparedness.

Introduction

The U.S. Geological Survey (USGS) Science Application for Risk Reduction (SAFRR) project's mission is to innovate the use of science in disaster risk reduction (DRR). Since 2006, among other projects, SAFRR has developed four major hazard scenarios: ShakeOut, ARkStorm, Tsunami Scenario, and HayWired, shown in figure 1. The SAFRR scenarios are large, collaborative projects that bring together hundreds of scientists, emergency managers, utilities personnel, engineers, economists, and social scientists to develop and workshop the effects of a hazard on infrastructure, the economy, the environment, and the population. The SAFRR scenarios are strategy-driven scenarios, designed to support hazard awareness and preparedness, as well as inspire innovations in hazard science and DRR.

Scenarios have widespread use in hazard planning and emergency preparedness exercises. A practitioner-based discipline, scenario planning is the process of creating plausible but improbable future narratives in which current decisions or trends can be played out or strategized (Schwartz, 1996; Chermack and Lynham, 2002). Scenarios are not intended to predict the future but to introduce uncertainty into planning, and in doing so, highlight relationships between key driving forces, interconnections, and systems that affect potential futures (Strong and others, 2020). The process of strategy-driven scenario planning is itself an output; through gathering stakeholders from multiple sectors to practice emergency decision making, scenario planners practice cross-sector communication, identify interconnections, and collaborate on strategic plans (Alcamo, 2008a).

After over a decade of hazard science collaboration and communication, SAFRR scenario planners want to know how the scenarios have been used, the extent of that use, and if the scenarios have innovated hazard science and risk reduction. The objective of this project is to provide a retrospective of the initial development, application, and evolution of the SAFRR scenarios. To accomplish this objective, a descriptive evaluation method was developed and applied to the scenarios. The evaluation method provided a consistent framework to write a description of the SAFRR history and give a snapshot of current use. The following research questions were chosen to frame the descriptive evaluation process:

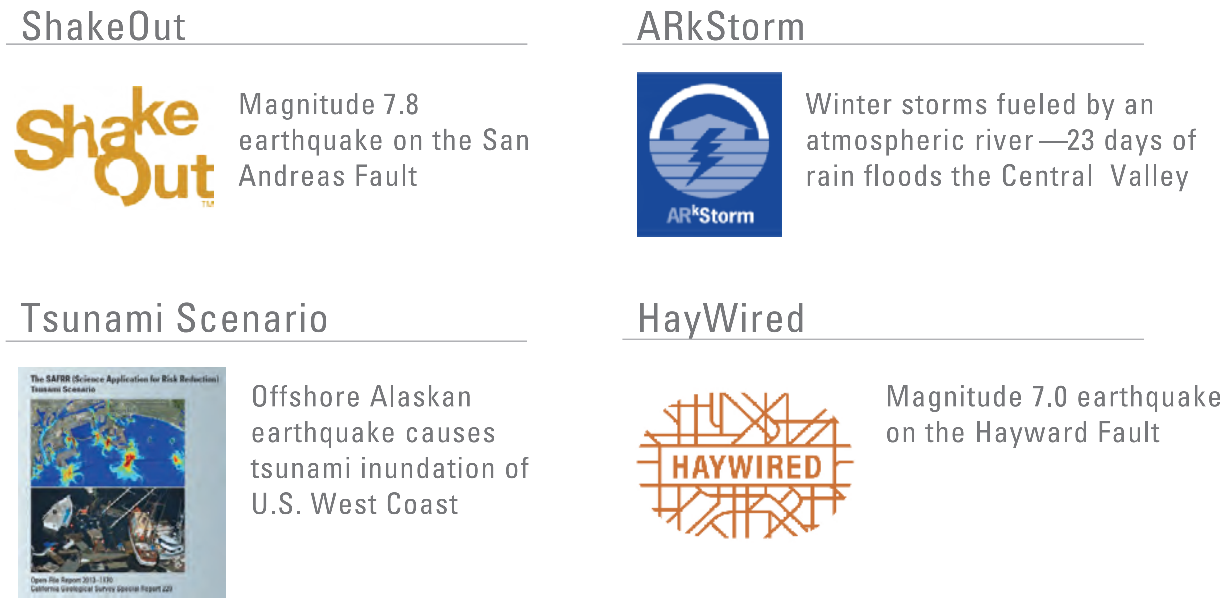

Figure 1. The four Science Application for Risk Reduction (SAFRR) Scenarios, with their logos and a short description of their hazards.

Research question 1 (RQ1)

What are the barriers and enablers to developing and deploying the SAFRR scenarios?

Research question 2 (RQ2)

Have the SAFRR scenarios changed **cultures of preparedness**[1] for disasters?

Research question 3 (RQ3)

Have SAFRR scenarios stimulated the development of new technologies or innovations for disaster response preparedness?

To approach these questions, this evaluation explored the relationships among the scenario planning processes and products, and how they achieved the goals outlined by the SAFRR scenario planners. Using **theory-based evaluation** as a foundation, this project created a logic model for the SAFRR scenarios, integrating the processes from scenario planning theory and DRR best practices with the inputs, outputs, and intended outcomes and goals of the SAFRR scenarios. To achieve the overarching goal of changing a culture of preparedness, SAFRR scenarios need to (1) create hazard awareness and knowledge; (2) contribute to hazard planning, study, and preparedness activities; (3) connect stakeholders in networks of shared risk; and (4) provide a foundation for hazard science and DRR innovation.

This report contains the findings from qualitative interviews, academic and media mentions, hazard mitigation plans, an evaluation tool, and more detailed histories of the scenarios. As a descriptive evaluation, this report does not provide impact or cost benefit analyses. This evaluation is limited to observations and cannot valuate the presence of the scenarios in DRR. However, this report includes evidence of scenario affects as discovered through qualitative interviews and research including but not limited to extent of use (for example, local–global), policy relevance, use in disaster emergency response, and scientific data usage. As these scenarios go back as far as 2006 and involve hundreds of collaborators and authors and millions of intended users, this evaluation is not a comprehensive assessment but rather a snapshot of how the SAFRR scenarios have moved through the world and some of the preparedness and mitigation work they have inspired.

[1]Glossary terms are shown in boldface text.

Literature Review

This section, titled “Disaster Risk Reduction,” starts with the basics of DRR to establish the definitions that are the most used in the field and are most useful to this evaluation. The precision of the definitions included is important to a basis of theory that is used to assess the SAFRR scenarios for their DRR efficacy and to define the components of the research questions that are used for the evaluation.

The second section of the literature review titled “Scenarios and Disaster Risk Reduction” is an introduction to scenario planning, detailing its origins, emerging theoretical and practical discoveries in the field, and definitions used by the leading names in the field. This is used to identify the SAFRR scenarios in the categories defined by the literature and evaluate them against the theoretical best practices of scenario use.

Disaster Risk Reduction

The essential purpose of DRR is to reduce the impact of disasters on society through analyzing and managing the causal factors of disasters and reducing exposure through mitigation, land management, planning, and preparedness. The field of DRR pulls together earth and climate scientists, social scientists, political and community leaders, and private industry to tackle local and global issues of vulnerability, exposure, and the adaptive and coping capacity of populations (Davies and others, 2015; United Nations Office for Disaster Risk Reduction [UNDRR], 2021).

What Makes a Disaster?

Natural hazards are inevitable. The natural systems affected by hazards have adapted to survive or thrive because of these events. Hazards become disasters at the intersection of human vulnerability and hazards. Vulnerability can exist where property, infrastructure, activity, and lives are not designed to accommodate the extremity of natural forces, resulting in damage and loss. Most basically, this is expressed by the foundational risk reduction equation: hazard × vulnerability = risk of disaster (Wisner, 2004; Birkmann, 2013).

As social scientists continue to study what makes human societies vulnerable, the model becomes more complex to reflect the complex nature of human systems. The World Risk Index, created by the Integrated Research on Disaster Risk program, recognizes four components of risk: exposure to hazards, susceptibility of people and societies exposed, coping capacities of the affected, and adaptive capacities (Birkmann and others, 2013). Figure 2 shows the four risk components and examples of how they can be present in a society. These components are large, complex systems within themselves and can look very different based on geography, external factors (for example, climate), and the communities at risk.

The field of disaster risk management has defined a cyclical framework of hazard response that cycles from preparedness to event, response, recovery, mitigation, and back to preparedness to event. Called the “Hazard Cycle” (fig. 3), this system is ubiquitous and used in government agencies like the Department of Homeland Security’s (DHS) Federal Emergency Management Agency (FEMA), first responder services, and other emergency management organizations (Tiernan and others, 2019). The preparedness stage of the cycle of emergency management has its own cyclical framework: plan, organize/equip, train, exercise, and evaluate/improve, which tends to be credited to FEMA but is used commonly within the field of emergency management (NIMS, 2019). Because the SAFRR scenarios are intended to be preparedness exercises, this literature review will focus on the concepts of preparedness and **resilience**.

Preparedness

National preparedness, as it pertains to the Nation’s ability to anticipate large-scale emergencies, is defined by the Presidential Policy Directive 8 from March 30, 2011 as “Actions taken to plan, organize, equip, train, and exercise to build and sustain the capabilities necessary to prevent, protect against, mitigate the effects of, respond to, and recover from those threats that pose the greatest risk to the security of the Nation” (White House, 2011, p. 5). Essentially, conceptualizing as many hazards as possible and anticipating how vulnerabilities will interact with those hazards, then adapting to and mitigating the hazards to save lives and reduce economic loss.

The U.S. Federal Government’s preparedness efforts use the all-hazards approach philosophy, a generalized policy that operates under the assumption that any form of preparation made for one hazard will have an umbrella effect of preparedness for other hazards (Adame, 2018). The United States may be having some success with this approach, as the most recent results from the 2018 National Household Survey (FEMA, 2018) show increases in nearly all indicators for household preparedness; 57 percent of households have taken three or more basic actions to prepare, an 11-percentage-point increase from 2017. There have also been increases in disaster awareness, local involvement in disaster training meetings and drills, and households setting aside money and supplies for emergencies since 2017 (FEMA, 2018). This is promising, and a little unprecedented, as FEMA’s 2014 report, “Personal Preparedness in America,” showed that household preparedness levels were dismal and had changed very little in decades (FEMA, 2014; FEMA, 2019).

Resilience

Resilience is the intended result of mitigation and preparedness. Though the term “resilience” has been used in DRR and hazard literature for decades, resilience became established among the world’s governments as a concrete goal in 2005, with the adoption of the “Hyogo Framework for Action” in the United Nations. The Hyogo Framework was expanded and replaced by the “Sendai Framework for Disaster Risk Reduction 2015–2030,” which prioritizes the development of resilient communities to reduce risk (Cutter and others, 2013; UNDRR, 2015b). The United Nations Office for Disaster Risk Reduction defines resilience as “The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions” (UNDRR, 2021). Resilient communities recognize that not all threats can be avoided or deflected and, thus, establish mechanisms that mitigate disturbances to reduce susceptibility and exposure (Burton, 2015; UNDRR, 2015b). Resilient populations also learn from a disruptive event and adapt behaviors and infrastructure to better meet future threats (UNDRR, 2015b; Sharifi, 2016).

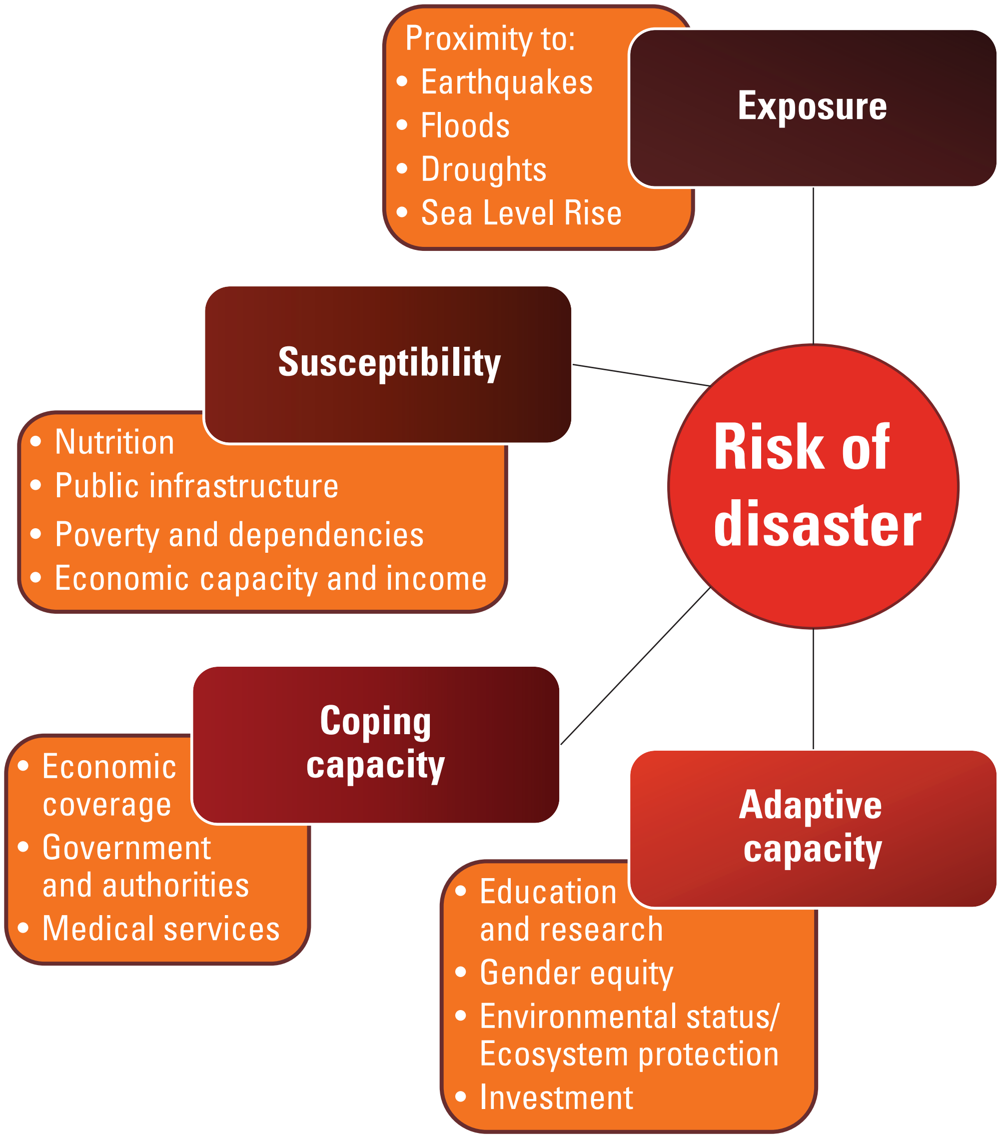

Figure 2. The four World Risk Index indicators and examples of how they can be present in a society.

Much of the literature dissecting resilience places a strong emphasis on the need for social capital, where individuals cooperate in collective action with families, communities, or other social networks and rely on each other for financial, physical, or emotional support (Burton, 2015; Wilkin and others, 2019). Social capital involves the resources that individuals can access via their social networks, which they can use in the event of a hazard (Aldrich and Meyer, 2015; Burton, 2015; Wilkin and others, 2019). These social networks can include neighbors, religious institutions, community organizations, and other relationships through which individuals in a community are connected (Aldrich and Meyer, 2015). The bonds created by social networks are divided into three main types: bonding, bridging, and linking. Bonding social capital is the relationships between close individuals, such as friends and family. Bridging represents the connections between individuals linked through social groups, such as class or race. And finally, linking is found in the connections between citizens with those in power (Aldrich and Meyer, 2015). The more interconnected and networked a population is along these three groups of social capital, with access to organizations that are familiar with resource collection and distribution, the higher chance of self-sufficient disaster response and recovery efforts (Burton, 2015; Wilkin and others, 2019). Social capital is a component of **community resilience**, which can be strengthened by developing a networked preparedness culture within the community.

Figure 3. Two cyclical frameworks used to guide emergency management, the hazard and preparedness cycles.

Culture of Preparedness

A relatively new concept in DRR, the phrase "culture of preparedness" was used in several articles prior to 2006, but the most widely referenced origin is in the 2006 book "The Federal Response to Hurricane Katrina—Lessons Learned" (herein referred to as "Lessons Learned"), written at the request of then President George W. Bush to identify the failures to manage Hurricane Katrina's disastrous impact on the Louisiana coast and create a roadmap to do better in the future (Townsend, 2006; White House, 2006). Containing 125 specific recommendations for DRR, "Lessons Learned" outlines specific requisites to build a U.S. culture of preparedness but does not define culture or culture of preparedness. Since then, culture of preparedness has been used casually by different academic and private entities to indicate a community's general activity in preparedness measures and has been used officially by organizations like the DHS to outline concrete organization goals and actions (Alperen, 2017; Rubin and Dahlberg, 2017; FEMA, 2019).

For most of the literature, a culture of preparedness is described as an elevated form of community resilience, addressing the need for culturally attuned support, communication, and preparedness action to maximize self-sufficiency in every community subgroup. The presence of ubiquitous preparedness and resilience on the individual and community levels is expected to reduce the strain on emergency response entities and enable populations to endure the lack of **lifeline** services while lifeline reconstruction efforts are underway (Townsend, 2006; FEMA, 2019). Simply put, increasing

Cultures of Preparedness Definition

Groups united by vulnerability to one or more hazards, sharing risk and common knowledge, norms, and communications that guide the conceptualization and behavior of preparedness.

community resilience may entail adding more first responders to a population, whereas creating a culture of preparedness may entail training the population to perform many first responder duties themselves.

As such, social capital plays a large role in a prepared culture, and well-established collaboration, communication, resource sharing, and social networks are indicators. Prepared cultures communicate with their governments, and vice versa, along with intergovernmental communication for coordination of mitigation, response, and relief efforts. Private institutions in prepared cultures engage with their stakeholders and governments to organize mitigation and repair work. Lines of communication, authority, and jurisdiction for emergency responders and managers are pre-established in a bottom-up, culturally aware intergovernmental and private institution network (Townsend, 2006; Marshall and others, 2007; Kapucu, 2008; White House, 2011; Kapucu and Khosa, 2013; Krüger and others, 2015; Alperen, 2017; FEMA, 2019). The various sources discussing Cultures of Preparedness are generally developing the concept in response to hazards and vulnerabilities in their region, specifically addressing the need to develop stronger measures of resilience and preparedness within all levels of their community. There is still a lack of a decontextualized definition for Cultures of Preparedness, therefore, the next section covers the definition created for this evaluation.

Defining Cultures of Preparedness

Culture is the ubiquitous mixture of social norms and behaviors that encompasses a social system. FEMA defines culture in its 2019 plan to build Cultures of Preparedness as "that complex whole, which includes knowledge, beliefs, arts, morals, law, customs, and any other capabilities and habits acquired by [a human] as a member of society" (FEMA, 2019, p. 11). Culture can define broad regions, such as Western and Eastern societies, with an overlay of local patchworks of culture that can depend on ethnicity, urban or rural locality, weather, geography, socioeconomic status, nationality, and local history, among countless other factors.

In the context of DRR, Cultures of Preparedness are groups united by shared risk to one or more hazards. These cultures are defined by the shared knowledge, norms, and communications that guide their conceptualization and behavior of preparedness. Numerous subcultures exist within these regions of vulnerability, and the concept of Cultures of Preparedness highlights varying perceptions of their state of vulnerability and what they do about it. Any work to bolster resilience within a culture requires a substantive understanding of these local systems. Without a cultural understanding, top-down implementation of preparedness policy and procedures will very likely fail (Wilkin and others, 2019).

Cultures of Preparedness in the United States

FEMA's "Building a Culture of Preparedness" report outlines a multilevel plan to increase national preparedness from the ground up by fostering trust, inclusion, communication, and support networks for all the disparate communities in the Nation (FEMA, 2019). The 2018 USGS risk plan outlines similar objectives, including a renewed focus on building partnerships with communities when collaborating on vulnerability assessments and risk analysis (Ludwig and others, 2018). Both sources emphasize that to have effective risk reduction, the United States must recognize that every community contains multiple cultures, and those cultures must be individually engaged in preparedness through inclusion, trust, and inter- and intracultural communication initiatives (Ludwig and others, 2018; FEMA, 2019).

The DHS mission focuses on individual citizen vigilance and responsibility. To the DHS, a culture of preparedness is when a group builds towards postdisaster self-sufficiency and predisaster mitigation (Townsend, 2006; Alperen, 2017). The DHS emphasizes the importance of taking initiative in a culture of preparedness, changing the Nation's reactive emergency management system to a proactive one, and for the American people to take initiative for their own safety (Townsend, 2006). The theme of community-level self-sufficiency extends to private enterprise, and "Lessons Learned" addresses the fact that most **lifeline infrastructure** is owned by private enterprise, and these institutions need to integrate community resilience into their organizational culture to minimize damage to critical infrastructure and see to its repair as quickly as possible (Townsend, 2006; DHS, 2021).

This shift in responsibility and expectations is proposed by FEMA and other DRR institutions for two primary reasons: (1) localities have the specialized knowledge and access required to prepare their population and infrastructure, and (2) FEMA's budget is not infinite. (Townsend, 2006; Marshall and others, 2007; Kapucu, 2008; Kapucu and Khosa, 2013; Krüger and others, 2015; FEMA, 2019). Researcher Mara Benadusi (2014, p. 174) describes this shift towards increased individual responsibility for community resilience as "a shock absorber that compensates for institutional inefficiency," criticizing governing institutions for their failures to take responsibility and undergo aggressive action in DRR. But as climate change induced hazards create increasingly severe disasters, FEMA's response capacity will become increasingly stretched (Smithhisler, 2018).

Examples of Public Initiatives in Building a Culture of Preparedness:

The "Ready Campaign," a public service campaign designed to educate the American people on preparedness, mitigation, and response to emergencies, launched the Community Emergency Response Team (CERT) program. CERT is a disaster response volunteer training program, and covers subjects like first aid, fire safety, and search and rescue operations. CERT volunteers can then take these skills back to their communities, and, in the event of a disaster, help manage emergency situations locally without waiting for external support systems. There are now CERT programs in all 50 States, and many Tribal and Territory jurisdictions (DHS, 2017).

Barriers in Disaster Risk Reduction

Despite recent increases in preparedness actions, citizens remain chronically underprepared for hazards (Townsend, 2006; Parlak and others, 2012; Adame, 2018). Many current efforts in DRR are not working as well as anticipated, and the global cost of hazards continues to increase alongside global vulnerability. Research indicates that most DRR strategies have been inadequate at anticipating the full, complex impact of hazards and thus fail to inform stakeholders about all the actions necessary to prepare and mitigate (FEMA, 2012; Davies and others, 2015). Some of the larger barriers are public perceptions of hazards and low **disaster literacy** (Mileti, 1999; Bourque and others, 2012; UNDRR, 2015a; FEMA, 2019), **risk communication** (Wood and others, 2012; November and Leanza, 2015), the disconnect between knowledge and action (Wachinger and others, 2013), and a lack of communication between different emergency response organizations and lifeline infrastructure organizations (Mileti, 1999, Weichselgartner and Kasperson, 2010; Davies and others, 2015).

There are multiple barriers to the public's threat perception and ability to react; people often perceive risk based on a combination of trust or lack thereof in authorities, sensationalized media attention, level of perceived individual control, recent experience with a hazard, and other biases (Wachinger and others, 2013). Unfortunately, this can result in skewed assessments, such as a high-risk perception of nuclear accidents and a low-risk perception of car accidents, despite the inverse being true. Since risk perception has been used to predict risk-related behaviors, low or skewed risk perception can inhibit the development of a resilient community (Bourque and others, 2012).

The general public's lack of disaster or risk literacy is an ongoing puzzle for the world's disaster relief organizations and confounds efforts to inspire citizens to take ownership of their own preparedness initiatives (Mileti, 1999; UNDRR, 2015a; FEMA, 2019). Low disaster literacy can be the result of the way risk is communicated. Many public education efforts are based on intuition or previous patterns of public service announcements instead of on processes based on empirical evidence (Wood and others, 2012). Warnings and public service announcements can have scientific jargon in them that can become too complex for an audience that has low disaster or scientific literacy level. On the other hand, if the messages are too brief or simple, the audience will wait to confirm the information and act based on how they see others acting (Wood and others, 2018).

If preparedness messages and campaigns are tailored correctly, people will process the information and demonstrate increases in preparedness awareness and intentions (Adame, 2018). Public messaging is also more effective if it includes instructions, such as the "Stop, Drop, and Roll" fire safety campaign or the "Buckle Up America" seatbelt awareness program (Townsend, 2006; FEMA, 2019). It is worth noting that even if risk perception was corrected to match the probabilities of hazards, people may still not prepare. Researchers have found what is called the risk perception paradox, where people with a high level of risk perception still do not take preparedness actions. Sometimes this is due to lack of agency or resources, sometimes due to trust that the government and authorities will handle the event, and sometimes it is simply a lack of urgency—people intend to prepare but do not get around to it (Wachinger and others, 2013).

Meanwhile, many professional disaster management entities and DRR research institutions are **siloed** and respond to hazards with limited collaboration with other public entities and lifelines (Mileti, 1999; Davies and others, 2015). There are shared interests and interdependencies within disaster management entities and scientific institutions, and given the fact that disasters create chronic resource constraints, collaboration is the most optimal way to manage emergency situations (FEMA, 2012). Although more is known now about hazards and disasters than ever before, these silos also apply to research institutions and applicable academic endeavors, limiting the integration of science into DRR (Davies and others, 2015). Disaster management entities, especially local government officials, report that there is a gap between themselves and the research being done on DRR. Decision makers in policy and practice typically underuse the available research-based knowledge and mention that researchers typically produce knowledge that is not directly useable (Weichselgartner and Kasperson, 2010; Davies and others, 2015). Information sharing activities also tend to be unidirectional, from scientist to practitioner, instead of a collaborative conversation about the practitioner's needs and knowledge gaps; thus, creating a lack of community participation in risk planning that inhibits the development of community resilience (Weichselgartner and Kasperson, 2010; Davies and others, 2015).

Many of the barriers in DRR involve communication and usability of information. There are current efforts in DRR and climate science to find different pathways for communication of actionable science. Davies and others (2015) encourage an ongoing process of joint learning between communities, civil society, scientists, and local governments. Theories and work in joint learning for actionable science have taken the form of coproduction of knowledge (a growing area of research interested in creating usable or actionable science through collaboration between scientists and decision makers [Meadow and others, 2015]); transdisciplinary research (nonacademic initiated research with multidisciplinary teams designed to be integrated into practice [Lang and others, 2012]); and engaging stakeholders in developing integrated scenarios—described in the following sections.

Scenarios and Disaster Risk Reduction

Scenario planning is still a developing field of study, though it is commonly used among hazard planning, mitigation, and preparedness practitioners. There are limited publications that evaluate the success of scenario planning in DRR, but researchers have collected anecdotes and positive correlations between an organization's use of scenarios and increases in resilience.

What is Scenario Planning?

> " * * * 'good' stories provide a context that gives an easy and natural explanation of why 'actors' behaved in the way they did. So story telling via scenario planning may be a natural way of making sense of the world."
>
> Goodwin and Wright, 2001, p. 2

Scenario planning, also known as scenario analysis or scenario thinking, is a long-term planning strategy that emphasizes flexibility and inventiveness. It is the "process of positing several informed, plausible, and imagined alternative future environments in which decisions about the future may be played out, for the purpose of changing current thinking, improving decision making, enhancing human and organization learning, and improving performance" (Chermack and Lynham, 2002, p. 376). Scenario planning first emerged in the United States after World War II in the military, as a strategy to anticipate enemy maneuvers. In the 1960s, Herman Kahn adjusted scenario planning to businesses and became the country's top futurist. It was not until Pierre Wack introduced scenario planning to the Royal Dutch/Shell corporation, which fortuitously prepared them for the oil price shock of the 1970s, that scenario planning became recognized as a crucial tool to ensure an organization's longevity (Schwartz, 1996; van der Heijden, 2011). Wack and his contemporaries were not interested in predicting the future but rather shaking decision makers out of their reliance on planning exclusively for probabilistic outcomes and into flexible mentalities to navigate the inevitable unpredictability of a complex world (Schwartz, 1996; Jones and Preston, 2011; van der Heijden, 2011).

The foundational theories that support scenario planning are futures theories, organizational learning theories, and systems theories, all of which seek to validate relationships between elements of a system. This means the scenario-building process should reveal networks among stakeholders and interconnectivities among the elements in the scenario's scope (Chermack and Lynham, 2002). These networks open pathways for shared resources and information among the multiple stakeholders and specialists during and after the scenario development process. Since emergency decision making is complex and multifaceted, scenario planning among a multidisciplinary group allows for emergency managers and stakeholders to practice making decisions together that involve consensus and collaboration. This diminishes the likelihood that decisions made under the pressure of an uncertain situation will have been planned in isolation and subject to the biases and limitations of just one person or organization (van der Heijden, 2011; Parlak and others, 2012).

The Scenario Planning Development Process

Though scenario planning lacks the foundational development tools available to decision analysis or statistical forecasting, several common-use frameworks have been developed by practitioners. Generally, scenario planning includes identifying predetermined trends, such as demographics, that will be present in all scenarios. The next and most important step is to identify critical uncertainties, which are plausible but improbable events; for example, an extreme natural hazard. Then, the actions of key players who will be affected by the critical uncertainties will be assessed, and finally, these components are written up in a narrative describing one or more futures (Goodwin and Wright, 2001). The scenario narrative that explores uncertainties is not a forecast (extrapolating current data trends into the future, such as weather conditions) or wild speculation (what if the earth spontaneously exploded?) but exists between those two factors on a spectrum of complexity and uncertainty.

When a plausible future storyline is generated, scenarios can be used for two primary purposes (1) strategy design and (2) analysis of a proposed strategy to select the most optimal option (Goodwin and Wright, 2001). If the scenarios are designed with participation from the intended users, the development and workshopping of scenarios should also help the users understand the causal factors they're exploring, learn from the multiple perspectives of the people around them, and practice collaboration (Riddell and others, 2018). Therefore, the key to success in the scenario planning process is the involvement of decision makers and stakeholders in both the development and the use of the scenario, so that the strategy design and analysis can benefit from a collaborative group that understands the scenario exercise (Goodwin and Wright, 2001;

Chermack and Lynham, 2002; Alcamo and Henrichs, 2008; Carlsen and others, 2012). Preparedness is then intrinsically produced by the planning body from within instead of disseminated top-down from authorities or leadership, and the scenario products are more likely to be relevant to the developers (Davies and others, 2015). This is what makes scenario planning a common tool for hazard preparedness—the anticipation of improbable disasters and collaborative planning with invested stakeholders.

Scenario Types

There are several different categories of scenarios depending on the kind of preparedness required by an organization. For DRR entities, **exploratory scenarios** that are based on historical disasters may be more useful, since DRR practitioners can use historical data of natural hazards to inform how another "big one" may affect an area. This is opposed to "backcasting," which is choosing a future goal (such as a carbon neutral world by 2050) and working backwards on how to get there, or "policy/intervention" scenarios, that play out a policy or intervention action to anticipate potential impacts (Alcamo and Henrichs, 2008; Mahmoud and others, 2009; van Vuuren and others, 2012; van Vliet and Kok, 2015). Scenarios can also be labelled as process oriented (scenario building activities are the goal, not an end product or policy); product oriented (an end product or policy is the goal, regardless of the process); qualitative, quantitative, and both qualitative and quantitative (also referred to as story-simulation or integrated scenarios; Alcamo and Henrichs, 2008; Kok and van Vliet, 2011), and participatory (the input of multiple stakeholders is key to the participatory scenario building process; Alcamo and Henrichs, 2008; van Vuuren and others, 2012). Scale is also important for scenario planning; top-down scenario planning is the use of scenarios to articulate global systems and change, such as global temperature models, whereas bottom-up focuses on a locality's influence or regional system changes (Carlsen and others, 2012; Birkmann and others, 2013).

Alcamo (2008a) categorizes scenarios by the intent of the process into inquiry-driven and strategy-driven scenarios. Inquiry-driven scenarios are model-based, where a researcher or scientist inputs various parameters (like excessive rainfall) into a local model to see what is affected (flooded areas). These are often used for short-term policy decisions and are limited to the size and scope of the scientist's model. Alternatively, strategy-driven scenarios include a high level of collaboration between the scenario designers and stakeholders, include techniques like brainstorming, and can take years to develop. Scientific models are often the foundation of these scenarios, which are then translated for stakeholders so the stakeholders can contribute their unique knowledge and needs to the project. The goal of strategy-driven scenarios is to create a wider viewpoint than usually found in inquiry-driven scenarios, while simultaneously achieving stakeholder buy-in to the conclusions of the scenario. Given the time and scope of strategy-driven scenarios, they may be more expensive, and the scientific community may not consider them rigorous enough because the assumptions and mental models underlying this type of scenario are usually not transparent or reproducible (Alcamo, 2008b; Kosow, 2015). By these definitions, the SAFRR scenarios are exploratory, story-and-simulation, strategy-driven, and participatory, which are referred to as strategy-driven for the rest of this evaluation.

Scenario Quality

There is a small selection of studies that define the characteristics of a quality scenario, though they largely focus on scenarios for businesses or firms. A meta-analysis by Kok and van Vliet (2011) synthesizes the categories for quality scenarios down to relevance, credibility, legitimacy, creativity, and structure, which are summarized in table 1. These characteristics have not been tested, and are not hard rules, but seem to represent a consensus among scenario planning theorists. Kok and van Vliet (2011) also observed that scenario planning using qualitative and quantitative methods indicates an increase in the creativity and structures of the scenario products, compared to scenario planning that was only qualitative or quantitative (Kok and van Vliet, 2011). Finally, to maximize quality in all scenario planning processes, the participation of stakeholders in development increases the chance of stakeholders collaboratively learning and working together, using the scenarios, and implementing the preparedness procedures outlined in the development process (Alcamo, 2008a; van der Heijden, 2011; Carlsen and others, 2012; Riddell and others, 2018).

Table 1. Kok and van Vliet (2011) criteria for scenario quality.

Creativity	The scenario deals with uncertainty and improbability, and a variety of implications of those events.
Structure	Specific to integrated scenarios, there needs to be internal continuity within the narrative and quantitative components of a scenario.
Relevance	How relevant are the scenarios to end users, and are the users' needs addressed?
Credibility	The scenario needs to be plausible and informed by stakeholders and experts.
Legitimacy	The scenarios need to incorporate a wide range of perspectives and ideas, including accessibility to various political stances, beliefs, and values.

Limitations and Drawbacks to Scenario Planning

There are limitations to strategy-driven scenario planning. Tracking decision making in large, complex scenarios is difficult, making the credibility and scientific work difficult to replicate or assess. Scenarios like these often lack measurable outcomes. Of course, the standard pitfalls generally applied to scenario planning also affect strategy-driven scenarios, as stakeholders struggle with perceptions of probability, complexity, and uncertainty.

Scientific Credibility, Traceability, and Consistency

Futures researcher Kosow (2015) identifies traceability and consistency as particular challenges for the strategy-driven scenario planning approach. During strategy-driven scenario construction, the decision-making processes and inputs are not always reproducible or understandable to those outside of the development process. Traceability would provide a full and detailed account of these underlying scenario assumptions, so that any end user can make informed decisions based on the scenario, but that would require detailed documentation of many planning meetings, workshops, and thought processes (Alcamo, 2008b; Kosow, 2015). Also, because of the fundamentally multidisciplinary nature of the planning team, maintaining consistency through multiple models, tools, and participant contributions is difficult. Strategy-driven scenarios are also intended to have multiple functions, targets, and users, which can produce inconsistent products (Kosow, 2015). A lack of traceability and consistency inhibits formal methodology and evaluation, minimizing opportunities for feedback on the scenarios.

Undefined Goals

Many of the goals and definitions outlined in scenario theory involve value statements, such as improved decision making or enhanced human and organization learning (Chermack and Lynham, 2002). These are undefined outcomes that depend on subjective judgements to determine success. Definitions are crucial at every stage of any strategizing process—even in the same small company, there may be different perceptions of goals, visions, values, and missions. Large-scale scenario planning endeavors make it even more difficult to ensure a streamlined, transparent commonality in language and vision (Goodwin and Wright, 2001) and formally evaluate the efficacy of a scenario, given the limited quantifiable goals and outcomes.

Perceptions of Plausibility, Probability, and Uncertainty

The concepts of plausible and improbable are notoriously difficult to convey. Stakeholders may focus more on the potential hazards that are familiar and incorporate their biases on subjective probabilities into the process, ignoring the need to prepare for the unexpected (Oppenheimer and others, 2007). To counter this, many DRR scenario practitioners will rely on historical hazard data to show that the improbable hazards are indeed plausible (van Vuuren and others, 2012). However, historical deterministic scenarios can feel like forecasts to decision makers and may lead to misinterpreting a one-in-a-hundred hazard probability as a prediction that a hazard will occur predictably once every hundred years. Moreover, decision makers may be inclined to focus on whichever narrative appears to be neutral or in the middle as a baseline or probable future and disregard scenarios that explore extremes (Hoffmann, 2017). This is especially salient now that climate change is increasing the severity of disastrous weather events (Smithhisler, 2018). Decision makers will need to understand and anticipate more extreme or unlikely scenarios that do not have a firmly established historical background (Oppenheimer and others, 2007).

Even expert scenario planners can underestimate the true range of uncertainty possible in a complex system (Jones and Preston, 2011). The most complex and well-researched scenario available may not adequately illustrate the impacts of a disaster, and the risk of underestimating uncertainties will increase as global climate change continues to affect our world in unpredictable ways.

Cost in Time and Resources

Ultimately, the success of integrative scenario planning requires flexibility, trust, consensus in recognition of a hazard risk, and the navigation of tensions between practical action and policy, all of which are generally time consuming (Davies and others, 2015). Scenario organizers need to continually revise, refine, and control the scenario development process, and the scenario tools are “only as good as the people who develop or use them” (Hoffman, 2017, p. 214). For many organizations, the process can be prohibitively time and resource intensive, which may limit the participation of crucial stakeholders, thereby undermining the legitimacy and relevancy of the scenario (Young and others, 2019). The scenarios will always be limited to the knowledge, expertise, and influence of those who can afford to participate. Scenario planners may risk underestimating global drivers that they cannot influence, and underexploring components that belong to sectors not represented by the planning group (Carlsen and others, 2012). Similarly, if the scenario focuses on producing a document for the sake of traceability for absent stakeholders, those stakeholders still may not have the time or technical expertise to sort through a long, dense report and will miss crucial information (Kosow, 2015). A focus on accessibility of information, sharing or providing resources, and strict attention to timelines and project management could mitigate this barrier for some stakeholders.

Introduction to the Science Application for Risk Reduction Scenarios

The Science Application for Risk Reduction (SAFRR) project, formerly the Multi-Hazards Demonstration Project (MHDP), and before that UrbanEarth (see app. 2), created four scenarios to address hazard risk in California and surrounding areas. ShakeOut, ARkStorm, Tsunami Scenario, and HayWired are strategy-driven scenarios designed to facilitate the creation and workshopping of science-based preparedness strategies. The goal of the scenarios is to innovate the use of science in DRR and change the cultures of preparedness for hazards.

ShakeOut Earthquake Scenario—A Magnitude 7.8 Earthquake on the San Andreas Fault

Building the ShakeOut scenario was initially inspired by conversations with emergency responders in California at the 100th Anniversary Earthquake Conference, held on the 100-year anniversary of the 1906 San Francisco Earthquake. Emergency managers requested a hazard scenario for the purpose of planning and practice, so from 2006–08, a team of scientists and local, State, and Federal stakeholders partnered with the MHDP and constructed an earthquake narrative (Becker, 2009). The San Andreas Fault was chosen because it is one of the most studied faults in the country, with an enormous wealth of existing data for the simulation modelling. The southern San Andreas Fault has generated magnitude 7.8 earthquakes on average every 150 years, making the scenario a plausible event (Jones and others, 2008).

From the beginning, MHDP engaged stakeholders around Southern California, including representatives from major lifeline industries. The scenario team included earth scientists, social scientists, economists, engineers, lifeline specialists, and emergency management officials, totaling 14 primary authors and 310 contributors (Jones and others, 2008). The authors and contributors participated in panels where the earthquake primary damages were described, and the potential effects on lifelines and infrastructure were then deliberated by industry representatives, engineers, and scientists. The panels developed several of the 20 studies that went into building the ShakeOut scenario, some of which were published in the May 2011 "Earthquake Spectra" journal's "2008 Great Southern California ShakeOut Special Issue" (Porter and Sherrill, 2011).

In May 2008, "The ShakeOut Scenario: U.S. Geological Survey Open-File Report 2008–1150 and California Geological Survey Preliminary Report 25" (Jones and others, 2008) was published alongside "The ShakeOut Earthquake Scenario—A Story that Southern Californians are Writing: U.S. Geological Survey Circular 1324" (Perry and others, 2008). The circular is a more readable report that focused on the story of the scenario, with day-by-day descriptions of damages and response. An additional four Open-File Reports (OFR) expanded the analysis of damages to small businesses, labor markets, and how the earthquake would affect regional population changes:

- "Potential Effects of a Scenario Earthquake on the Economy of Southern California: Intraregional Commuter, Worker, and Earnings Flow Analysis" (Sherrouse and Hester, 2008a)
- "Potential Effects of a Scenario Earthquake on the Economy of Southern California: Baseline County-Level Migration Characteristics and Trends 1995–2000 and 2001–2010" (Sherrouse and Hester, 2008b)
- "Potential Effects of a Scenario Earthquake on the Economy of Southern California: Small Business Exposure and Sensitivity Analysis to a Magnitude 7.8 Earthquake" (Sherrouse and others, 2008a)
- "Potential Effects of a Scenario Earthquake on the Economy of Southern California: Labor Market Exposure and Sensitivity Analysis to a Magnitude 7.8 Earthquake" (Sherrouse and others, 2008b)

Over the course of 2008, thirteen more supplemental studies (accessible at https://www.usgs.gov/programs/science-application-for-risk-reduction/science/shakeout-earthquake-scenario) were produced that cover the following topics (USGS, 2018):

- Older reinforced concrete buildings
- Elevators
- Fire following earthquake
- Hazardous materials
- HAZUS (a natural hazard analysis tool developed by FEMA)
- Hospitals
- Oil and gas pipelines
- Railway network
- High-rise steel buildings
- Analysis of risk to southern California highway system
- Telecommunications
- Unreinforced masonry (URM) buildings
- Woodframe buildings

The project also produced a video called "Preparedness Now" about the scenario (USGS, 2008). The ShakeOut scenario rollout events were in November 2008 and included the first "Great California ShakeOut," a drill for practicing the earthquake safety behavior "drop, cover, and hold on," along with: California's Golden Guardian week-long emergency exercise; a conference; street fair; earthquake preparedness games; and an outreach initiative to encourage participants in the ShakeOut events to "take one more step" in earthquake preparedness (Becker, 2009, p. 13). The Great ShakeOut drill is now an annual global exercise. For more information on the development and use of ShakeOut, see appendix 2.

Previous Evaluations and Studies on ShakeOut

New Zealand held its first nationwide ShakeOut drill on September 26, 2012. Over 1.3 million people registered through the New Zealand ShakeOut website. An evaluation of the event by McBride and others (2014) used a survey method that invited respondents to observe how their business, school, or household participated in the ShakeOut drill, with over 5,000 surveys completed. Three of the same researchers performed a follow-up evaluation the following year in 2015, sending another survey to a random sample of 5,000 people who had signed up on the ShakeOut website to investigate the longer-term effect of the drill (Becker and others, 2017). Respondents answered questions about whether the people around them actually practiced "drop, cover, and hold on" and for how long. McBride and others (2014) initial survey found that more than 60 percent of respondents participated in the drill and that most heard about ShakeOut through their workplace or school. For those who were reluctant to participate, embarrassment seemed to be a factor. The follow-up survey revealed that ShakeOut participation stimulated other preparedness activities, including increasing preparedness actions at home by 51 percent and at work by 40 percent, a 32 percent increase in developing an emergency plan at home or work, a 29 percent increase in people undertaking an emergency exercise, and a 27 percent increase in participating in earthquake-related meetings. A total of 64 percent of respondents also sought out further information on earthquakes prompted by ShakeOut participation (Becker and others, 2017).

An evaluation framework was created in 2014 for research in two Washington State school districts, evaluating how the ShakeOut drill resulted in children's learning and adaptive response. The study found that through ShakeOut, most children had a strong base of knowledge for the correct indoor behavior in an earthquake, though fewer children knew what to do if they were outside. The study recognized that their findings could not determine if the ShakeOut drill would reduce injuries in the event of an earthquake (Johnson and others, 2014).

In 2020, another evaluation of the New Zealand ShakeOut drill was performed, using another survey to investigate respondents' attitudes about earthquake preparedness as well as behaviors. This study corroborated earlier findings by the previous evaluations; people who participated in the Great New Zealand ShakeOut were more likely to know the correct actions in the event of earthquakes and were more likely to perform other preparedness behaviors around the drill, such as creating a home emergency plan. This study also found ShakeOut participants to be less fatalistic and more realistic about earthquakes and were more optimistic about themselves and their homes surviving earthquakes (Vinnell and others, 2020).

Tanes and Cho (2013) evaluated the effectiveness of the ShakeOut game "Beat the Quake" and found that playing the game led to higher levels of preparedness knowledge and perceptions of self-efficacy and responsibility for preparedness. The efficacy of the game was corroborated by another survey of ShakeOut participants in California, which also analyzed the people who participated in the drill (Adams and others, 2017).

ARkStorm—Winter Storms Fueled by an Atmospheric River—23 Days of Rain Floods the Central Valley, California

Earthquakes have been considered California's most dangerous and costly hazard, partially because many Californians have experienced a large earthquake in their lifetimes. However, extreme winter storms and flooding can pose a more expensive and dangerous threat to the region. California has a history of extreme flood events caused by storms that only recently have been revealed to be fueled by **atmospheric rivers** (Cox and Jones, 2010). Wanting to maintain the connections and momentum from the ShakeOut scenario, the SAFRR team (then still known as MHDP) began planning a winter storm scenario to raise awareness and support preparedness for California's other "big one" in 2008 (Porter and others, 2011).

Inspired by the extreme winter storms and flooding of 1861–62, the scenario's winter storm was created by stitching together storm data from January 1969 and February 1986. The source scientists then factored in an unusually rainy autumn to set up a situation where the water tables of the area and aquifers would be reaching capacity (Cox and Jones, 2010). Models indicated that the subsequent 500–1,000-year flood would overwhelm the State's 100–200-year flood protection infrastructure and subsequently flood the Central Valley, several counties, riparian areas, and some coastal communities. This led to the name ARkStorm, where "AR" stands for "Atmospheric River" and "k" stands for "1,000" representing the 500–1,000-year storm recurrence probability (Porter and others, 2011).

From 2008 to 2010, primary authors (39) and collaborators (80) developed estimates of the flooding, landslides, and coastal inundation, and estimated the subsequent damages to lifelines and flood protection infrastructure along with agricultural and economic losses. The team also modelled evacuation needs and costs, costs to building damage and insurance claims, and environmental and health issues (Porter and others, 2011). On January 13, 2011, the Porter and others OFR titled "Overview of the ARkStorm Scenario: U.S. Geological Survey Open-File Report 2010-1312" was published, coinciding with the ARkStorm Summit, a two day invitation-only conference with key stakeholders from across the State to introduce the ARkStorm findings. A video was also produced for the project and called “This is ARkStorm” (USGS, 2011). Part of the ARkStorm project involved the development of CoSMoS, the Coastal Storm Modelling System, a dynamic model of storm-induced coastal flooding, erosion, and cliff failures. CoSMoS has since grown into an independent USGS program centered at the Pacific Coastal and Marine Science Center (Barnard and Erikson, 2021).

Recognizing the effects of ARkStorm were overwhelming to tackle on a statewide scale. Scenario planners downscaled the scenario for two separate exercises in Ventura County and the Lake Tahoe region, called ARkStorm II and ARkStorm@Tahoe, respectively (McKenna, 2011; Hosseinipour and others, 2013; Albano and others, 2014). For more information on ARkStorm’s development and use, see appendix 2.

Tsunami Scenario—Offshore Alaskan Earthquake Causes Tsunami Inundation of U.S. West Coast

Through the connections made as participants in ShakeOut and ARkStorm, representatives from the Ports of Los Angeles and Long Beach began talking to SAFRR leadership about what kind of damage a tsunami could do to the ports and surrounding infrastructure. This coincided with the 2007 publication “Increasing Resiliency to Natural Hazards: A Strategic Plan for the Multi-Hazards Demonstration Project in Southern California,” in which the authors included assessing offshore earthquake tsunami hazards as a goal, working from the existing USGS research on offshore geologic faults, landslides, and global seismic data (Jones and others, 2007). Tsunamis in California have a historical precedent—the 1946 and 1964 Alaska earthquakes and the 1700 Cascadia earthquake caused tsunami inundation at different points of the California coast (Ross and others, 2013a). For these reasons, the scenario organizers began organizing a tsunami scenario as ARkStorm was approaching publication. By this time (2011), the project had evolved from the MHDP into SAFRR.

After the devastating March 11, 2011, Tōhoku earthquake and subsequent tsunami, the Tsunami Scenario source modelers chose to increase the magnitude and change the location of the source earthquake to provide an exercise that would help prepare stakeholders for a similarly unanticipated event. The economic importance of the Ports of Long Beach and Los Angeles (and their requests as primary project partners) drove the decision to position the source so that the tsunami would create particularly damaging inundation for that region, though the scenario was expanded to investigate affects along the entire west coast of the United States (Ross and Jones, 2013). The scenario was set on March 27, 2014, coinciding with the 50th anniversary of the 1964 Alaska earthquake and tsunami, and was a joint effort between 61 authors and 174 contributors over 3 years (Ross and Jones, 2013).

This scenario, learning from ARkStorm’s successes at targeting specific stakeholders and regions, was aimed at emergency managers, business continuity planners, maritime managers, land use planners, corporate real estate managers, and elected officials associated with California’s coastline. Project leaders from the State of California held over 90 panels, workshops, and information sessions with key coastline stakeholders, and the scenario was used to review California’s tsunami policy through the California Geological Survey (CGS; CGS, 2021a) and the California Office of Emergency Services (Cal OES; Ross and Jones, 2013). Three information products were published on September 3, 2013

- “The SAFRR (Science Application for Risk Reduction) Tsunami Scenario” OFR 2013-1170 (Ross and Jones, 2013),
- “Tsunami Propagation Movie” (Lynett, 2013), and
- “The SAFRR Tsunami Scenario—Improving Resilience for California” Fact Sheet 2013–3081 (Ross and others, 2013b).

These publications were followed by workshops in Los Angeles, Santa Barbara, San Diego, Santa Cruz, and San Francisco, where scientists and engineers from the scenario development teams directly communicated the scientific results to key stakeholders (Ross and Jones, 2013; USGS, 2013). In 2014, the Art Center College of Design collaborated with SAFRR to create a tsunami public service announcement, which was released February 25, 2014 (Sandoval, 2014). For more information on the development and use of the Tsunami Scenario, see appendix 2.

HayWired—A 7.0 magnitude earthquake on the Hayward Fault

With major earthquakes every 100–220 years, the Hayward Fault is among the most active and urbanized fault lines in the United States, running 74 miles along the east side of the San Francisco Bay area. For this reason, SAFRR scenario planners chose it as the source for another earthquake scenario (Detweiler and Wein, 2017). Scenario developers wanted to focus particularly on the effects of telecommunications, as society’s increasing reliance on cell phones and the internet has changed the face of hazard impacts, response, and recovery. The scenario development officially kicked off November 2013, with the name “HayWired” to emphasize the interconnectedness of the region’s telecommunications and electric lifeline infrastructures, and the challenge of responding to earthquake impacts if those infrastructures are damaged (Hudnut and others, 2017).

SAFRR had been working with stakeholders in the San Francisco Bay region since the beginning of HayWired’s development, but in 2017, SAFRR leadership organized stakeholders in the HayWired Coalition, a group of over 50 organizations working together to communicate HayWired’s findings in their own communities. California's Business, Consumer Services, and Housing Agency (BCSH) also created an awareness and resilience campaign called the "HayWired Outsmart Disaster Campaign," which was targeted at small- and medium-sized businesses to support their preparedness efforts (Hudnut and others, 2018). Outsmart Disaster has since grown to be a multi-hazard initiative that spans California.

To create opportunities for rigorous review and continued stakeholder engagement as the scenario developed, project organizers chose to release the HayWired report in volumes. HayWired Volume 1, "The HayWired Earthquake Scenario—Earthquake Hazards," was published April 24, 2017 (Detweiler and Wein, 2018a). HayWired Volume 2 "The HayWired Earthquake Scenario—Engineering Implications" was published on the anniversary of the 1906 San Francisco Earthquake, April 18, 2018, along with "The HayWired Earthquake Scenario—We Can Outsmart Disaster" Fact Sheet 2018-3016 (Detweiler and Wein, 2018b and Hudnut and others, 2018, respectively). These publications coincided with a rollout event that included a media tour of the Berkeley stadium, which is bisected by the Hayward Faultline and has been extensively retrofitted for earthquake resilience, and the debut of the "Get Ready! HayWired" informational video (Cox and Cascio, 2018; PEER, 2018; USGS, 2018). Chapters from HayWired Volume 3 "The HayWired Earthquake Scenario—Societal Consequences" were published beginning October 18, 2019 (Detweiler and Wein, 2019; USGS, 2018), and the chapter on telecommunications was in review at the time of this publication. For more information on HayWired's development and use, see appendix 2.

Evaluation Methods

The SAFRR scenarios are not small projects. Involving hundreds of authors, collaborators, and stakeholders, the scenarios are an ambitious foray into a multidisciplinary endeavor with a singular overarching mission: to innovate the use of science in DRR. After a decade of scenario development and use, dozens of products, and millions of people engaged, has SAFRR accomplished this mission? To answer this question, this evaluation will attempt to explore how the scenarios have been used, what risk reduction actions have resulted from that use, and what are some lessons learned from the scenario planning process.

The SAFRR scenarios, and other scenarios of the same scope and magnitude, do not have a formal process for evaluating success. This evaluation developed a logic model to organize the processes and goals of scenario planning projects. The logic model facilitated the development of an evaluation tool to assess how the scenarios approached different processes and goals. This project is a descriptive evaluation and does not formally address the effects of the scenarios. The evaluation is limited to observations of how the scenarios were developed, were applied, and evolved over time. Causal claims or value judgements about how the scenarios have affected the world of hazard management cannot be inferred from the results. However, this report includes evidence of affects through qualitative interviews and research and discusses some of the implications of that evidence.

Logic Model

A logic model is a common tool for project designers and evaluators to represent the relationships between the inputs, processes, outputs, short-term outcomes, long-term outcomes, and effects of a program, as shown in figure 4. Evaluations assess the relationships among these components. For example, an outcome evaluation is an assessment of whether the outputs result in the intended outcomes.

Because this evaluation covers all four scenarios, a logic model built from the overarching mission statement of the SAFRR program is used to construct the project goals,

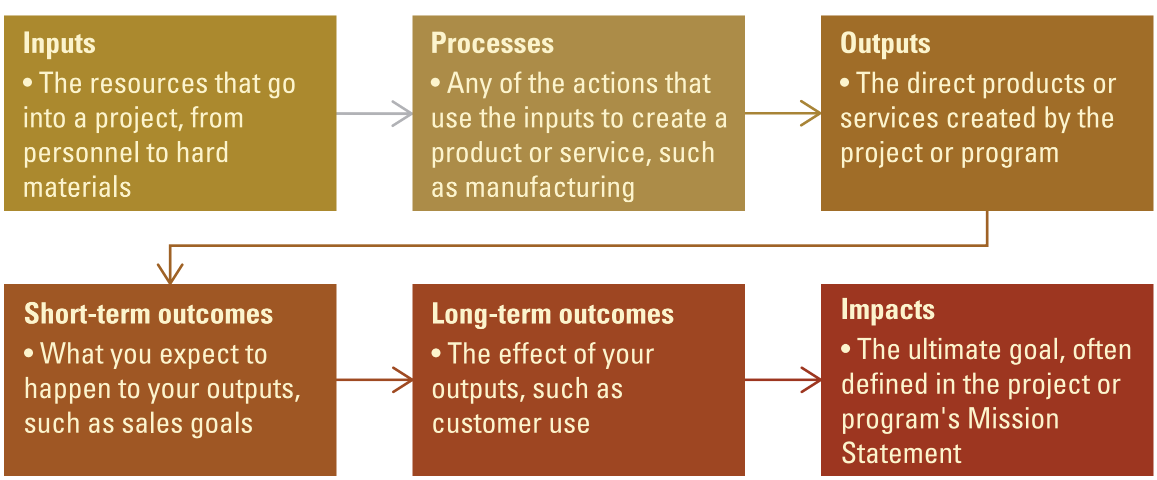

Figure 4. The layout of a general logic model with brief examples of the components.

The Science Application for Risk Reduction (SAFRR) Mission Statement

The mission of SAFRR is to innovate the application of science to reduce the risk of natural hazards for the safety, security, and economic well-being of the Nation (SAFRR, 2018).

instead of an individual scenario's project mission statement. However, this project only addresses the SAFRR scenarios; it does not address SAFRR as a program.

SAFRR's mission statement includes three main components: to innovate DRR science, to facilitate the use of science in DRR, and to reduce risk. These components were used to create a list of outcomes, which were combined with the expected outcomes of scenario planning theory: increased stakeholder knowledge of the hazard, application of the scenario for planning and response exercises, and increased communication among stakeholder networks. Using the logic model developed for the Tsunami Scenario as a template (Ross and others, 2013a), the evaluation team added and organized these outcomes and inserted scenario theory into the activities section to guide the organization of inputs to outputs and outcomes.

For this evaluation, the inputs are limited to the information used to build the scenario narratives. Inputs such as personnel and funding are not factored into this evaluation. Processes are limited to scenario planning activities, and thus many of the operational activities of project management are excluded. While a traditional logic model is a linear model, and the following SAFRR scenario logic model in figure 5 is represented as such, the strategy-driven scenario process has a cyclical feedback nature. Scenario planning processes create and refine information that gets fed back into the project as inputs. For example, workshops on how damaged water mains will affect firefighting after an earthquake reveal vulnerabilities that then become inputs for the subsequent impact data. Further, the processes of stakeholder engagement and collaboration creates outcomes independent of the outputs, such as stakeholders forming networks and feeling ownership of the scenario products because of their participation in developing the products. The logic model in figure 5 was developed in conjunction with a more detailed version, shown in table 1.1, used to isolate connections between the different components.

The Research Questions

The evaluation questions were designed to explore how the scenarios meet the SAFRR project's mission statement and lead to the outcomes defined in the logic model shown in figure 5. The three evaluation questions are as follows:

- Research Question 1 (RQ1)
  - o What are the barriers and enablers to developing and deploying the SAFRR scenarios?
- Research Question 2 (RQ2)
  - o Have the SAFRR scenarios changed Cultures of Preparedness for disasters?
- Research Question 3 (RQ3)
  - o Have SAFRR scenarios stimulated the development of new technologies or innovations for disaster response preparedness?

RQ1: What are the Barriers and Enablers to Developing and Deploying the SAFRR Scenarios?

This research question addresses factors that have helped or hindered the scenario projects. Understanding the processes of development and use will help inform future scenario planning work, as well as explore the scenarios as platforms for science communication and use. The terms for RQ1 are defined below. Data used to address RQ1 will include previous evaluations and studies, as well as qualitative interviews.

- **Barriers:** The social, institutional, physical, or intellectual obstacles that affect the ability to access, design, or use the SAFRR scenarios.
- **Enablers:** The social, institutional, physical, or intellectual supporting factors that affect the ability to access, design, or use the SAFRR scenarios.
- **Developing:** Any activity involved in the scenario planning process, including providing expert opinions; building scientific models or tools to support the narrative; workshopping the narrative, model, or tool usability; using the scenario to create a drill or disaster plan; writing the scenario methods and reports; or other forms of collaboration.
- **Deploying:** Any form of use of the scenarios, including publishing and distribution to an audience; use in a model; revision and adaptation to appeal to a specific audience; and end use as a participant in a drill or exercise based on the scenarios.

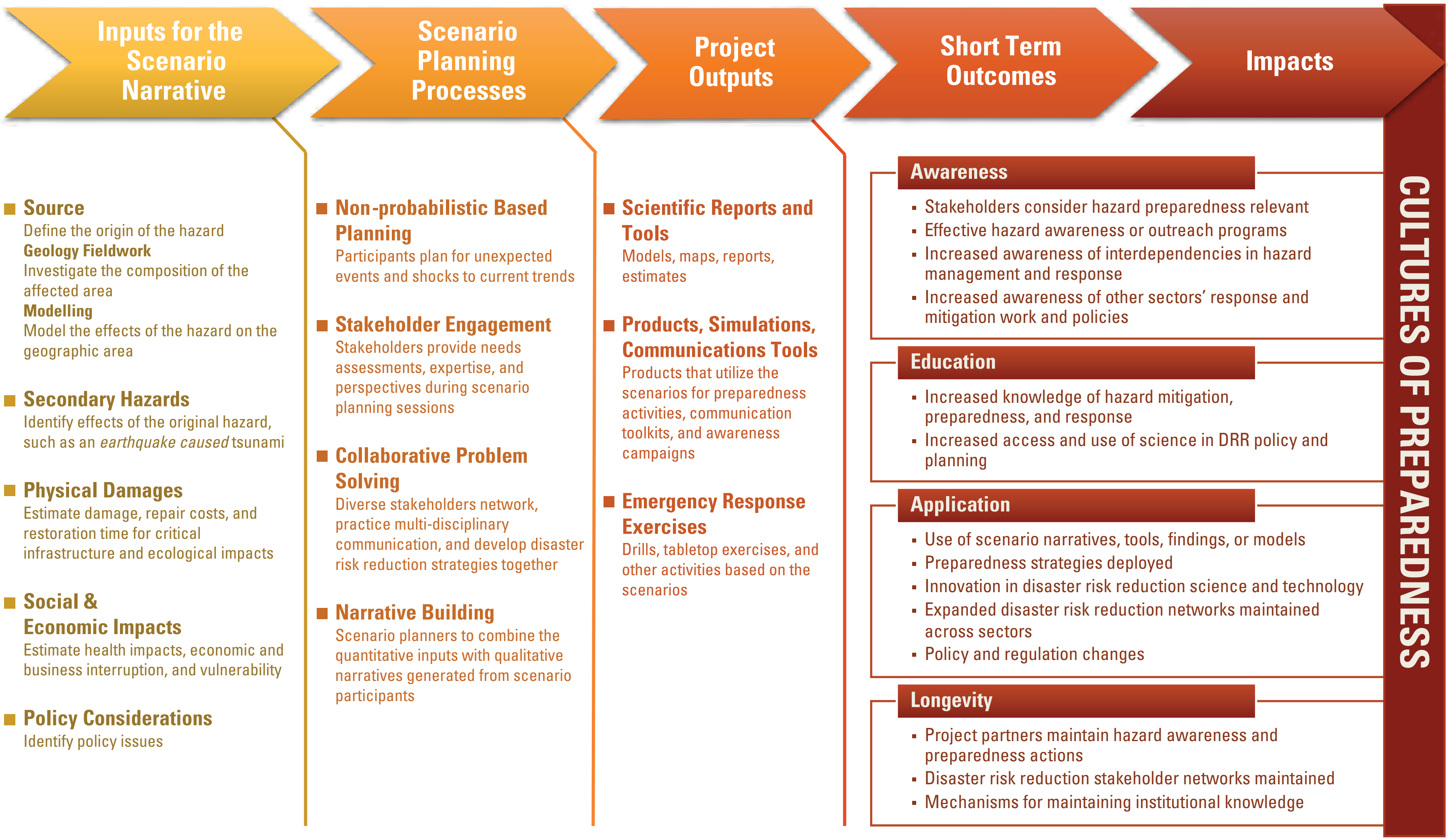

Figure 5. The logic model for the Science Application for Risk Reduction (SAFRR) scenario evaluation. (DDR, disaster risk reduction)

Cultures of Preparedness

Groups united by vulnerability to one or more hazards, sharing risk and common knowledge, norms, and communications that guide the conceptualization and behavior of preparedness.

RQ2: Have the SAFRR Scenarios Changed the Culture of Preparedness for Disasters?

The second research question explores how the scenarios interact with different groups affected by the hazards addressed in the scenarios. Data collection was designed to identify changes in group knowledge, norms, or behaviors in disaster preparedness, specifically in the form of the intended outcomes listed in the SAFRR evaluation logic model in figure 5. It should be noted that identifying a change in a culture of preparedness does not necessarily equate to a reduction in risk. The changes may be neutral or negative.

To explore changes in a variety of cultures, examples of scenario use are collected through qualitative interviews, online searches for scenario exercises, presentations, and other activities, such as use in news media and academic papers. Forms of use that contribute to the outcomes defined in the SAFRR scenario logic model (fig. 5) are presented as evidence for a change in a culture of preparedness.

RQ3: Have SAFRR Scenarios Stimulated the Development of New technologies or innovations for disaster response preparedness?

The final piece of the SAFRR mission statement is to foster innovation in DRR science. Innovation is any new or significantly improved concept, tool, or process that is implemented (OECD, 2018). Many papers working on the definition, measurement, or analysis of innovation address the use of the subjective term "significantly." There seems to be a consensus that the inclusion of "significantly" is useful to illustrate the difference between innovative improvements and standard improvements. Implementation is the important criteria that separates invention from innovation. Of course, there is subjectivity involved in determining whether a product or process is truly new or significantly improved. Is it still innovation if it is new to the organization but not to the world? What constitutes significantly improved? Innovations can also be radical or incremental, depending on whether the innovation has a higher or lower degree of impact (Janger and others, 2017).

Problem 1. What are the Novelty Thresholds of New and Significantly Improved Processes, Products, or Tools Specific to Public Sector Projects?

Consistency is key to answering this question. It is most important for the organization in question to have a method of determining innovation for their own purposes, so it is not necessarily a problem if one organization recognizes innovation as new-to-organization whereas another classifies it as new-to-market (Galindo-Rueda and Van Cruysen, 2016). For the purposes of this evaluation, new-to-organization is considered innovation because the scenarios are public projects designed to reach multiple levels of organizations and sectors to change or improve DRR processes. For example, new policy in one region is considered innovative, even if similar policy initiatives have been adopted elsewhere (Demircioglu, 2017).

Problem 2. What Constitutes Use or Implementation if a Process, Product, or Tool Must Be Both New and Implemented?

Quantifying implementation is complex for innovations in service, systems, or concepts, as measurement instruments cannot rely on easily quantified data, such as product sales, to estimate the number of users that have adopted an innovative concept (Janger and others, 2017). Is it implemented if one person adopts the innovation, or if the outcome only makes slight changes among a small group? For the purposes of this evaluation, implementation is defined as widespread adoption of an innovation within an organization, widespread use of the innovation within a group, or using of the scenario models or concepts as a foundation for new science or conclusions.

Examples of innovation are collected through assessing academic mentions for use of the scenario to create innovative work, reports of innovations from interviewees, and reports of innovations from the scenario OFRs. The examples of innovation from the SAFRR scenarios documented in this report will be divided into two categories, development or use, as illustrated in figure 6, to organize the varying forms of innovation recorded. Development innovations are split into SAFRR project inputs and outputs, to differentiate between innovation science and processes used to create the scenarios, and the scenario products. Since the SAFRR scenarios are public projects intended for use in multiple sectors, the use innovations will be categorized via Gault's list (Gault, 2018, p. 620) of public project innovations, which are any new or significantly improved aspect of service; service delivery; administrative or organizational structure; and conceptual, policy, or systemic innovation. This evaluation will leave many of the subjective assessments, such as scope, radical versus incremental, and importance of the innovation, to the discretion of future researchers.

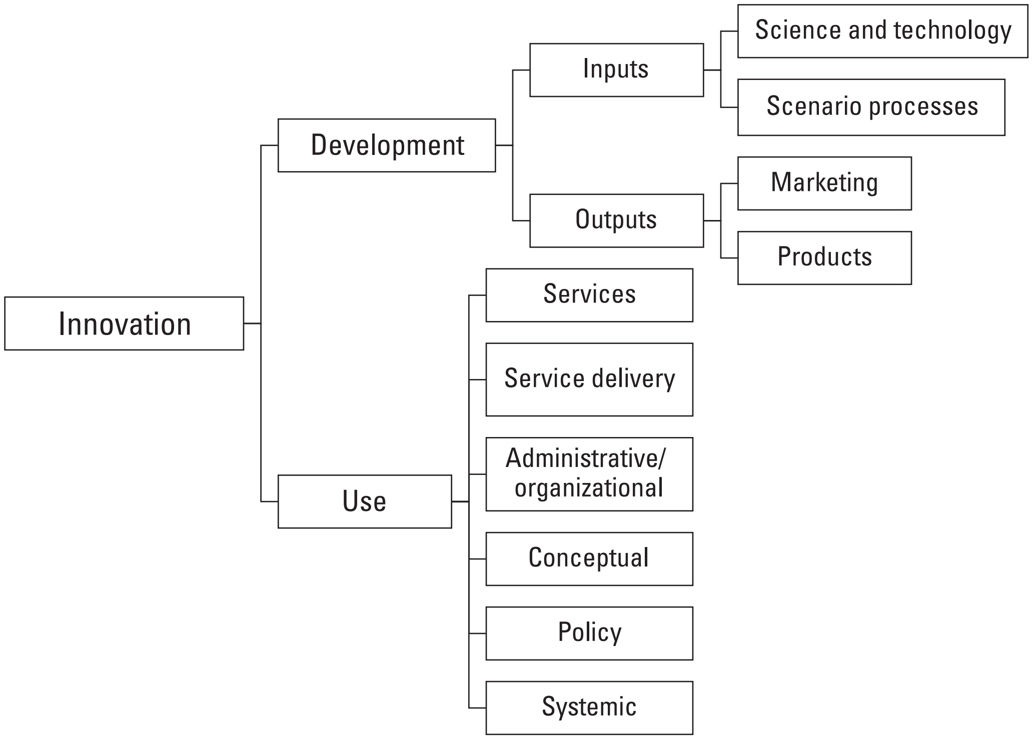

Figure 6. The multiple categories and subcategories of innovation used in the Science Application for Risk Reduction Scenario Retrospective.

Data Collection Methods

The following sections detail the development of an evaluation tool to formalize the assessment of the scenarios and the methods for collecting primary and secondary data.

Primary Data Collection—Qualitative Interviewing

Qualitative interviewing was chosen as a method to collect primary data from the scenario participants. The intention is to gain a deeper understanding of how perspectives about these scenarios differ among practitioners from different sectors, as well as to explore the individual experiences with the development, use, and innovations of these scenarios.

Constructing the Interview Protocol

The interview protocol opens with an explanation of the project and disclaimers about participant anonymity. The next questions ask how and when the subject got involved in the scenarios to orient the interviewees from the beginning of their experiences. The subsequent questions explore factors that helped and hindered the interviewees' development or deployment experiences and any solutions they implemented. The interview process followed an outline for consistency, as shown below:

- Introduction
- Greetings and getting started
- Scenario role identification
  - o How did the subject get involved?
  - o Expand on their role in scenario planning
  - o Establish use and (or) development
  - o Form and extent of use and (or) development
- Barriers and enablers
  - o Define barriers and enablers
  - o What barriers or enablers affected the subject?
  - o What solutions solved mitigated the barriers?
  - o Explore extent of difficulty barriers created and helpfulness that enablers provided
- Preparedness
  - o How the subject has seen the scenarios being used
  - o Preparedness indicators

  - o Disaster risk reduction network and community pathways
  - o Lifeline panel suggestions for sector-specific groups
  - o Extent of scenario use in different disaster risk reduction fields
- Innovation and new technology
  - o Introduce innovation as an extension of use
  - o Define innovation: new and implemented
  - o Expand on previous examples of use
  - o Ask about the subject's own work is appropriate (authors that designed models/scientific processes)
- Request for follow-up

Addressing how the scenarios have been used for preparedness required some consideration to how interview partners would interpret the concept of preparedness. Participants were asked about any way they may have used the scenarios to collect a general array of responses that the interviewer could assess later. Open-ended questions about preparedness indicators (such as expanded DRR networks) were also used. Innovation was considered an extension of use and uses, as well as development, and sometimes came up when interview partners were discussing how they overcame barriers in scenario planning. The interviewer also asked about any innovations or new or improved products or processes that resulted from these scenarios if interviewees were unsure what to classify as innovations.

Interviewee Selection

Interviewee selection for this qualitative study was purposive. The interviewer selected subjects that were most able to give in-depth, knowledgeable responses to inform the research questions, known as information-oriented selection (Sargeant, 2012; Brinkmann, 2013). Potential interviewees were chosen to represent a variety of positions in a range of sectors—government agencies and offices, lifeline industry representatives, and private partnerships—to maximize the potential of capturing multiple perspectives from the developers and users who have different needs and pressures. Scenario participants and users are defined as follows:

- Developers—Primary authors credited by the scenario publications and key stakeholders who were part of the scenario design process. Developers can overlap with users. Because strategy-driven scenarios are developed by their intended user base, many developers are expected to also use the scenarios;
- Contributors—Collaborators and expert consultants are credited as contributors in the scenario publications. They provided data or insight but did not take part in designing the scenario products; and
- Users—Organizers or intermediaries that take the scenarios and apply them to their community, or end users, such as students performing an earthquake drill based on the scenarios.

The potential interviewees were selected from a list of all the authors and contributors credited in the scenario reports. Individuals that were involved in multiple scenarios were selected first for their potential to provide longer-term perspectives on scenario use and development. Other individuals were selected to provide a range of sectors and roles. Because the list of developers and contributors includes the target users for these scenarios, this method provided user as well as developer perspectives. Other users were found through research or were suggested by interviewed developers. These users were then vetted for sector and scenario and added to the list of potential interviewees. The final selection of potential interviewees was diverse but not representative of the larger population of SAFRR scenario developers, contributors, and users.

Interview requests were emailed to potential interviewees and included a brief project description (see figure 1.1). Beginning in February 2020 and ending February 2021, one team member conducted all the interviews using telephone or video conferencing platforms. After 20 interviews, the study reached a level of data saturation, as the information gathered became repetitive enough to not perform any further interviews. Table 2 shows the interviewees' sectors and the scenarios they engaged with, as well as their role as developer, contributor, user, or combination. Throughout this process, all names were kept anonymous.

The interviews with people in any given sector are not necessarily generalizable to represent all people within that sector, but they do provide evidence of how people with different specializations and experiences interact with these scenarios. Since the interviews were intended to be conducted remotely, the Covid-19 pandemic did not interrupt the research design. However, the Covid-19 pandemic did create additional strains on the time and energy of emergency managers, hazard scientists, government officials, and essential workers, many of whom were our intended interview subjects. One sector that is underrepresented in the interviewees is emergency responders and emergency managers, due to the pandemic and the large, ongoing forest fires in California at the time of the interview process.

Coding the Interviews

The interviews were transcribed by a professional transcription service, Landmark Associates Inc. The interviewer then coded the transcripts using the qualitative data coding software NVivo (2020). The transcripts were

Table 2. Interviewees by sector and which scenario(s) they were involved in to explore the presence of four hazard scenarios in cultures of preparedness and their role in disaster risk reduction as part of data gathering for the U.S. Geological Survey Science Application for Risk Reduction (SAFRR) Project.

[The scenarios are marked by colors that correspond to their branding. SO, ShakeOut (yellow); AS, ARkStorm (blue); TS, Tsunami Scenario (gray); HW, HayWired (red); C, Contributor; D, Developer; U, User]

Scale	Sector	Scenario				Total number of scenarios experienced
		SO	AS	TS	HW	
Federal	Government	C				1
Federal	Government	C	C			2
Federal	Government					1
Federal	Government	D	D	D	DU	4
Federal	Government					1
Federal	Government	DU	DU	C	DU	4
Federal	Government			DU		1
Federal	Government	D				1
Federal	Government	DU		D		2
Federal	Government			DU		1
International	Private				DU	1
National	Private	DU	D	D	DU	4
State	Government			DU		1
State	Government			U	CU	2
State	Lifeline	U	U		C	3
State	Lifeline	CU	CU		CU	3
State	Lifeline	DU	DU			2
State	Lifeline		CU		CU	2
State	Academic	DU			CU	2
State	Private				CU	1
Total from each scenario		**11**	**10**	**8**	**10**	**39**

then reviewed by another evaluation team member to provide intercoder reliability for how interviewee perspectives were interpreted. The coding choices were discussed between the two evaluators with the intent to limit bias on the part of the interviewer. Theoretical codes derived from scenario planning and DRR literature and codes based on the research questions were used for the initial coding, with titles such as “Barriers” and “Enablers” as top-level codes, and “Stakeholder Engagement” as a subcode of “Enablers.” The interviews were analyzed using grounded theory, and codes were continually added, grouped, and regrouped as emerging themes and concepts were used to develop the theoretical framework of the study (Corbin and Strauss, 1990). As an example, many developers discussed the fact that deadlines were a barrier to fully developing the precise, foundational science of the scenarios; therefore, a code titled “Deadlines” was placed under “Barriers.” However, other collaborators and users listed the sequential process of scenario development (each section’s data are dependent on the section before it) as a barrier, because any failures to meet deadlines in the early sections compounded delays for the later sections. “Deadlines” was then shifted out of “Barriers” to its own top-level code, and the conversations around deadlines revealed a delicate balance between the need for more time to complete complex science and modelling and the need to produce content in a time-sensitive manner because of the schedules and time constraints of other developers and users.

All interviews were recoded and reviewed multiple times. The codebook that was developed over the course of this process is available in table 1.1. Insights into the relationships between the codes were recorded in memos through the NVivo program.

Developing the Structure for Analysis and Evaluation

Overarching themes about what interviewees valued in a scenario or what made the scenarios useful and usable emerged from characteristics within the code groups. Discussing the barriers and enablers of developing and deploying the scenarios was a means to discover how the scenarios achieved (or failed to achieve) the intended outcomes, shown in figure 5. Although Kok and van Vliet's criteria (Kok and van Vliet, 2011) for effective scenarios (creativity, structure, legitimacy, relevance, and credibility, as described in the Literature Review section on Scenario Quality) is comprehensive for many kinds of scenarios, the fact that the SAFRR scenarios are intended for such a wide range of regional hazard preparedness and disaster risk reduction activities creates a need to expand those criteria.

For example, developers and users both expressed the need for usable products from the scenarios, and for the scenarios to dictate feasible preparedness actions. Codes such as "tools," "drills and exercises," and "accessible actions" were grouped into a concept titled "Actionable." Actionable encompasses the need for the scenarios to have instructions, tools, drills, workshops, exercises, and other preparedness activities that are accessible and tailored to different stakeholder groups. Continued use of the scenarios for hazard preparedness and awareness is categorized as "longitudinal" by the evaluation team, as interviewees discussed the value of mechanisms for continued hazard awareness and follow-through with preparedness activities after the scenario project timeline was finished. To be useful for hazard preparedness, the scenarios need to provide awareness and information about the science and best practices of hazard management, meaning the scenarios need to be educational. Kok and van Vliet's criteria (Kok and van Vliet, 2011) legitimacy, credibility, and structure emerged through the interviews as components that supported a relevant theme for both the developers and users that were interviewed, and the concept of creativity supported a theme that the scenarios need to be thorough in their analysis of multiple downstream hazard impacts through multiple perspectives. Overall, the research and interview analysis revealed five overarching themes—actionable, longitudinal, educational, relevant, and thorough (ALERT)—that served as enablers for the development and use of the scenarios, ultimately supporting the intended outcomes. These themes became the foundation for the analysis and organization of the evaluation tool created for this project, described in the "Actionable, Longitudinal, Educational, Relevant, and Thorough (ALERT) Evaluation Tool Methodology" section of this report. A summary of ALERT is shown in figure 7.

Secondary Data Collection

Secondary data collected for this evaluation comprises local hazard mitigation plans (LHMP), media and academic mentions, previous evaluations and studies, and online searches for examples of scenario use.

Local Hazard Mitigation Plans

The Disaster Mitigation Act of 2000 (Public Law 106-390, 144 Stat. d) incentivizes local governments to evaluate the hazard risk in their municipality and develop hazard mitigation plans. A LHMP must be approved by

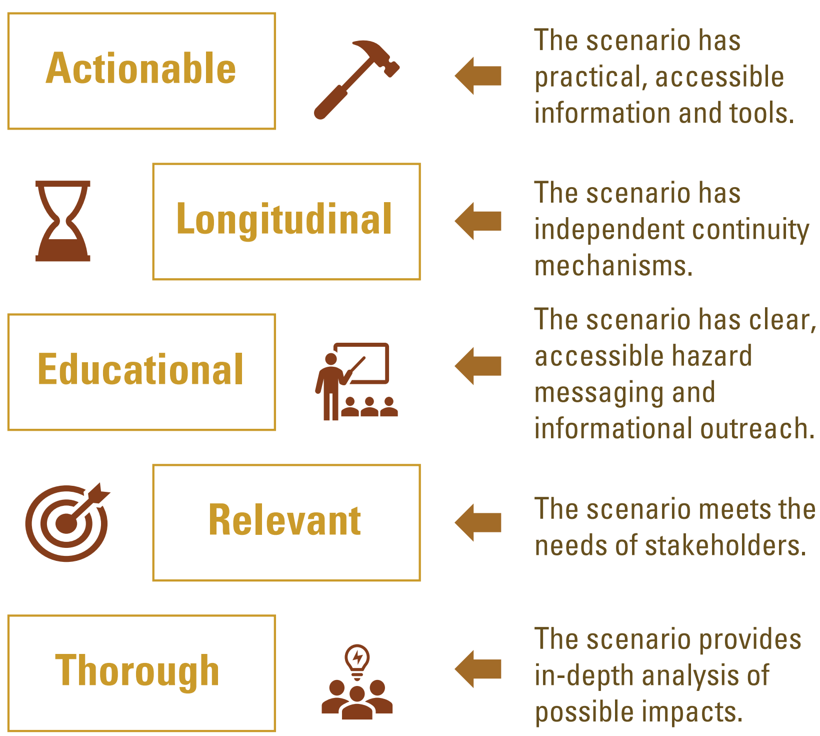

Figure 7. The actionable, longitudinal, educational, relevant, thorough (ALERT) categories and brief descriptions.

FEMA to be eligible for disaster relief grants from the Hazard Mitigation Grant Program. LHMP also enable future mitigation project funding awarded through the Flood Mitigation Assistance program, the Pre-Disaster Mitigation grant program, and the U.S. Small Business Administration's loan program. Ideally, this results in a more independently resilient community that will require less Federal emergency relief assistance. This evaluation chose to review State and local LHMP as an indicator for a State or local government's awareness, use, and potential planning efforts or preparedness plans based on the scenarios.

To determine county and city LHMP use, the list of California counties and incorporated cities was obtained from the California State Association of Counties (CSAC, 2014). Each city and county were searched through both Google and their own websites, using the terms "LHMP," "hazard mitigation plan," "HMP," "mitigation plan," "hazard plan," "hazard planning," "multi-jurisdiction plan," "disaster plan," and "disaster planning." If, at that point, no LHMP was identified, the county or city was marked "ND" for no data.

If a county or city LHMP was found, then it was searched for the following terms: "ShakeOut," "Shake Out," "ARkStorm," "Ark Storm," "Tsunami Scenario," "HayWired," "Scenario," "MHDP," "SAFRR," "USGS," and "CosMoS," as well as lead author names to search the references. In a spreadsheet, the LHMP were recorded whether they used the scenarios or not, and the data collected were input into ArcMap and used to create maps or scenario use, shown in figures 21–24. The maps include overlays that show the scenarios' areas of influence.

LHMP data collection occurred from November 2019 to July 2020, with the latest LHMP recorded having been approved in March 2020. Updates or publication of any county or city LHMPs after that date are not represented in the findings.

Media Mentions

Understanding how news sources utilize these scenarios to communicate current events and community news will help illustrate the scenarios' place in public knowledge. News headlines tend to only use a formal name if the subject is a public figure or known brand—the existence of the scenario names in titles without a descriptive clause will indicate the news sources assume the scenarios have name recognition with their average reader. Passing references in the body of the article also indicate that the news staff assume common knowledge. Further, media mentions that relate the scenarios to real life hazards indicate a link between awareness of the hazard and the scenario and that the scenarios are tools used to address said hazards. Where applicable, this evaluation provides a timeline of the scenarios' media mentions compared to real life analogous hazards.

The news data collection methods for ShakeOut are different than HayWired, ARkStorm, and Tsunami Scenario. Because of the lack of long-term media tracking analytic software on the USGS scenario websites, media mentions for the latter three were manually collected using search engines, such as Google News, as well as news articles searchable via the academic databases described in the following section. These data are limited by whether the news article or media mention is recorded, cached online, and qualified as a news source to the news search engines and academic databases. For the manual searches, the scenarios were searched using the terms shown in table 3.

Articles that referenced the scenarios were read to ascertain the depth of engagement and assigned to the following categories:

- Casual use— Passing references to the scenarios. Maximum one sentence with vague description, such as "Other hazard scenarios, like ShakeOut, use this method";
- Descriptive use— Describing the scenario with two or more sentences, including preparedness instructions or advice from scenarios. Could include a call to action for preparedness;

Table 3. Search terms used for media mentions of four major hazard scenarios—ShakeOut, ARkStorm, Tsunami Scenario, and HayWired.

[SAFRR, Science Application for Risk Reduction; USGS, U.S. Geological Survey]

Scenario	Search Terms	Notes
ARkStorm	"ARkStorm"	The term "ARkStorm" is sufficiently identifiable that it is easily searched without other terms.
Tsunami Scenario	"Tsunami Scenario" AND "SAFRR" "Tsunami Scenario" AND "USGS" "Tsunami Scenario" AND "Ross"	Tsunami Scenario's lack of branding necessitated the inclusion of the term "SAFRR," "USGS," and lead author "Ross" to isolate the appropriate results
HayWired	"HayWired" "HayWire" AND "USGS"	Incidentally, this evaluation discovered that many news sources referred to the HayWired scenario as a scenario on the Hayward Fault published by the USGS. A search for "Hayward" AND "USGS" resulted in too many hits to manually review, causing HayWired to be underrepresented in this part of the study

- Use in scientific or practitioner model— Academic or professional use of the scenario data or models to create new scientific conclusions or proofs or demonstrate a need not detailed in the scenario reports; or

- Use in policy or procedure— Private, public, or nonprofit entities incorporating scenario preparedness stipulations in policy or procedures for their company, region, or target population.

Many categories overlapped, so the article was assigned to the category that indicated the most engagement. For example, if the scenario was described and then used to outline planning or policy, it was assigned to the “use in policy” category.

Because of ShakeOut’s successful public campaign, now managed by the Southern California Earthquake Center (SCEC) through ShakeOut.org, a manual search through hundreds of thousands of web hits and assessing depth of interest was not feasible. The evaluation team established a collaboration with SCEC’s website management team, who provided access to their tracking metadata platform Cision (2020). The platform tracked an estimate of over 67,000 media mentions since the genesis of the website, using the search terms defined in table 4.

A limitation of Cision’s data is that Cision uses an algorithm to identify and sort the media mentions based on the search terms. The algorithm cannot differentiate between shakeout used in the context of a disruption and ShakeOut used in the title. To prevent overidentification, the algorithm requires key search terms to be used along with ShakeOut to be counted as a mention, such as earthquake. This process has an unknown error margin and articles that, for example, talk about a global shakeout in trade after an earthquake would be counted, even though they are not talking about ShakeOut the scenario. Cision’s data also include television, radio, and press releases, among other forms of news media that were not included in the analysis for ARkStorm, Tsunami Scenario, or HayWired because of the limitations of manual collection, so ARkStorm, Tsunami Scenario, and HayWired are underrepresented because of lack of information from those media formats.

Academic Databases

Given the scenarios are scientific products, this evaluation assesses their presence in academic literature. Passing references and casual use in academic literature that name the scenarios but do not explain or define them indicate that the authors assume the scenarios are common knowledge within their field. Papers that use the scenarios to expand the conversation of hazard science and disaster risk reduction are noted as indicators of increased application and education. Innovations in science are partially measured by whether scientific papers use the scenarios to create new models or proofs or add to the scientific conversation of hazard management. This is an imperfect metric of scientific innovation; not all the papers that use SAFRR scenario data or models will have created innovative science, but for the purposes of this study, the total number serves as an indicator that innovation is present.

Academic in this context refers to peer-reviewed journal articles, graduate-level theses, cited conference papers from conferences put on by academic and research institutes, USGS circulars, and other grey literature. The USGS has not consistently tracked citations of the scenario publications, so the citation search was done with manual searches through

Table 4. ShakeOut search algorithm terms in Cision (2020).

[SCEC, Southern California Earthquake Center; ECA, Earthquake Country Alliance]

Search Terms for Total Media Mentions		Notes
“Great ShakeOut” OR “Great ShakeOut’s” “the Great ShakeOut” OR “the Great ShakeOut’s” “Shake-Out” OR “ShakeOut’s”	AND “drill” OR “drills” AND “earthquake” OR “earthquakes” OR “quake” OR “quakes” OR “ShakeOut Report”	These terms were used to collect as many mentions of the ShakeOut awareness campaign and drill as possible. Mentions of “Shake-Out” alone without the other terms were excluded to only count media mentions that came with information about the campaign, and to avoid counting the common phrase “shake out.”
Additional Search Terms for Key Messages		**Notes**
The words “Drop cover hold” in proximity to each other The words “prepare earthquake” OR “preparation earthquake” OR “preparedness earthquake” in proximity to each other “SCEC” OR “SCEC’s” “ECA” OR “ECA’s”		These terms were used to assess which key messages were included in the ShakeOut media mentions, identifying how the media mentions are informing people about the campaign.
Criteria for Level of Engagement		**Notes**
NOT frequent use of “ShakeOut_” = Casual Use Headline use of “ShakeOut_” = Headline Coverage Frequent use of “ShakeOut_” = Feature Coverage		Cision’s code does not include a criterion for the word “frequent” that is accessible to the evaluation team, but we will accept it as congruent with our definition of casual use, and feature coverage is counted as descriptive use. At this time, we cannot use Cision to determine use in model/proof or use in planning/procedure.

the Cornell Library database, the Colorado State University Library database, the USGS Library database, and Google Scholar. To search the databases, the same methods were used for search terms as described in the “Media Mentions” section of this report, with the addition of ShakeOut. The words “ShakeOut” and “USGS” were used together in the database searches. The term “USGS” needed to be included, since “shake out” is a common phrase, and “shakeout” in different contexts is used in economic, business, mining, and metalworking fields. Some sources referred to the scenario as Shake Out, and because of the commonality of the phrase shake out, it was not possible to search the large number of references that used those words separately. Papers that referred to the scenarios were read for the level of engagement. The evaluator used the same four categories as in the “Media Mentions” section of this report; casual use, descriptive use, use in model/proof, and use in planning/procedure.

A limitation to this method is that not all academic journals and databases are accessible through the academic databases searched. Papers that were not hosted in the online databases used for this study were excluded, as were papers that misspelled the scenarios.

Awareness

- Stakeholders consider hazard preparedness relevant
- Effective hazard awareness or outreach programs
- Increased awareness of interdependencies in hazard management and response
- Increased awareness of other sectors’ response and mitigation work and policies

Education

- Increased knowledge of hazard mitigation, preparedness, and response
- Increased access and use of science in DRR policy and planning

Application

- Use of scenario narratives, tools, findings, or models
- Preparedness strategies deployed
- Innovation in DRR science and technology
- Expanded DRR networks maintained across sectors
- Policy and regulation changes

Longevity

- Project partners maintain hazard awareness and preparedness actions
- DRR stakeholder networks maintained
- Mechanisms for maintaining institutional knowledge

Figure 8. The outcomes from the Science Application for Risk Reduction (SAFRR) Scenario evaluation logic model. (DRR, disaster risk reduction)

Research

There are several existing studies or evaluations on different parts of some of the scenarios. Relevant studies were read and summarized for key findings. The summaries are included in the “Introduction to the SAFRR Scenarios” section of this report and provide examples of use, affect, and evidence of intended outcomes.

Many organizations and local government bodies have information online about their use of the scenarios. Developers and users have written reflection papers and reports and have also given public interviews about the scenarios. These sources were used to develop an abbreviated history of the scenarios, found in appendix 2. Forms of use besides those already described in this report, such as conferences, exercises, and presentations, were corroborated and recorded, either in the histories of the scenarios or in a timeline of scenario events, found in appendix 3.

Actionable, Longitudinal, Educational, Relevant, and Thorough (ALERT) Evaluation Tool Methodology

There is not an established, formalized method for evaluating scenarios of this scale and type. As the amount of data collected over the course of this evaluation grew, the need to organize and formalize a method of assessment grew. The four outcomes—awareness, education, application, and longevity—from the SAFRR evaluation logic model that this evaluation is testing for, shown in figure 8, are complex concepts with multiple indicators of success and multiple methods employed by the SAFRR scenarios to achieve those outcomes. Tracking the different indicators across the four different scenarios requires a tool in the form of a series of checklists.

The five DRR scenario planning themes discovered through the course of the evaluation—actionable, longitudinal, educational, relevant, and thorough (ALERT)—became the organizing structure for the indicators. Establishing relevance, for example, is a prerequisite for stakeholder engagement, which is in turn a prerequisite for making stakeholders aware of hazards and preparedness opportunities. As such, “relevant” is a primary theme for the ALERT evaluation tool and corresponds to the first indicator under the logic model’s outcome “awareness.” The theme “thorough” corresponds to scenario planning best practices for exposing vulnerabilities, anticipating improbable and complex disaster situations, and supports the outcomes awareness, education, and application. The other ALERT tool themes "actionable," "longitudinal," and "educational" correspond to the "application," "education," and "longevity" outcomes.

Each ALERT category has multiple subcategories. For example, the "education" category has subcategories of indicators that highlight aspects of modern pedagogic theory, marketing and campaigning best practices, and DRR communication strategies. Factors that contribute to multiple categories, like stakeholder engagement, are included as subcategories in the applicable categories to weigh their importance. To capture the general lessons learned about scenario project organization, the tool begins with a checklist titled "Overall Scope," which has subcategories for project design and team preparation.

The checklist categories were arranged in a series of spreadsheets, marked with a "0" or a "1." "0" indicates the scenario did not use the method or process and "1" indicates the scenario did use the process; these are then totaled for each category and subcategory. There are no target numbers; the totals are intended to draw attention to variations among the categories. Low totals for a category could indicate opportunities for improvement or could be the result of factors outside the scenario planners' control. Alternatively, for a scenario's individual goals, one of these categories could be less essential to the overall success, so a lower score in that category may be expected and not an important indicator. This tool is a prototype, used to organize the lessons learned from the SAFRR scenarios and track methods to achieve outcomes.

Evaluation Findings

This section covers key themes from the interviews, media and academic engagement, the presence of the scenarios in county and city hazard plans, a series of examples of SAFRR scenario innovations, and the ALERT evaluation tool. Information collected on the development and use of these scenarios is written up as a descriptive history, which is included in appendix 2, and "A SAFRR Scenario Timeline," in appendix 3. Information from appendix 2 is referenced as findings through this section and in the "Discussion" section of this report.

Interview Findings

The interview findings are divided into barriers, enablers, and preparedness, and are detailed in the following sections. Some factors identified as barriers are considered enablers by other interviewees. Many of the enablers reported were solutions to barriers. Preparedness captures some of the concepts around resilience, hazard mitigation, and preparedness from the interviewees' perspectives. Interviews are numbered at random to protect anonymity.

Barriers

Three overarching categories of barriers emerged from the interview findings: project delays, multi-disciplinary interactions, and project organization. Interviewees discussed the causes of these barriers, which are outlined in figure 9.

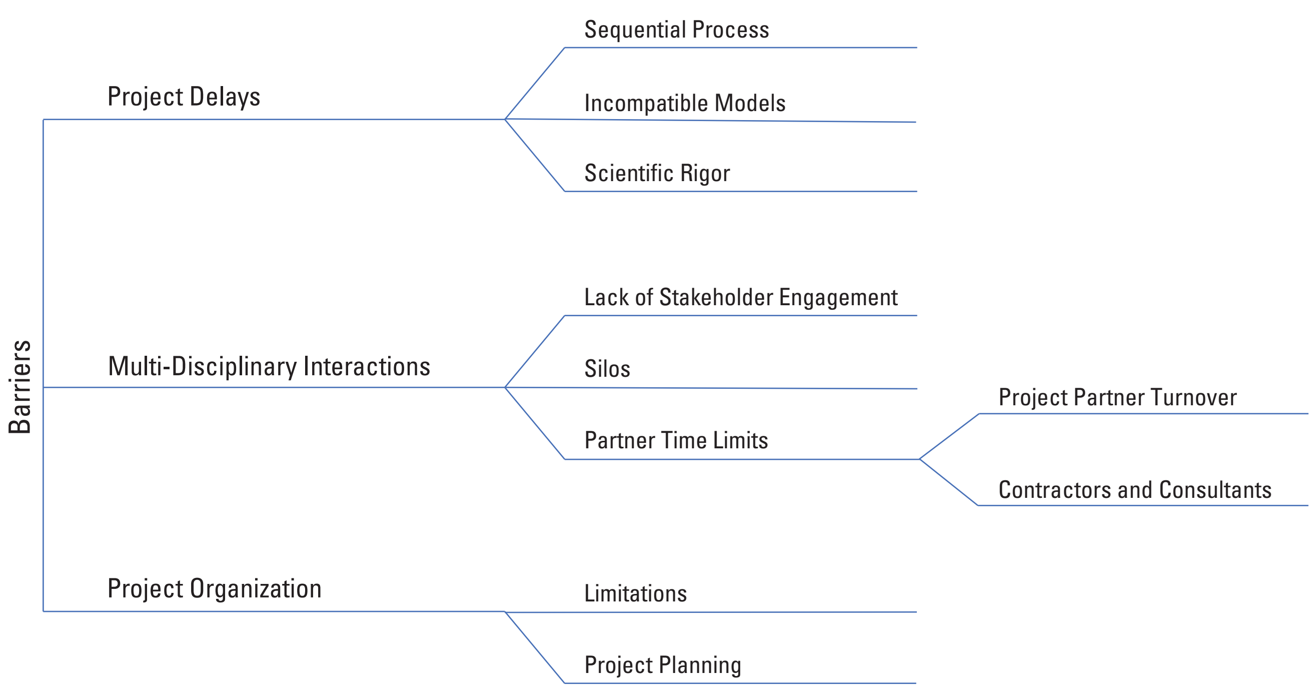

Figure 9. Common barriers to developing or deploying the Science Application for Risk Reduction (SAFRR) scenarios.

Many of the following barriers are well known to SAFRR scenario organizers, and many of the enablers listed in the subsequent section address how scenario planners and users addressed the barriers listed here.

Key Findings:

- Project delays deterred downstream analyses and user engagement;
- Working with people from multiple disciplines and sectors created complex conflicts in timelines, partner availability, and partner accessibility; and
- The intended design of the projects was unclear to many interviewees.

Project Delays

The scenarios were developed in a sequential process, with contributions from many different people, most of whom were not regular collaborators. Later sections, such as economic loss analyses, relied on the earlier sections, such as the models for lifeline interruptions, and any delays in the earlier chapters compounded project delays for those working on the later chapters. Delays at the beginning of the project were reported to be caused by uncertainty about how detailed and precise source modelling needed to be to estimate damage, what was a plausible scenario, and how much scientific confirmation was necessary before passing the source material on. Some developers reported that many scientists working on the sources of the hazards were concerned about making the scenarios too extreme, wanting to work in the realm of probable instead of improbable hazard preparedness. Differing expectations on scientific rigor and timeliness created strain between project organizers and developers. However, scientific rigor was considered an enabling factor for both developers and users in getting the scenarios used.

Incompatible models between the different disciplines also caused unexpected delays as different groups had to translate materials and terminology from each other into their own fields of study and analytic software. For example, the seismologists' data and programs for earthquake ground shaking did not automatically fit into the data and software used by infrastructure engineers. However, interviewees were overall positive about learning how to work with others outside their discipline and reported enjoying explaining their work to people in other disciplines.

> "Because it's sequential, because you don't know exactly what you're gonna get, and because you've never done it before, you [haven't] necessarily asked for everything, or this person doesn't know what to give you, and you didn't know how to ask"
>
> Interviewee 1, 2020, on receiving data from source and impact modelers.

The developers that were interviewed had differing perspectives on deadlines. For some, not meeting deadlines throughout the project compounded difficulties for the later chapters to be completed in time. However, the science and engineering that went into the scenarios is complex, detailed, and innovative, and some developers found themselves needing more time to develop the science to a high standard and were frustrated by strict deadlines. Rushing deadlines also rushed peer review in the first two scenarios, which compromised the perception of their credibility for some.

Multidisciplinary Interactions

Although multidisciplinary collaboration has many benefits, there are challenges to working with these groups—it is difficult to coordinate many different people from different backgrounds. Because the SAFRR scenarios rely on these diverse teams for development and use, some of the barriers involve not being multidisciplinary enough.

Lack of Stakeholder Engagement

For the developers that were involved in project organization and obtaining the stakeholder partners, a common barrier was that despite outreach, some stakeholders would not engage. The conjecture from five of the interviewees was liability. Interviewees thought some lifeline organizations did not want to share potential vulnerabilities out of concern for the liability of admitting to but not fixing those vulnerabilities. Identifying who to engage within the stakeholder organizations was also reported to be a challenge because some of the organizations have tens of thousands of employees.

Another concern shared by both developers and users was that project partner expertise and abilities had sometimes been overlooked, and a consultant or contractor had been brought in to perform an analysis that the project partner would have had more accurate information to complete. In one case, a consultant's analysis reported hazard damage of infrastructure that was two orders of magnitude larger than the analysis done by the organization responsible for that infrastructure, according to an interviewee from the organization. This interviewee felt that reporting the consultant's analysis on the damage (1) ignored their organization's input and expertise; (2) implied their organization did not know how to build, fix, or analyze their infrastructure; and (3) ignored their input to make a more dramatic hazard scenario, undermining the credibility of the narrative. This interviewee reiterated that problem had been solved for them as project partners in a subsequent scenario but recommended that scenario leadership review organizational charts of their project partners to ensure they were maximizing use of the partner's expertise.

Silos

One enduring barrier to these scenarios, and DRR in general, is that many agencies and organizations are siloed, discrete, isolated, or stovepiped, meaning they did not communicate or work with other agencies or organizations. Interviewees recognized that silos happen because of limitations on communication or collaboration due to jurisdiction, legal requirements for official processes, or just time and manpower. Groups within an organization can also be siloed, and the information they provide may not represent the whole of their organization. Silos contributed to the difficulties of engaging relevant stakeholders, as it made communication across multiple sectors (or even communication within a single organization) challenging.

> "We struggled to get political parties or agencies or, you know, business, government to talk to each other * * * they all had their protective spheres and silos."
>
> Interview 4, 2020, on interdependencies in lifeline interactions.

> "If it's an interdisciplinary project that brings together folks, and that's the other real problem: is that people are willing and love to come together, but their day jobs keep them so siloed that, unless you have someone whose job it is, like [SAFRR project manager Dale Cox] to organize these, * * * it just doesn't happen. People are too busy in their own day job. It's an invaluable source that the USGS provides by having these interdisciplinary teams."
>
> Interview 11, 2020, on SAFRR's role in bringing together siloed groups.

Partner Time Limits

Even if a representative of a stakeholder group became involved, that was no guarantee their organization would continue to use the scenario—those individuals could be promoted, leave the organization for another position, or retire. The scenarios may have been promoted in the organization by an individual but were not embedded in the institutional memory, and the organization would forget the scenario existed due to staff turnover.

> "Our partner engagement, they rotate out every 6 months. If you're talking with the Coast Guard, you're talking with anyone in the military, if your project lasts more than a year, there's a 99 percent chance your partner has changed."
>
> Interview 17, 2020, on partner organization staff turnover.

Consultants and contractors are also on set contracts with a certain funding amount, and project partners often work with annual budgets, hard-to-schedule decision makers, and competing project timelines, making project delays disruptive. Some project partners had to disengage with the scenarios entirely and work with other hazard initiatives to complete a goal within a fiscal year or for a specific event, though the depth and precision of the science developed for the scenarios was considered extremely useful to the user interviewees.

Project Organization

Limitations

The USGS is an agnostic organization that is neutral in its research and presentation of science. As such, representatives of the USGS cannot recommend policy or advise political action. USGS developers and community partners expressed frustration over this—that USGS had directed the project so far but had to fall short of direct policy recommendations, making the scenarios feel unfinished to some interviewees. Many scenario organizers wanted to recommend best practices in hazard management to project partners, and some users expressed a wish for the USGS scientists to explicitly recommend action.

> "Those decisions, they can be informed by a big thick report, but you need warm bodies to say, "Okay. Forget about the fact that—forget about this 500-page document. I'm here to tell you about these six pages that matter most to you." Right? That can't be the job of somebody working with the U.S. Geological Survey, but it wasn't anybody else's job. You produce this hugely important—this potentially important work, but it doesn't reach its potential. It doesn't get fully used, because you have to throw it over the transom and hope that somebody on the other side picks it up and runs with it."
>
> Interview 10, 2020, a developer on how not being able to recommend policy impacts the usability of the scenarios.

> "I know science-based organizations like to just stick to the objective facts, but to the degree to which they can say, here are our recommendations for what should be done based on maybe a more narrow perspective. * * * rather than us having to read through hundreds of pages to create our own assessment of what the next step is, I think if there's some way that they can share that in a way that acknowledges that they don't know the context of the decisions that need to be made."
>
> Interview 17, 2021, a user on wanting clear science-based recommendations.

The above quotes from a developer and a user also recognize the lack of usability in the OFRs and a need for multiple products breaking down the information or someone to act as an intermediary to communicate the relevant parts of the reports to stakeholders.

Project Planning

The scenario projects are large, complex, and have many moving pieces being coproduced by multidisciplinary teams. When program evaluation and review technique diagrams, workflow diagrams, weekly conference calls with preset agendas, or timelines were used, interviewees indicated they were helpful, but interviewees indicated project management and organization tools had not been used enough. The projects lacked clear, preset, measurable project goals, leaving the scenario developers open to speculation about whether they were accomplishing what they were intended to accomplish or if there was any oversight to the projects. Consensus was that the project managers and leadership had done excellent work taking all these pieces of the projects and threading them together; however, the lack of detailed project management tools created barriers for all parties involved, including the managers themselves.

> "I don't think it was really a USGS experience to have such a complex project and * * * have a tool or experience with using a tool to line it all up."
>
> Interview 1, 2020, a developer reflecting on the role of project planning and design.

Also important to project planning is a deep knowledge of the external stakeholders already working in the field of hazard awareness and management. Three interviewees expressed concern that members of the scenario planning team had not researched what the State was already doing to address the same hazard covered by a scenario and had proposed outreach activities that would potentially compete with the State's efforts. They identified this as a failure to plan the project around stakeholder needs and what was already being done.

Enabling Factors

The following section describes what helped interviewees work with the scenarios, overcome barriers, and achieve the intended outcomes of scenario planning, though what some considered enablers were barriers to others. Many of the enabling categories overlap or share indicators, such as stakeholder engagement, which was considered necessary for all the enabling factors. Figure 10 outlines the main categories of enabling factors.

Key Findings:

- Stakeholder engagement was crucial for all the following elements and is a consistent theme throughout the enabling factors for developing and using the scenarios; and
- Key to getting the scenarios used, and having them stay useful, were
    - accessible action items,
    - continued promotion by dedicated stakeholders,
    - developing the scenarios as educational and awareness tools,
    - relevance to multiple groups and multiple hazards, and
    - the thorough depth and breadth of scenario topics and detail.

Stakeholder Engagement

Stakeholder engagement was considered the focal point and foundation of the scenarios for the interviewees. Engaging stakeholders was considered crucial to the other enabling factors, from ascertaining the needs of end users for project design to partnering with stakeholders for facilitating policy development. Interviewee perceptions of stakeholder engagement took the form of three primary themes—multidisciplinary, coproduction of knowledge, and a clear and elevating purpose—all of which are components that appear throughout the enablers.

While most interviewees defined a stakeholder as anyone who was not a primary author, the "Discussion" section of this report explores the concept of authors as stakeholders and considers stakeholders to include all participants and affected populations.

Multidisciplinary

Overall, interviewees talked about how involving stakeholders created collaborative relationships in the design, development, and use of the scenarios, and that the multiple perspectives and sectors brought different skills into the project. Though headed by the USGS, interviewees viewed the scenarios as projects that were co-owned, supported, and made possible through the work of many groups from various sectors of public, private, academic, and nonprofit work. Further, five of the developers specifically said that the multidisciplinary collaboration between themselves and other developers of different disciplines and users from different sectors made the projects fun.

> "And that's why I think it was so great to bring everyone to the table, I mean, everyone brings with them their own history and experience, right, and by opening the doors to the castle and allowing everyone to come in to the USGS, for these discussions and events, I think you bring everyone's expertise."
>
> Interview 4, 2020, on the USGS organizing collaborative, multidisciplinary opportunities.

Aligning the multiple hazard response groups was considered important to interviewees, both in making sure the preparedness messaging and strategies are clear and consistent but also to practice for response and recovery efforts by having networks and communication precedents in place.

> "I think part of these scenarios is getting everybody to have a seat at the table so that there can be not just a multidisciplinary, you can see the problem from all angles, but you also create a united front in emergency management or disaster risk reduction efforts"
>
> Interview 10, 2020, on the scenarios as a tool for bringing together communities that share a common hazard.

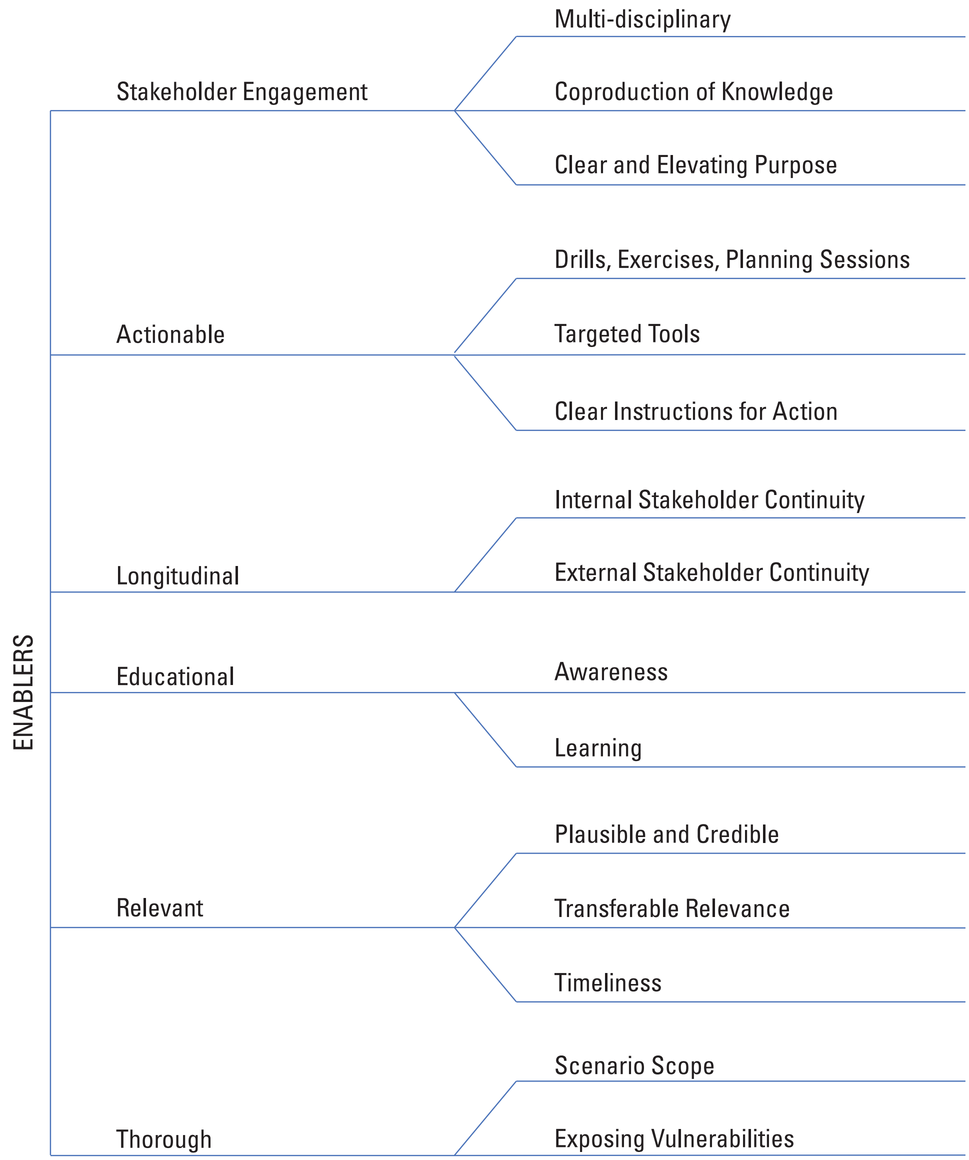

Figure 10. Enablers to developing or deploying the Science Application for Risk Reduction (SAFRR) scenarios. Stakeholder engagement supports all the subsequent enabling factors in this diagram.

Some interviewees discussed the nature of the USGS as a well-known Federal organization that enabled the scenarios to be recognized on a larger stage. However, the notability and influence of the USGS created a power imbalance according to two interviewees, inspiring one State government stakeholder to get involved to maintain influence over disaster messaging so as not to have contradictory or competing messages with the State.

Coproduction of Knowledge

During the process of working with stakeholders, developers reported learning about the importance of having stakeholders approach the development and scientific teams with specific problems or needs. When the intended user groups participated in the scenario development, scenario planning teams felt they created buy-in among those stakeholders, which inspired continued use of the scenarios. Buy-in was achieved through having participated in scenario development, which gave stakeholders a true stake in the scenario's perceived use and success. By participating in the production of the scenario narratives, collaborators and users reported feeling pride and ownership in the scenarios. Users who collaborated on the scenario design remarked that they repeatedly use the scenario for disaster exercises, tests of emergency plans, or investing in preparedness actions like earthquake retrofitting. Developers also reported seeing end users trust the credibility of the scenarios because representatives from their sector were involved in the scenario development or dissemination.

> "That was also one of [Dale Cox, SAFRR project manager]'s real skills that were really important, is getting the partnerships that people can feel like they had a stake in it at the beginning."
>
> Interview 12, 2020, on getting buy-in from project partners early in the scenario development process.

> "I learned that it can help to think about the education and outreach right from the beginning * * * as the process went along, I began to see more and more how getting the public involved early and often improves the final product, makes it more useful."
>
> Interview 10, 2020, a developer reflecting on collaborative creation of knowledge as opposed to top-down knowledge production.

Clear and Elevating Purpose

Developers were clear that the projects could be difficult, long, and frustrating, but all developers and contributors interviewed apart from one felt that the scenarios had been worth it, that they would save lives, and that the science, the experience, and the networks they built were all valuable. Most of the interviewees believed the scenarios were important to hazard risk reduction. Interviewees spoke highly of the people they worked with who had gone above and beyond, stating that some had been staying past their contract to make sure their work was understood and usable.

> "Those are some of the people I've continued working with because they had such commitment to it and wanted to make sure that what they had done was getting in—being used well."
>
> Interview 20, 2020, on source modelers continuing to participate in scenario planning sessions after their sections and contracts were completed.

Developers felt particularly rewarded when working with end users and communicating science to stakeholders. Some discussed how necessary it was to bring science to stakeholders that needed the information, and how involving them in scenario development was one way to break down the ivory tower of academia.

> "People are dying because they don't understand our science. We should not be continuing to create science for academic journals."
>
> Interview 12, 2020, on why it's important to create usable science, working with communities, instead of just publishing papers in journals.

Actionable

Interviewees considered the development of multiple products like drills, exercises, and workshops as important means for getting the scenarios used. Also important to interviewees was how the scenario developers tailored each of the scenarios to targeted stakeholder groups and brought the scenario products directly to them.

> "ARkStorm has only really worked when we got it down to a more local level. The thing is though, you don't want to do this level of work just for one county. * * * To get it really used, you've got to go back to the county level to engage with it."
>
> Interview 12, 2020, a developer discussing the need to tailor the scenarios to local levels and engage directly.

When developing action items, one developer talked about the importance of covering the low hanging fruit for action items, meaning the easy preparedness instructions that were financially accessible to a wide group. The developers also realized that education and awareness alone were not enough to inspire preparedness action; action items needed to be brought to stakeholders and there needed to be continued collaboration to inspire follow-through. Not being able to recommend policy was considered by both developers and users as a hindrance to effective action, so working with stakeholders that could recommend policy or action was important to inspiring action.

Users and collaborators found the workshops and exercises useful for their own understanding of the scenarios and their use as planning tools in their own organizations. All interviewed users and collaborators brought information or tools from the scenarios back to their organizations, running preparedness exercises or instigating changes for resilience. However, many users and contributors expressed that they wanted more clear, straightforward instruction on the next steps for hazard preparedness.

Longitudinal

Developers and contributor interviewees were not just interested in the scenarios getting used, but that use continued over time. Recognizing project partner turnover as a barrier, many developers were interested in ways to maintain scenario use among stakeholders after the project was officially over and the project leadership was no longer promoting it. The clear and elevating purpose also aided in continuity, as many developers and contributors continued to work with the scenarios after project completion because they believe the scenarios are effective DRR tools.

Internal Stakeholder Continuity

Interviewees valued the continued efforts of SAFRR team members to maintain connections between the DRR networks created during the scenarios. After the primary scenario narrative development was finished, SAFRR leadership continued to work with the scenarios by tailoring them down to smaller municipalities and working with those municipalities directly. This was credited for a lot of the in-depth use of the scenarios, as well as continued push back against silos.

External Stakeholder Continuity

Given the nature of the USGS and representatives not being able to recommend policy, USGS SAFRR leadership relied on non-USGS project partners to create policy recommendations. For these scenarios to have the full effect on their regions, developers felt they needed the engagement, buy-in, and commitment of key stakeholders in decision-making arenas. The concept of coproduction of knowledge, discussed in "Stakeholder Engagement" at the beginning of this section, seemed to be the key to long-term use among stakeholders, especially regarding the concepts of buy-in and ownership of the scenarios.

Developers from State level non-USGS organizations reported using the scenarios for policy development and recommendations, noting that their participation not only helped shape the scenarios into something they could use, but also familiarized them with the scenarios so that it was easy to turn around and apply them without needing time to learn about them or their tools.

Educational

Interviewees were invested in raising awareness and spreading knowledge about hazards. This section covers both awareness (teaching people there is a hazard risk) and learning (teaching people about their hazard risk and what to do).

> "What's important is outreach to the public: that they understand that there's a hazard, they understand where it is, and they understand what to do. There's an outreach piece which complements the alert and warning piece. If people hear that there's a warning but they don't know what it means or what to do, then it's useless, so it all works hand in hand."
>
> Interview 10, 2020, on the importance of pairing outreach with education on hazards.

Awareness

Awareness discussed in the interviews applied to both general public knowledge of hazards and risk, as well as the hazard awareness of project planners, partners, and decision makers in the region, such as elected officials, utilities, and businesses. Interviewees also discussed raising awareness of the scenario projects themselves.

Developers were mindful of needing to use different strategies for outreach, changing methods depending on the scenario. Since earthquakes can affect everyone in the region, a large public campaign was created for ShakeOut. Meanwhile, tsunamis affect only a small area and population (when compared to earthquakes) and so targeted outreach to key decision makers was chosen for Tsunami Scenario. Developers and users reported that targeted outreach by scenario planners to smaller municipalities or regions seemed more effective for getting the scenarios used and reported engaging more stakeholders in this targeted fashion with each scenario.

Interviewees considered the large public rollouts of the scenarios, involving media, local decisionmakers, scientists, and key stakeholders, to be useful in generating awareness. The fact that the USGS had name recognition and a large platform was considered an important feature of garnering media attention.

> "The media days that were hosted by USGS were great * * * and just the media coverage and the recognition that happened that day was incredible. It was a really big boost to being able to get off and running with the partnership. That was very well executed."
>
> Interview 14, 2020, on the HayWired rollout.

The exception was Tsunami Scenario's rollout, where the team planned six events geared towards decision makers instead of a larger rollout, wanting to just target key stakeholders.

> "It was most effective of the rollout series from the scenarios because we went right to them and took it to them where they were"
>
> Interview 20, 2020, on the Tsunami Scenario rollout.

Rollout and outreach events were also considered valuable for recruiting stakeholders who had not previously known about the project. The public event and media coverage alerted more stakeholders, who could engage with the coalitions, campaigns, or continued outreach work done by scenario planners and project partners. This strategy was used for HayWired in particular, creating the potential for continuous recruitment of stakeholders as each report on the project was published.

Learning

All parties reported learning more about hazards. Developers reported learning about hazard risks and impacts over the course of their participation in development—learning from their own science; learning from each other, project partners, and contributors; and incorporating that learning into the scenario development. Developers from multiple disciplines also discussed the value of learning how to communicate their own work as a result of having to explain their scenario contributions to diverse groups of other developers, contributors, and stakeholders.

> "It was really helpful not only for us to kind of communicate to them, but for them to communicate to us about what's actually important. What kind

of metrics are important, what kind of products are important, like how do they actually make decisions? * * * I think at least for me, and I'm sure a lot of others, [working on the scenario] got us thinking that this whole stakeholder engagement is like a two-way process and we have to find out like what do they actually need to make a decision?"

Interview 19, 2020, a developer talking about their experience working on a scenario teaching them about outreach and the importance of science communication.

Involving stakeholders from diverse backgrounds in the development of scenarios also enabled a collaborative learning environment, where stakeholders taught each other about hazard impacts and their interdependencies, instead of the information coming top-down from the scientists. The diversity of the scenario development group also improved the accessibility of the information, as multiple perspectives were involved in creating the information that they were also disseminating.

The variety of products and messaging was also considered important for educating stakeholders about the scenarios and increasing accessibility to the information provided by the scenarios. Fact sheets, circulars, presentations, movies, and rollout events were all cited as important learning tools by different interviewees, many of whom noted that the large OFRs are not accessible to most stakeholders.

"These things [Open-File Reports] tend to be academic, and they get put on a shelf. I'm a huge fan of scenarios for flood issues because the social science tells us that, for rare but plausible events, we, as humans, have to learn about them and process them through stories. Can't just give us a bunch of facts and numbers and expect that we're gonna take any action on them."

Interview 10, 2020, on scenarios as learning tools.

Relevant

Relevance is a common theme in scenario planning theory and DRR, and one that concerns developers and users. Interviewees mostly regarded stakeholder or user engagement as necessary to create a relevant product, even if it was just asking what products the intended users wanted. Most considered the ongoing participation of stakeholders as a means to consistently refine the scenarios into relevant products, especially by ascertaining the needs of the stakeholders first and then building a product to meet those needs.

Relevance was supported by three primary themes: the believability of the scenarios (the scenarios were considered plausible and credible), the fact that the products or information from the scenarios were useful for general preparedness, and the timeliness of the scenario's products.

Plausible and Credible

Users and contributors all cited the credibility of the USGS and the contributing scientists as reasons why they felt the scenarios were plausible. Several users and contributors expressed that they were unaware of the extent of damage that a given hazard could do and said they would have questioned the plausibility of the scenario if it were not so clearly based in rigorous science. The USGS was considered by all interviewees as a credible, respectable scientific institution.

"I think the USGS, the reputation behind the data was key. Then also they gave us a better data set than I think anyone else could offer us."

Interview 19, 2020, a user discussing their perception of the level of reliability for HayWired's source data.

When talking about the reputation of the USGS and using the bureau's credibility to promote these projects, USGS developers and contributors were also quick to emphasize that the project partners were indispensable and that these scenarios were a product of collaboration.

The scientists' use of historical precedent to develop the hazard source, consensus among multiple scientists, and the fact that the scenario source science was more detailed than other scenarios they had experienced, supported the plausibility and credibility of the scenarios according to both contributors and users.

"A core issue of the successful scenarios is being able to make a point that this is a consensus of a scientific community."

Interview 12, 2020, a source scientist discussing the scientific rigor of the scenario narrative.

One developer reiterated that the SAFRR scenarios were intended to fill in the gaps of hazard modelling and science that has been traditionally left out of scenario planning.

"The ShakeOut event or the HayWired scenarios, again, the benefit is well vetted, peer reviewed, all the best minds brought together to produce these things that are high quality that we can point to, we know everyone else is pointing to it * * * and it's held to a higher standard, right? It's just more credible that way."

Interview 13, 2020, a user from a lifeline industry, commenting on the scenario's scientific rigor and high profile.

Generalizable

For the scenarios to be relevant to a wider audience, and thus more useful, both users and developers wanted the scenario information and preparedness actions to be applicable to general hazard preparedness. Lessons from ShakeOut, for example, were considered applicable to earthquake preparedness anywhere. Several interviewees specifically mentioned the fire following earthquake sections from ShakeOut and HayWired as having been useful during the California wildfire seasons in 2017, 2018, and 2020.

Several interviewees expressed concerns about the generalizability of the scenarios, given they are so specific in the hazard affects. One user recognized the need for multiple hazard risk education tools to help groups understand that even if they do not live in an area impacted by a specific scenario, their area may still be at risk for the same hazard. Two developers were concerned the specificity would deter the stakeholders from using the scenarios—the stakeholders may assume the scenarios do not apply to their region or that the scenarios would only prepare their region for one specific event. However, several other interviewees remarked on the specificity of the scenarios making them more salient to end users; for example, some people may not have a concept for earthquake magnitudes, but they can easily grasp specific numbers of damaged buildings. These interviewees went on to say they could then extrapolate the stories to create relevance in other regions, using the concrete and easier-to-grasp examples of damage provided by the scenarios.

Timeliness

Timeliness has been partially discussed above in the "Project Delays" subsection of "Barriers." Timeliness means producing scenario materials in time for stakeholders to use for a scheduled event or exercise. All users interviewed expressed that having a set timeline and receiving products on that timeline is crucial. If the scenario materials are not produced in time for a set event or project budget deadline, then the work scenario planners are doing becomes irrelevant as the stakeholders have to move on and use other methods or information.

> "Relevance is timeliness * * * Because if a scenario is being developed for a specific purpose like a national level exercise, these folks worry about it for about eight months, and then they walk away * * * You wanna get in, do a scenario because it's for a very specific topic, and you get out."
>
> Interview 17, 2020, a developer on developing the scenarios for a specific use.

Deadlines were referenced by developers and users as both barriers and enablers. While they can be used to keep the projects timely, and enable planning for project partners, they can limit the depth of scientific inquiry available to scenario developers.

Thorough

The category thorough came from conversations with interviewees about the importance of including stakeholders to expand the scope of the project narrative and design as well as exposing vulnerabilities because people with multiple perspectives contribute to the scenarios. Multiple disciplines working together enabled participants to explore damages through the lens of interdependencies, exposing vulnerabilities that stakeholders disclosed or discovered through the scenario planning process. One interviewee discussed the value of including community watchdog groups, such as people who monitor local refineries or manufacturing installations for behavior that those companies may not report, such as storing hazardous chemicals in vulnerable locations. This enabled a more detailed, accurate analysis of effects on a community.

Users also appreciated the depth and breadth of topics covered. The high level of detail over a broad scope made the scenarios more usable and relevant by covering a wide range of topics with scientific precision. The thorough detail of the source modelling was considered valuable by users who were savvy with data and modelling.

> "Having parcel-level data that was really—it's the richest scenario that we've ever worked with in terms of just the depth of the data and the rigor that went into it, which was perfect for us to then stick it into our process."
>
> Interview 16, 2021, on using the HayWired models for regional planning.

For developers, covering more topics of impact (for example, including agriculture damages) increased their perceptions of the accuracy and depth of downstream analyses, allowing for more interesting and innovative science to be produced.

> "I had gone broad and shallow in prior scenarios trying to cover as many different topics, at least a little bit, as possible. With HayWired, I wanted to go narrower and deeper too—for variety and so that I wasn't just doing the same thing over and over again. It's just a bunch of chapters that go deep. I wanted to produce a new fundamental knowledge, something that people could build on for new science."
>
> Interview 10, 2020, a developer on the depth and breadth of HayWired.

Not all developers agreed on the level of detail and number of topics. Some thought the source modelling was too thorough and took too much time, others thought the users would not care about the level of detail in any part of the report and just needed to know what to do should a hazard occur.

Preparedness

The following section reports some of the concepts that interviewees had about preparedness and the scenarios. For examples of use and preparedness activities, see appendix 2. Figure 11 outlines the main categories of preparedness.

Key Findings:

- Participating in scenario planning enabled many of the interviewees to create new, or strengthen existing, networks with other stakeholders from different sectors. Some of these networks of scientists, DRR

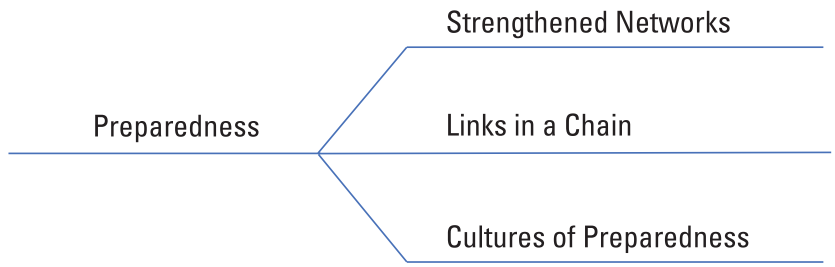

Figure 11. Common concepts of risk preparedness from the interviewees' perspectives.

practitioners, and private companies continue to work together on mitigation, preparedness, and response initiatives;

- The scenarios are part of a larger effort in DRR by many of the entities that worked on the scenarios and identifying scenario affect is difficult in that context; and
- Scenario lessons learned, and preparedness behaviors need to be embedded in the culture of a group or organization to be reliable.

Networks Strengthened

The scenarios were credited for creating and strengthening networks of lifeline representatives, decision makers, and scientists. One lifeline representative interviewee created a mutual aid response program after collaborating with other agencies on a scenario and was able to utilize that network during a recent disaster. Creating networks across agencies was a goal of the scenarios and was important for addressing interdependencies and creating plans for cascading hazards. Coordinated networks also enabled consistent hazard messaging and information, as well as preparedness and response plans.

> "I just think it was just such a joy to, everyone just thought it was so much fun, to work together and to have a common story. It was also fun to just work with the folks from the center for art design to go through that creative process, that design process. That was just really fun. It helped to build relationships that continue today. Taking that opportunity to just do something that's fun, but yet relevant."
>
> Interview 11, 2021, on how enjoyable it was to participate in collaborative exercises, which helped to build relationships.

Links in a Chain

Another concept that emerged, especially from developers, was that their role in DRR was to be a link in a chain; essentially, their work on the scenarios existed in a larger chain or network of hazard preparedness activities, and that measuring their affect was difficult.

> "It's just one more piece of information effort that goes into someone's worldview, so to isolate out the impact of the scenario, and that would be quite difficult because someone might need to hear something 10 times. On the 10th time, maybe it was the HayWired scenario. Maybe it meant something, and they did something. That's not to say that nine other times before then, that person failed in their communications."
>
> Interview 1, 2020, on the importance of repeating information through multiple channels to build on existing hazard messaging efforts.

Scenario developers were aware that their work built on previous efforts and was a contribution to continuing work, not necessarily an end goal in itself. They were aware that getting people and institutions to adopt preparedness measures was difficult and an uphill battle for DRR practitioners.

Cultures of Preparedness

Interviewees reflected on their experience with different groups adopting or rejecting the scenarios. Some counties reportedly rejected the scenarios outright, because of the size and overwhelming damages to their regions that the scenarios described. Other agencies had longstanding preparedness strategies that relied on individual knowledge and personal relationships between one or two people, and scenario planners found themselves in a position of having to impress the need for embedded preparedness strategies and protocol in the organizations. The levels of cultural integration of preparedness activities, interest, and awareness were different with every project partner and stakeholder group, and navigating all those levels of knowledge, needs, and interests with one product was a challenge. Many developers recognized the need for preparedness activities to become embedded in the norms and protocols of different organizations, and to not rely on individual knowledge or relationships, otherwise when that individual moves on, the hazard preparedness and knowledge leaves with them.

One contributor considered the scenarios to be a sort of ambassador for the USGS. He considered the scenarios as valuable tools that both increased public knowledge of hazards, as well as establishing the USGS as a well-known public science institution that was working for the good of society.

> "* * * especially in Southern California—the Southern California ShakeOut just is huge for * * * just raising social consciousness."
>
> Interview 7, 2020, a contributor on the impact of ShakeOut.

Media Mentions

The following findings are not comparable among the scenarios. The scenarios also had different rollout and campaign strategies that caused variations in media attention, and the methods for tracking media data are different for ShakeOut. Tsunami Scenario opted out of promoting a large rollout event and awareness campaign, so as not to interfere with the State of California's work with the National Oceanic and Atmospheric Administration's (NOAA) TsunamiReady initiative, and as such did not generate a media presence.

Key Findings:

- Media sources treat ShakeOut as a commonly known brand. ARkStorm, Tsunami Scenario, and HayWired are not assumed to have name recognition.
- ShakeOut, ARkStorm, and HayWired are referenced in the media in conjunction with reporting on real-life hazards.
- Large rollout events positively correlate to high levels of media engagement.
- ShakeOut media engagement has been trending upwards, with annual spikes in October corresponding to the ShakeOut drill.
- ARkStorm's highest media engagement cluster was during the winter storms and flooding in early 2019, as the media related the extreme weather to the scenario.
- Tsunami Scenario total mentions are found in eight media articles.

ShakeOut

Cision's algorithm for media engagement differentiates the level of engagement based on word frequency and inclusion of multiple search terms (Cision, 2020). Figure 12 shows that 17,058 of the ShakeOut media mentions from February 2008 to May 2021 indicate casual use (passing reference), where the ShakeOut search terms occur only once or twice in the media piece. The other categories are what Cision calls earned mentions, where the ShakeOut search terms appear more frequently, and the articles cover the subject in more depth (Cision, 2020). Passing references to ShakeOut make up approximately 40 percent of the media mentions, likely because of the annual Great ShakeOut campaign. The frequency of passing references and headline coverage likely indicates that the news media cycle assumes that the name ShakeOut has name recognition and can be casually referenced with minimal explanation.

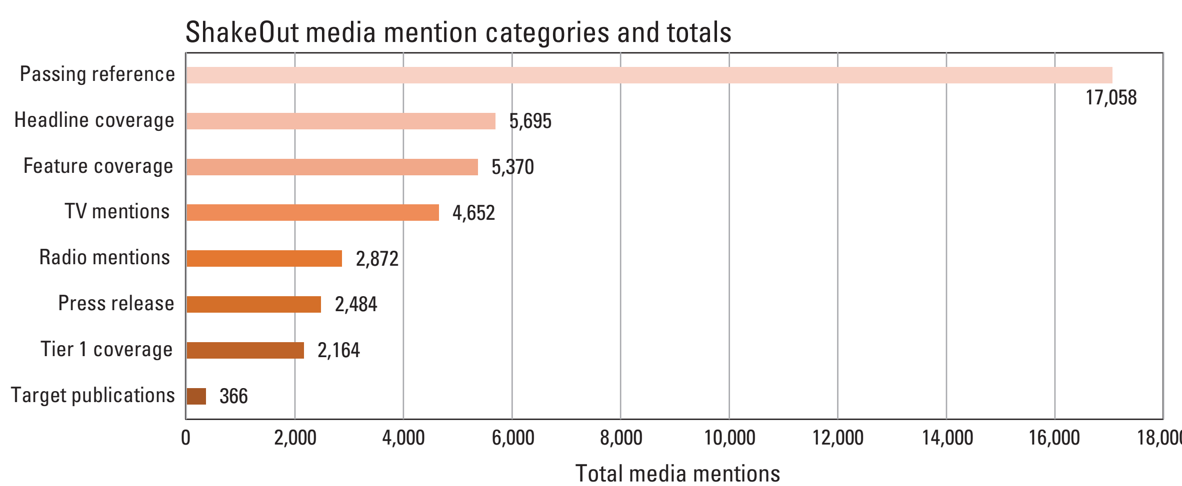

Figure 12. ShakeOut media mention categories and totals as tracked by the media software company Cision, February 2008 to May 2021. Graphs were made and modified using the Cision (2020) platform.

To see media engagement over time, figure 13 shows two axes for ShakeOut. On the left y-axis is earned mentions for media sources. The color gradient shows social mentions, using the same terms as well as hashtags and shared content on social media sites. This evaluation does not address social media, as tracking social media mentions for all the scenarios is beyond the scope of this project; however, since social media tracking is built into the Cision package, it is included here to demonstrate that a rise in social media use has eclipsed other forms of media.

The ShakeOut campaign's annual October drill explains the evenly spaced spikes in media engagement. However, the total mentions for ShakeOut may be overrepresented. News articles such as a recent report on Japan's Covid-19 related recession used the term "earthquake," referencing the March 2011 earthquake's disruption to the economy that was compounded with a global shakeout of trade. This news item had been recycled through at least 42 different news sources in May 2020 creating an artificial boost to the numbers for the ShakeOut campaign (Cision, 2020).

On a regional level, spikes in ShakeOut mentions can be found because of reporting on recent earthquakes, with many articles reminding their readers to "drop, cover, and hold on." Cision graphs in figure 14 demonstrate the ShakeOut mentions in the United States for the month before and month after the magnitude 5.7 earthquake in Salt Lake City, Utah, on March 18, 2020. A review of the 105 articles shows that they are indeed referencing ShakeOut when reporting on the March 18 earthquake. ShakeOut media mentions increase after earthquake events, indicating that the media considers ShakeOut to have real-world applications in earthquake reporting.

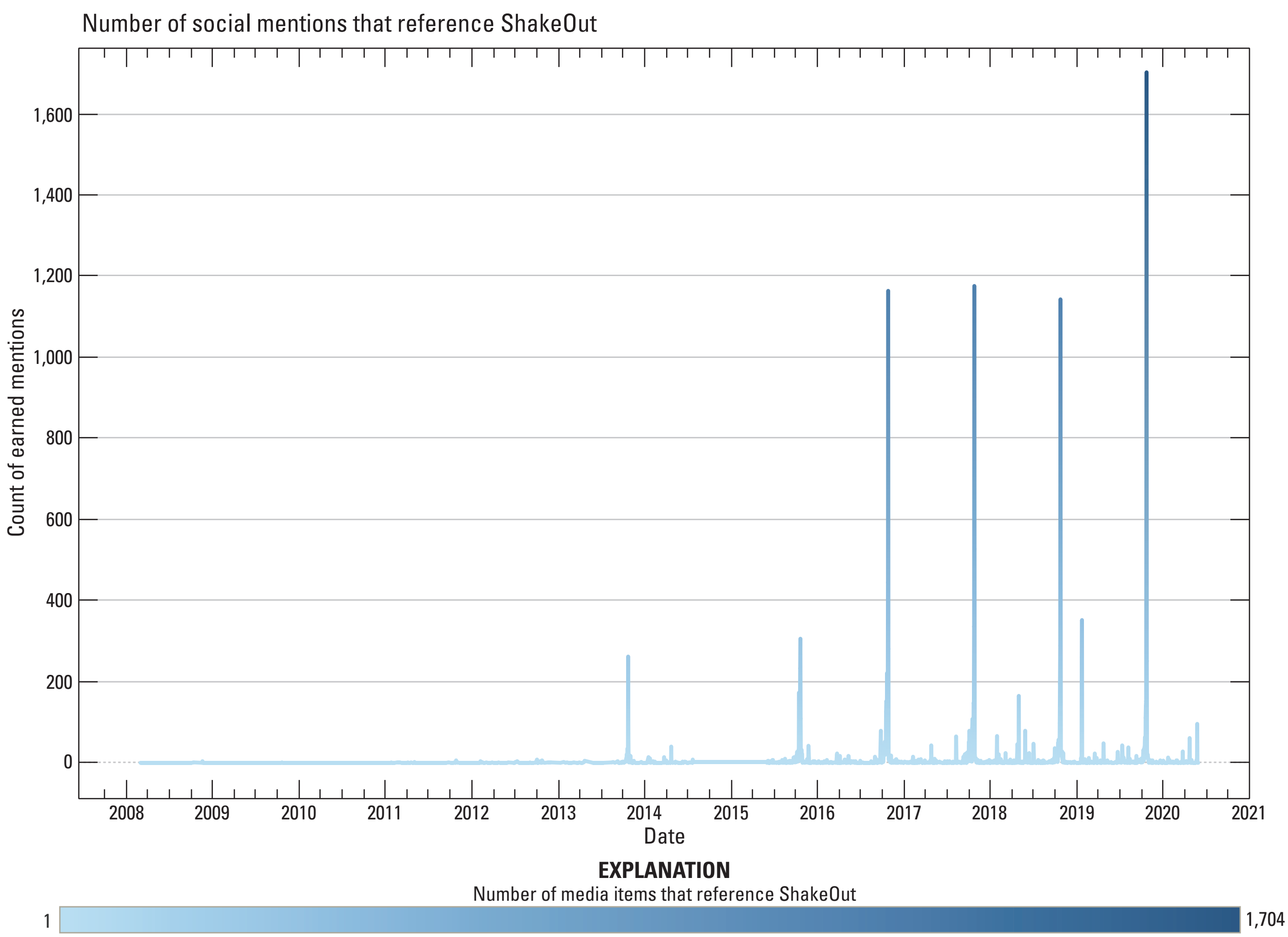

Figure 13. ShakeOut media mentions as tracked by the media software company Cision, February 2008 to May 2021. Earned mentions include headline coverage, feature coverage, TV mentions, radio mentions, press release, tier 1 coverage, and target publications. Social mentions include earned mentions as well as hashtags and shared content on social media sites. Graphs were made and modified using the Cision (2020) platform.

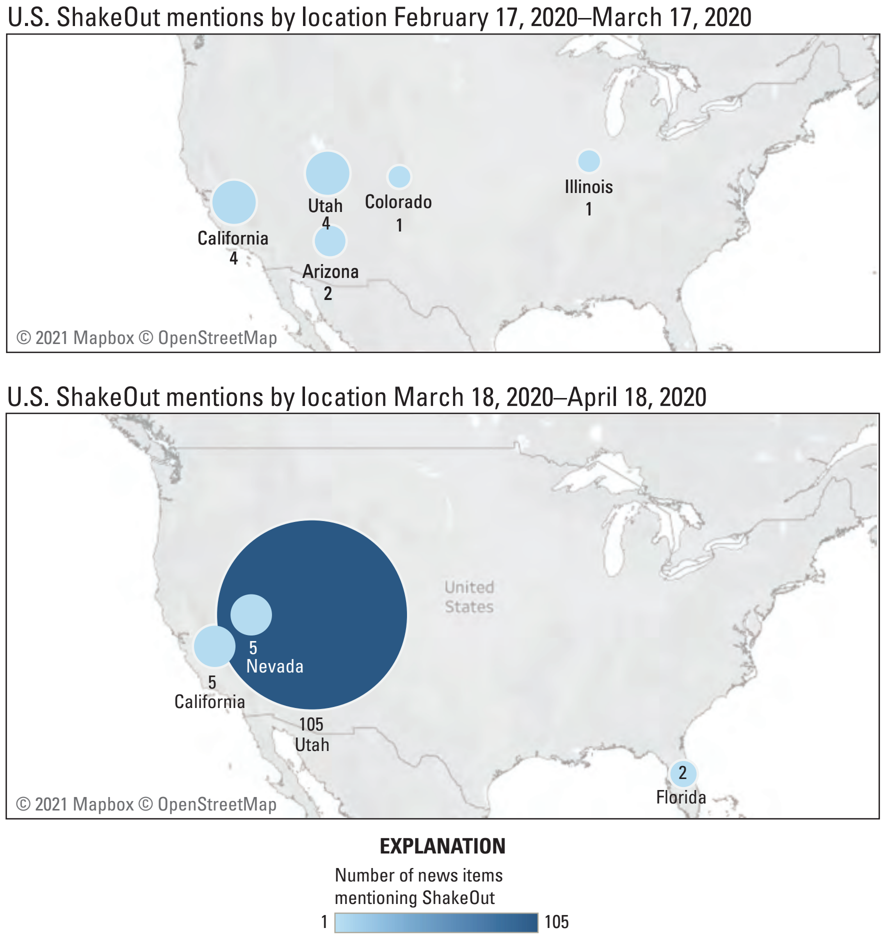

Figure 14. ShakeOut media mentions by location as tracked by the media software company Cision, from February 17 to March 17, 2020 (top), compared to March 18 to April 18, 2020 (bottom). Maps were made and modified using the Cision (2020) platform.

ARkStorm, Tsunami Scenario, and HayWired Total Media Mentions

For ARkStorm, Tsunami Scenario, and HayWired, shown in table 5, passing references comprise approximately 20 percent of their media mentions, compared to ShakeOut's approximate 40 percent, and descriptions make up the rest. This indicates that they have less casual name recognition than ShakeOut, though that makes it more likely for news items to include more information about the scenarios.

ARkStorm, Tsunami Scenario, and HayWired were named in 13, 1, and 11 headlines, respectively. For several of those headlines, the scenarios' names were printed in quotes or next to brief descriptors, such as "USGS shows what could happen to Bay Area with HayWired Earthquake Scenario" by Fresno's Fox 26 News website (Fox 26 News Staff, 2018). Given the scenario names are accompanied by descriptive clauses, these headlines do not indicate that the news team considers the scenarios well-known brands or public knowledge.

Table 5. Total media mentions for three of the hazard scenarios, marked by colors that correspond to their branding: ARkStorm (blue), Tsunami Scenario (gray), and HayWired (red).

Scenario	Casual use	Descriptive use	Use in model or proof	Use in planning/procedure	Total	Name in headline
ARkStorm	20	84	0	1	105	(13)
Tsunami Scenario	2	6	0	0	8	(1)
HayWired	21	73	2	2	98	(11)

ARkStorm Over Time

The collected ARkStorm media mentions from development in July 2011 to August 2019 are shown in figure 15, with the orange line on the left axis. There are three notable spikes in media engagement—ARkStorm's publication in January 2011, and during the winter storms of February 2017 and February 2019. Late 2017 through mid-2018 also show increased activity, as the media increased publications about climate change and hazardous flooding, citing ARkStorm as an example of a megaflood (Brinklow, 2017). A review of the articles during the peaks in February 2017 and February 2019 show that ARkStorm is referenced in conjunction with unusual flooding due to precipitation. The right axis shows the average monthly precipitation data, collected from NOAA's California Nevada River Forecast Center (CNRFC, 2021). The spikes in precipitation correspond to the annual winter storms around December through February. Overall, the media related ARkStorm to real flood events in California, as well as a model for the increase in future flood risks due to climate change.

HayWired Over Time

HayWired Volume 1 was published April 24, 2017, but did not have a public rollout until April 18, 2018, accounting for the spike of media mentions at that time, shown

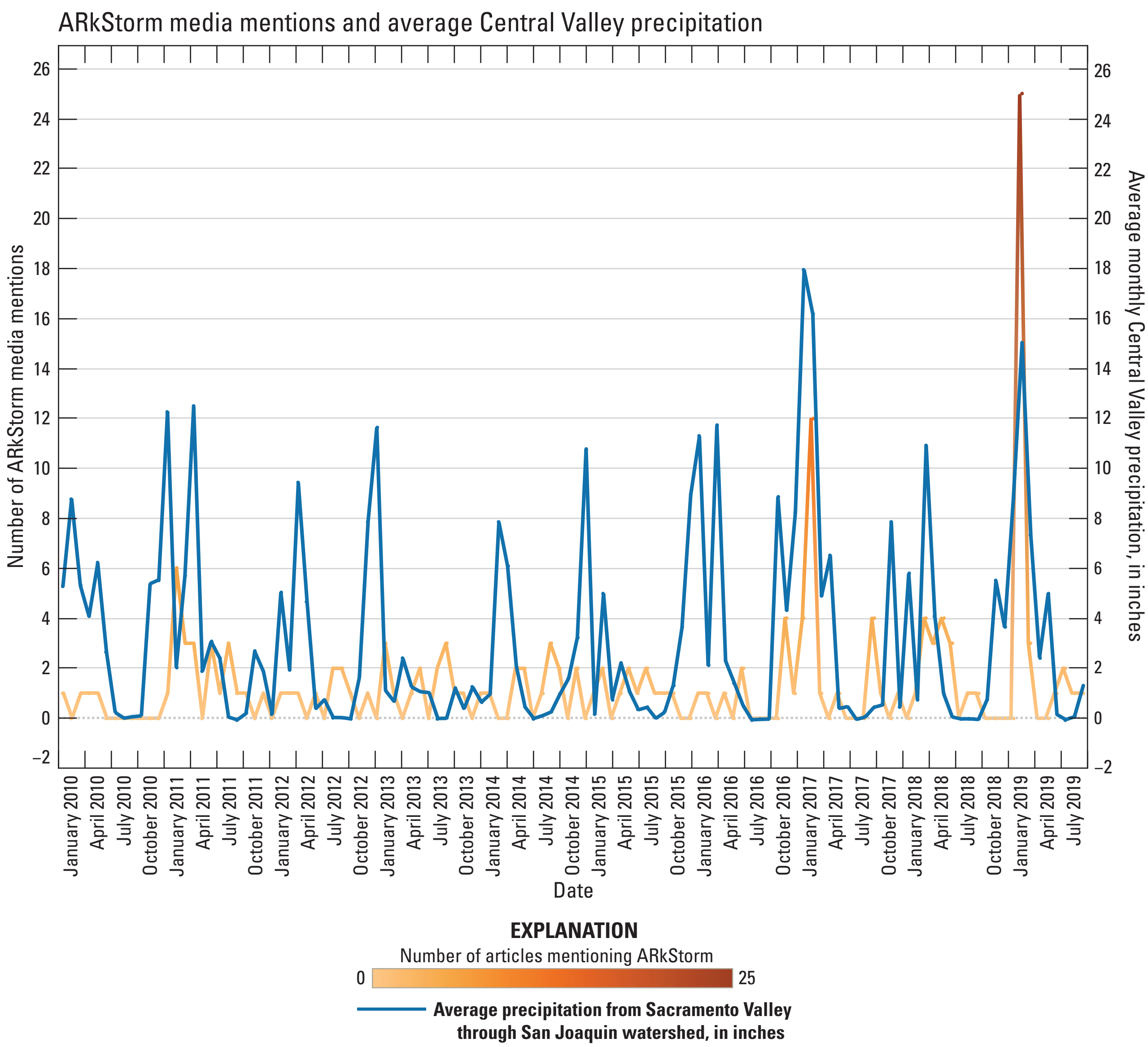

Figure 15. Increases in ARkStorm media mentions corresponding to spikes in the average monthly Central Valley, California precipitation.

in figure 16. In 2019, a series of earthquakes hit across California, and news reports on the earthquakes referenced HayWired as a cautionary tale.

Unlike ShakeOut, articles that mention HayWired tend to go into more detail about the scenario's projected damages, and specific preparedness efforts that the city ought to take or is taking, rather than individual preparedness efforts such as storing water and "drop, cover, and hold on." This study did not track mentions for Outsmart Disaster, the earthquake resiliency campaign that started with HayWired, but has since expanded to a multihazard approach (see app. 2).

Academic Mentions

The SAFRR mission is to innovate the application of science to reduce the risk of hazards, and part of that is to publish new, useful academic contributions to hazard and DRR science. The following section explores how the academic sector has engaged with the scenario materials.

Key Findings:

- Data and models from all four scenarios have been used to develop new methods, findings, or processes in hazard and DRR science, indicating they have stimulated the development of new technologies or innovations;
- Many authors refer to ShakeOut without explanatory clauses, indicating their assumption that ShakeOut is common knowledge in their field;
- ARkStorm is used as an **eponym.** Atmospheric river storms have been referred to as "ARkStorms" in several papers; and
- Tsunami Scenario is used significantly more for its models and data than the other scenarios, and less as a general example of a tsunami disaster.

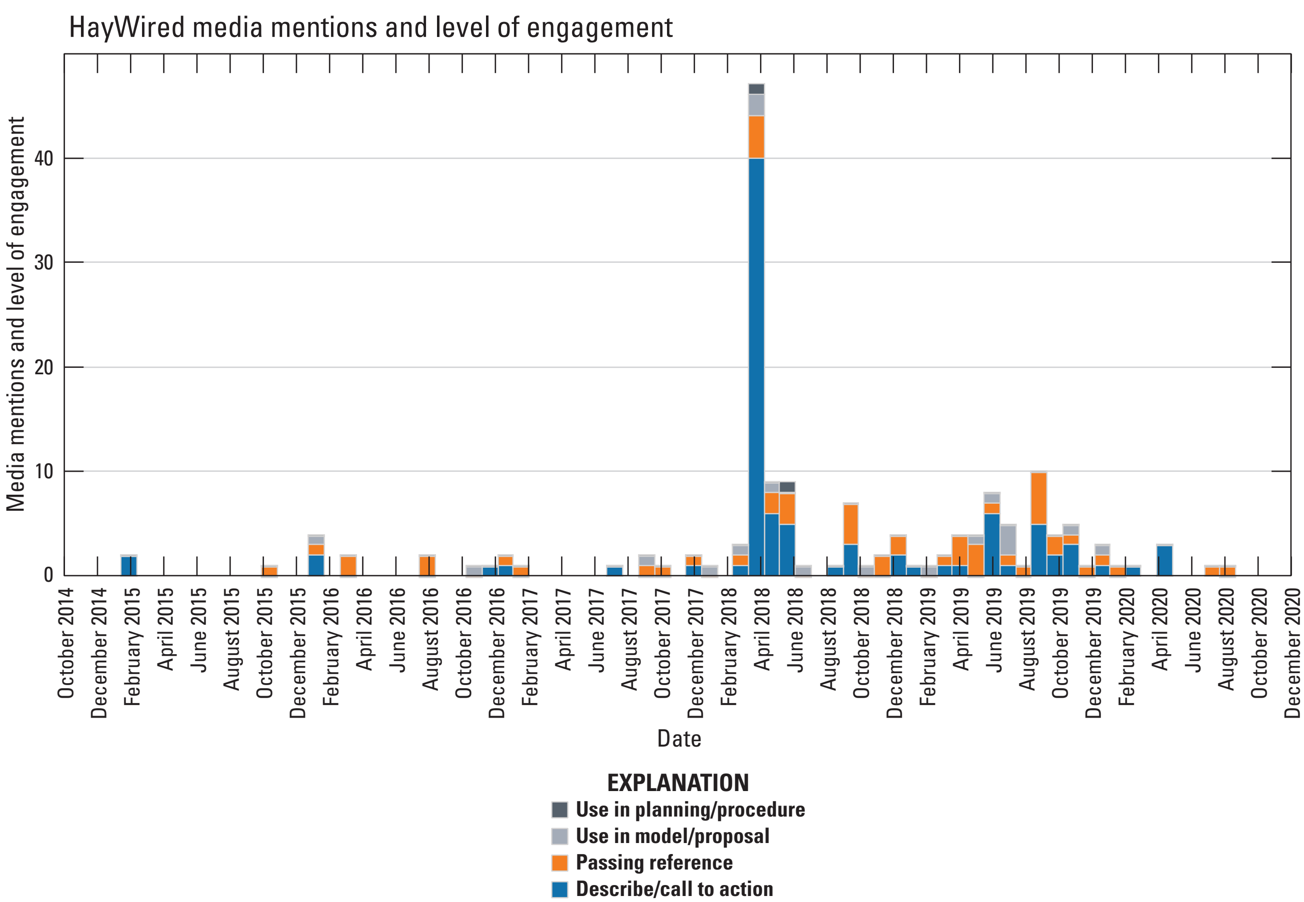

Figure 16. HayWired media mentions and level of engagement.

The total academic papers found and catalogued for this project are shown in table 6. These numbers are not comparable across the scenarios, as they have come out at different times and address different topics. These numbers are a minimum, as the study is limited to the available databases.

Tracking citations, and then the subsequent citations and downloads, illustrates the scenarios' presence in a larger conversation in academia. As many databases track citations and downloads differently, or not at all, or limit tracking to papers within their own databases, these numbers are a minimum estimate. The following figures 17 through 20 have a pie chart representing the papers that cite the scenario publications and their level of engagement, with a ring outside the pie chart to represent the number of times those papers have been cited. The furthest ring outside the pie chart represents the number of times those papers have been downloaded. The figures use concentric rings to represent a ripple effect of information about the scenarios moving away from the initial publications.

Table 6. Total academic mentions for all four hazard scenarios, marked by the colors that correspond to their branding: ShakeOut (yellow), ARkStorm (blue), Tsunami Scenario (gray), and HayWired (red).

Scenario	Passing Reference	Describe or Call to Action	Use in Model or Proof	Use in Planning or Procedure	Total
ShakeOut	104	59	128	9	300
ARkStorm	54	32	24	3	113
Tsunami Scenario	19	9	27	3	58
HayWired	27	13	19	0	59

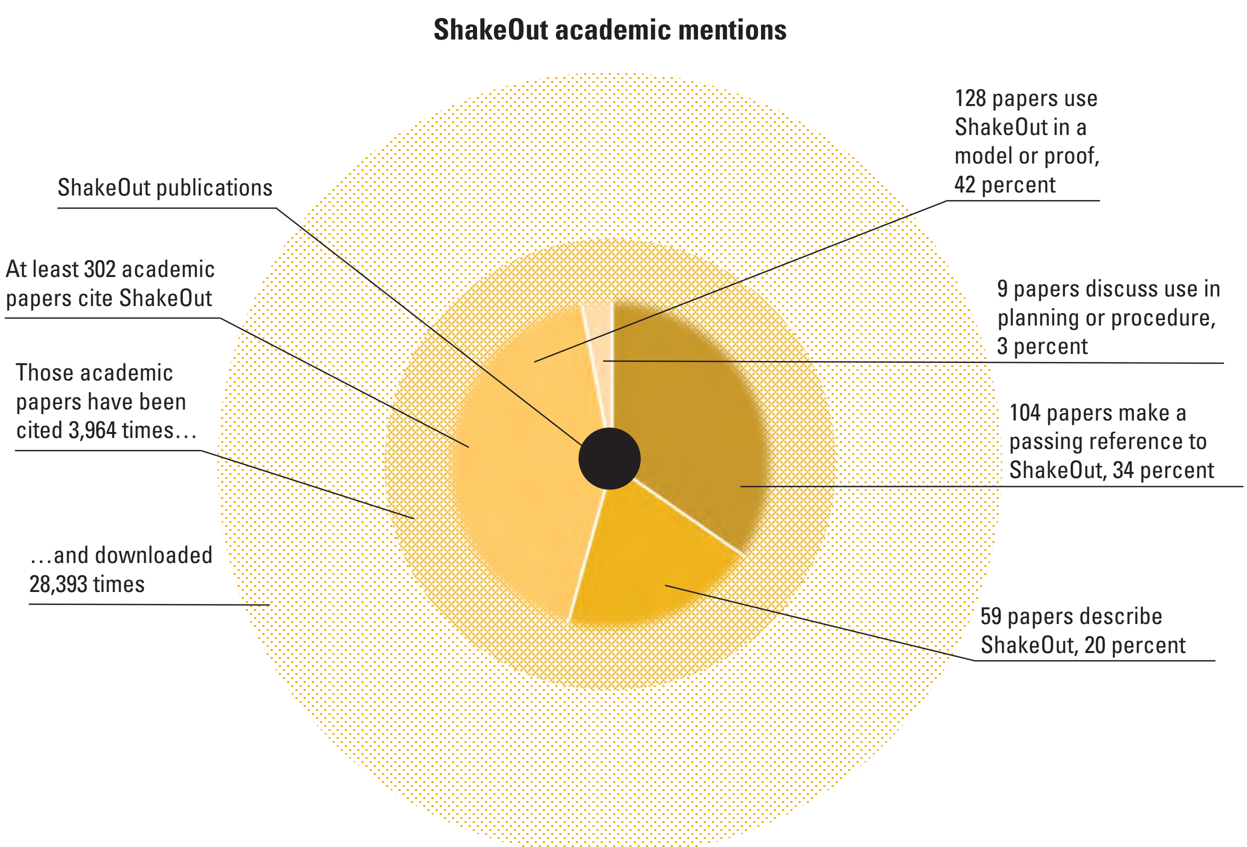

Figure 17. A graph of the ShakeOut academic mentions, centered on the original publications and showing the expanding rings of influence the scenario has had in academic publications.

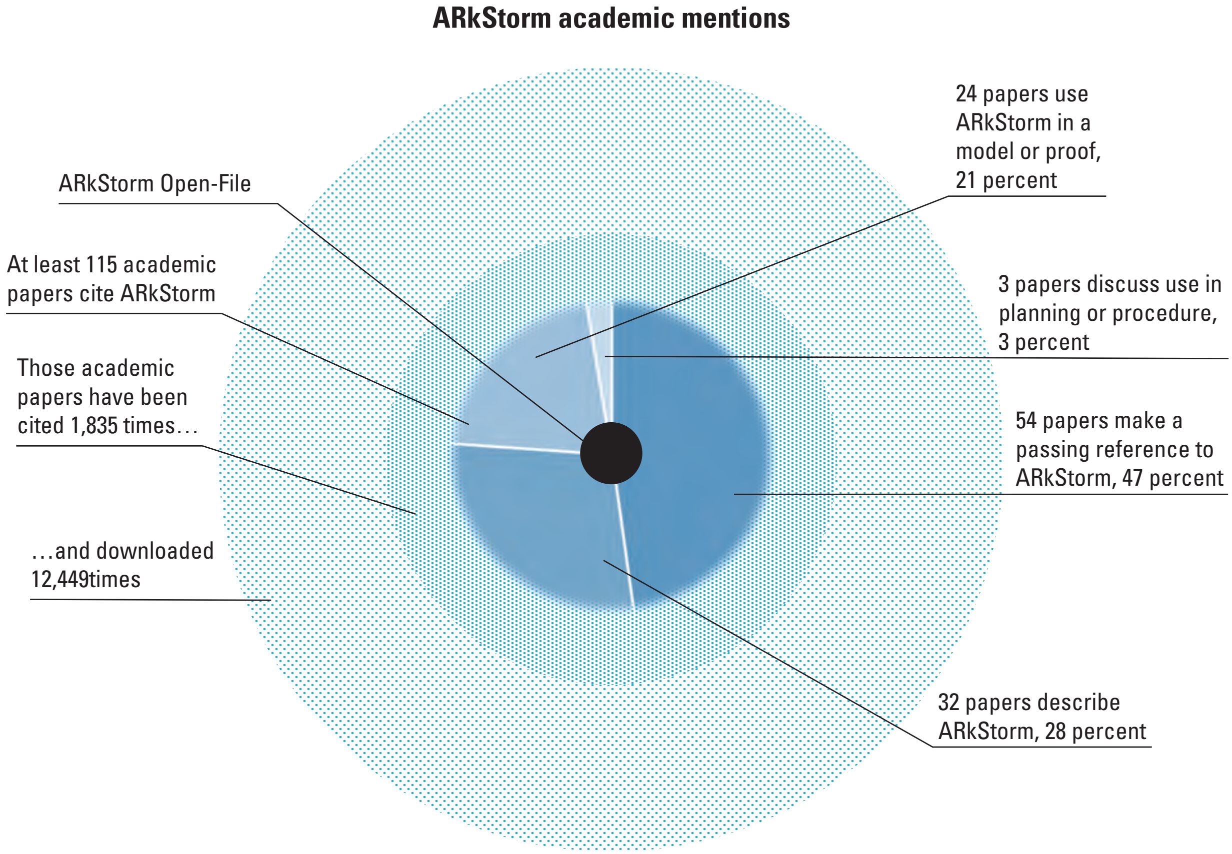

Figure 18. A graph of the ARkStorm academic mentions, centered on the original publications and showing the expanding rings of influence the scenario has had in academic publications.

ShakeOut

ShakeOut, being the oldest and most well-known scenario because of the Great ShakeOut campaign, has the largest academic effect of the scenarios. Of the 300 papers that cite the ShakeOut publications, 128 use ShakeOut data, models, or findings in models as proofs to expand scientific conversation on earthquakes and preparedness, as shown in figure 17. The 104 papers that make a passing reference to ShakeOut will say something similar to, "* * * other hazard scenarios, like ShakeOut, also use this method * * *" indicating that the authors expect there is some name recognition and common knowledge of ShakeOut in the academic circles of earthquake hazard awareness.

ARkStorm

ARkStorm is used as an eponym for atmospheric river fueled storms in many of the recorded mentions. This, along with using ARkStorm in a passing reference, at nearly 50 percent of academic mentions as shown in figure 18, indicate there is some expectation of common knowledge within the relevant fields. The use of ARkStorm data in models indicates potential innovation.

Tsunami Scenario

Tsunamis affect a smaller area than earthquakes and winter storms, so not having as many academic papers as ARkStorm or ShakeOut does not indicate that this scenario is not scientifically valuable but rather that tsunami science may be a smaller field than earthquake or storm science. Further, nearly half of the papers that referenced Tsunami Scenario use the scenario's data to model their own scientific inquiries, indicating it was more valued as a scientific source rather than a casual reference to tsunami preparedness, as shown in figure 19, where nearly 50 percent of academic mentions were use of Tsunami Scenario data or models. Although the scenario does have papers that give it a passing reference, its name is self-explanatory and does not indicate expectations of common knowledge.

HayWired

As of May 2021, HayWired had not been completely published, and many of the chapters useful to planning and procedure are still in review or have only been recently released. As a result, no academic papers discussed its use in planning or procedure, but that is expected. These numbers may be low

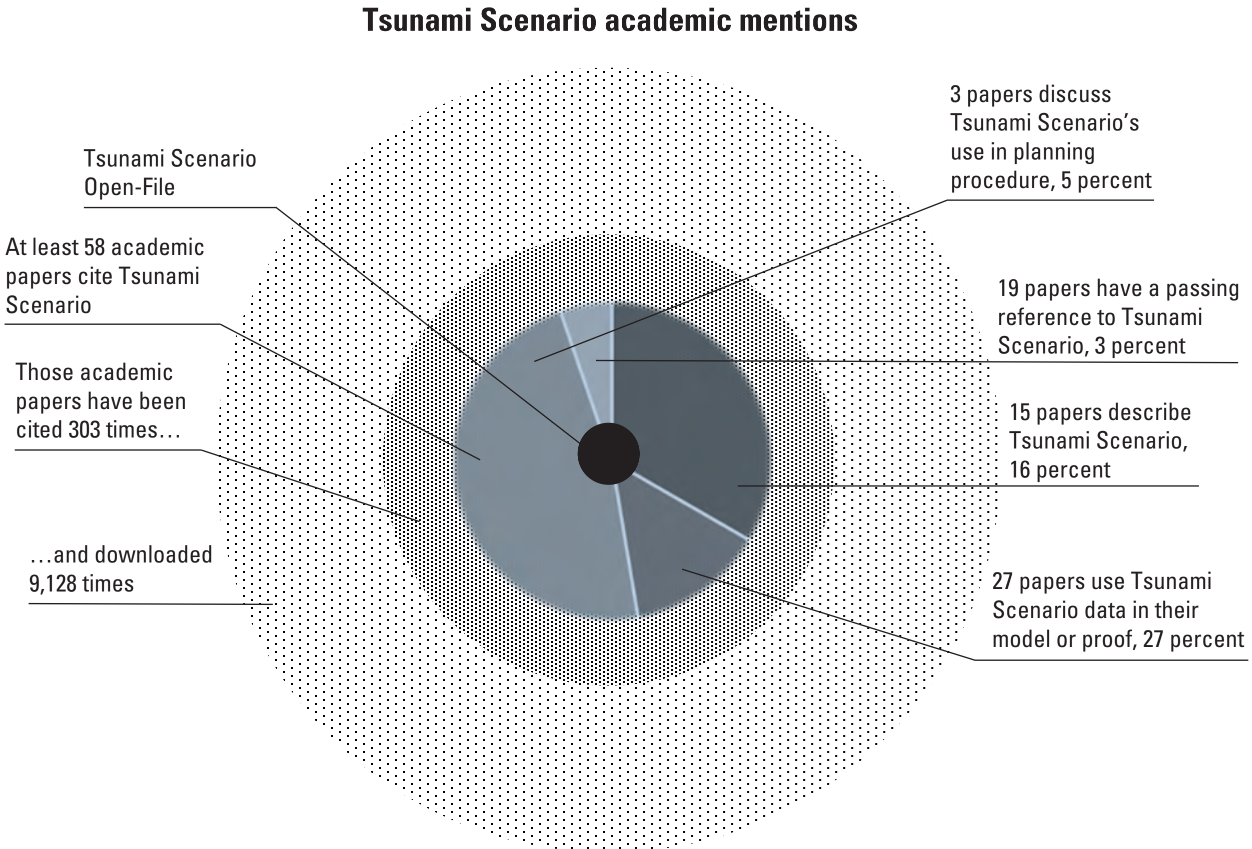

Figure 19. A graph of the Tsunami Scenario academic mentions, centered on the original publications and showing the expanding rings of influence the scenario has had in academic publications.

given the sometimes extremely slow cycle of journal writing, reviewing, and publishing. Although it is referenced in passing for 45 percent of the mentions, as shown in figure 20, many of the mentions referred to HayWired using a phrase similar to "HayWired Earthquake Scenario by USGS" and not just "HayWired," indicating that this scenario does not have the common knowledge associated with brand recognition. Many sources not captured in this dataset referred to HayWired as USGS' Hayward Fault scenario, as well, which may result in underrepresenting HayWired in academic mentions.

Local Hazard Mitigation Plans

The results for California county and city LHMP are presented in the following maps (figs. 21–24). Map overlays of scenario hazard impacts have been added, apart from ARkStorm, because a flooding overlay could not be found. The maps are not comparable to each other. Since the different scenarios affect different regions, an inland region would not use Tsunami Scenario in its LHMP. These findings are also available in the appendix in table 3.2. Not represented is the State of California's Hazard Mitigation Plan (HMP), which uses all four scenarios.

The purpose of the maps is to visualize which counties and cities are affected, and whether they use the scenarios in their LHMP. The presence or absence of a scenario in a LHMP is not the sole indicator of whether that municipality has experience with or used the scenarios. Inclusion of the scenarios in the LHMPs could be via independent contractors hired to write the LHMP, and municipality officials may be unaware of the scenarios. The exclusion of the scenarios from the LHMP could be because the municipality used other sources for hazard identification and preparation for the plan, but the municipality may have extensively used the scenarios for planning exercises and preparedness outside the LHMP.

Key Findings

- ShakeOut is used in 34 LHMPs, ARkStorm in 23, Tsunami Scenario in 7, and HayWired in 8.
- Many of the cities and counties that cite ShakeOut are referring to the annual drill.
- ARkStorm references are somewhat inconsistent with the area of acute ARkStorm damage, indicating it is generalizable to different areas beyond the Central Valley of California.

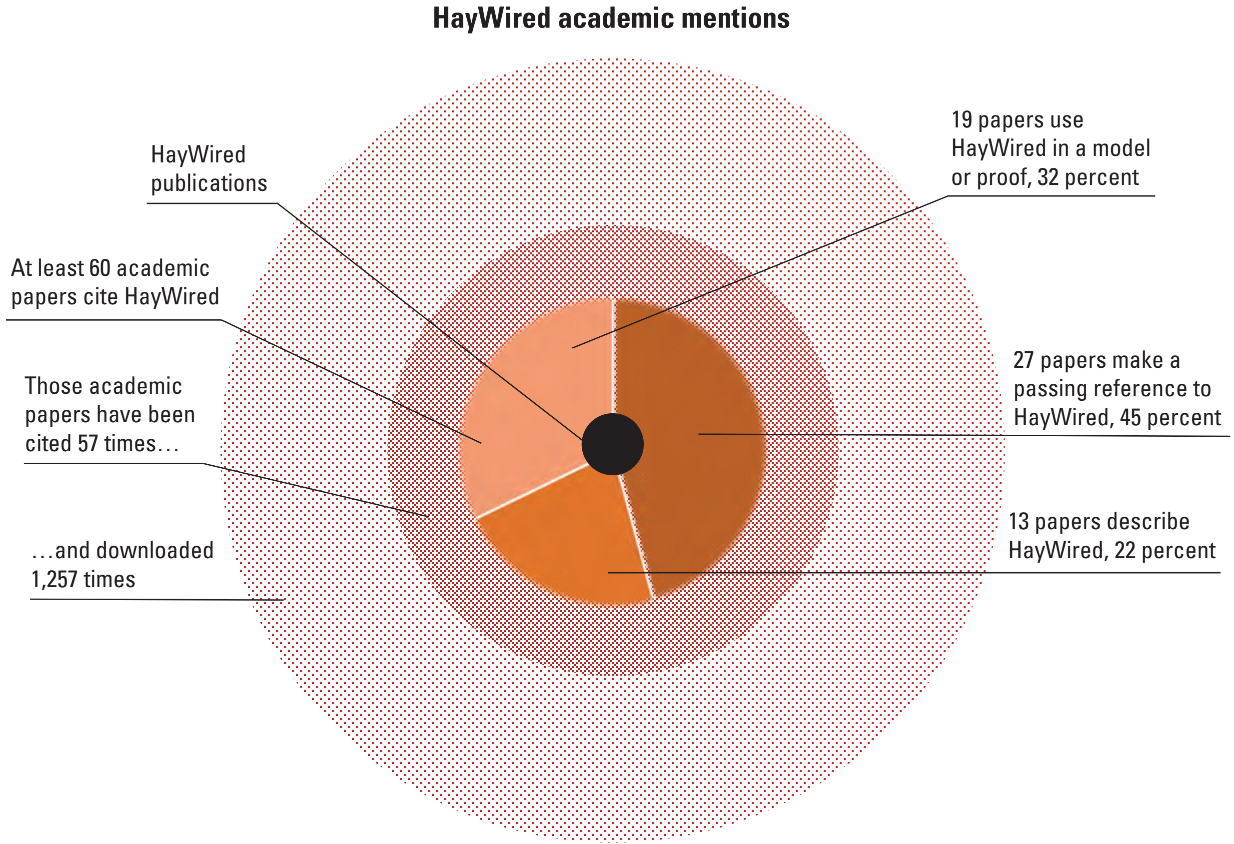

Figure 20. A graph of the HayWired scenario academic mentions, centered on the original publications and showing the expanding rings of influence the scenario has had in academic publications.

- Many coastal counties and cities cite the Association of Bay Area Governments (ABAG) for tsunami information. ABAG is a project partner and has used Tsunami Scenario for tsunami awareness and information consistently since publication.
- HayWired is referenced along the area of impact. Many LHMPs in the surrounding areas were written before HayWired publication, making it too early to estimate HayWired use through LHMPs.

ShakeOut

In the map of ShakeOut LHMP usage (fig. 21) there is a cluster of cities that reference ShakeOut in their LHMPs that follows the highest range of ground motion in the ShakeOut scenario. Approximately half the counties in the impacted range also reference ShakeOut. Several counties and cities outside the ShakeOut scenario's range of affect reference the scenario, often because they cite the Great Annual ShakeOut drill as part of the earthquake preparedness plan. Altogether, 34 cities and counties cite ShakeOut as part of their preparedness plans, many of which refer to the "Great ShakeOut" campaign.

ARkStorm

The map for use of ARkStorm in county and city LHMPs (fig. 22) shows 14 counties using ARkStorm, spread out across the State of California. Ventura County, site of the regional ARkStorm II project (see app. 2), has integrated ARkStorm into its LHMP. The city of Piedmont (near San Francisco) specifically referenced ARkStorm@Tahoe in its LHMP, which is interesting as Piedmont is about 150 miles away from Lake Tahoe. Two counties that make up part of the Lake Tahoe basin, Placer and Nevada, have ARkStorm in their LHMP. However, Placer, Nevada, Sacramento, Madera, Colusa, Calaveras, and Lake Counties all hired the consulting company Foster Morrison to write their LHMP, and Foster Morrison replicated their chapter on ARkStorm for all seven counties. It is uncertain if ARkStorm is known to those counties' emergency management personnel or if any of their preparedness efforts were inspired by ARkStorm.

San Luis Obispo County uses CoSMoS in their LHMP, which was developed through ARkStorm, and has since been the basis for multiple west coast modelling projects and initiatives (see app. 2 for details on the development of CoSMoS). San Luis Obispo also does not reference ARkStorm. For more information on the CoSMoS projects and team, visit https://www.usgs.gov/centers/pcmsc/science/coastal-storm-modeling-system-cosmos.

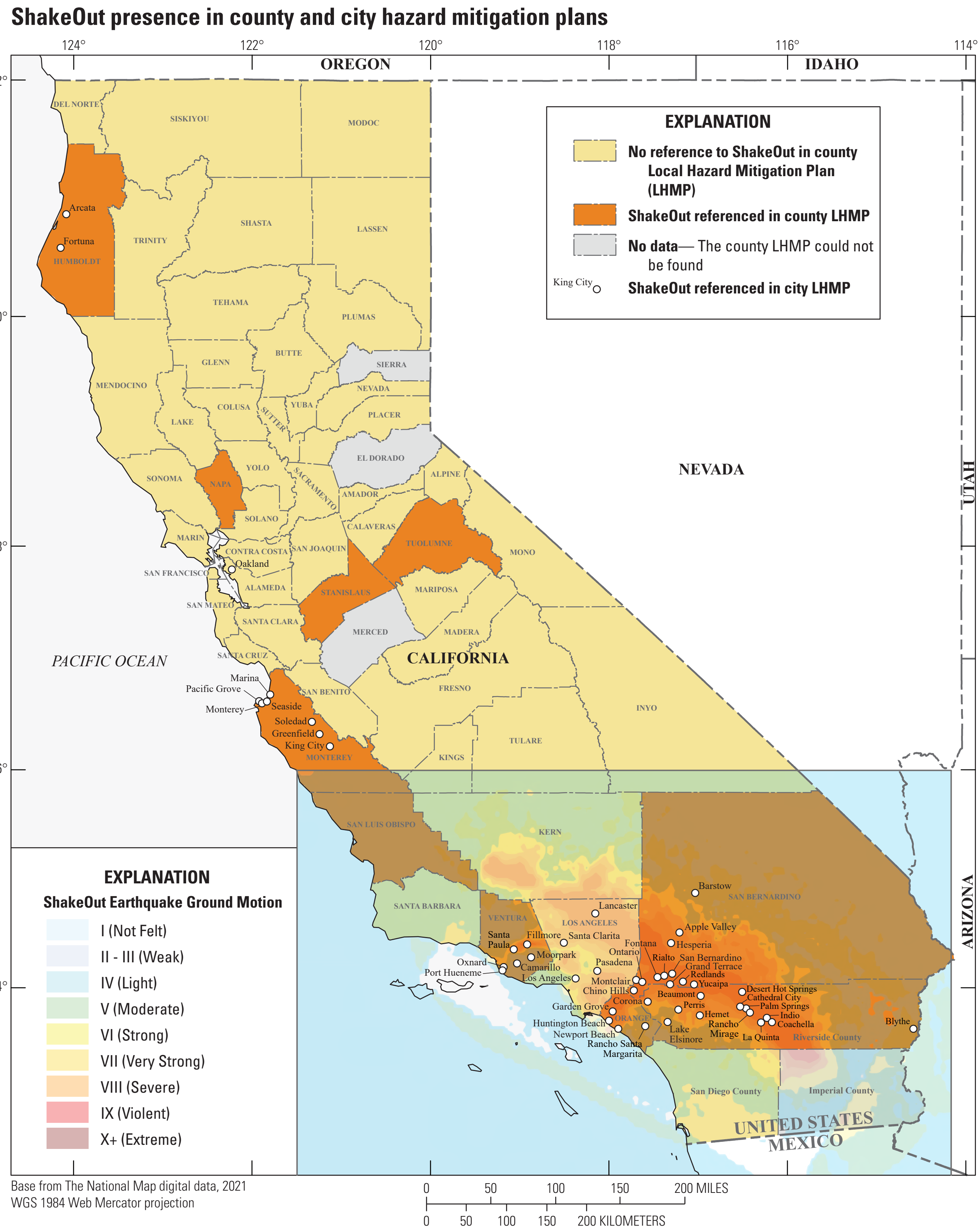

Figure 21. A map of references to ShakeOut in county and city Local Hazard Mitigation Plans (LHMP). ArcMap overlay for ShakeOut ground motion provided by the U.S. Geological Survey “Southern California 2008 ShakeOut M7.8 Scenario” (available at https://services.arcgis.com/DO4gTjwJVIJ7O9Ca/ArcGIS/rest/services/SoCal_7_8/FeatureServer/0).

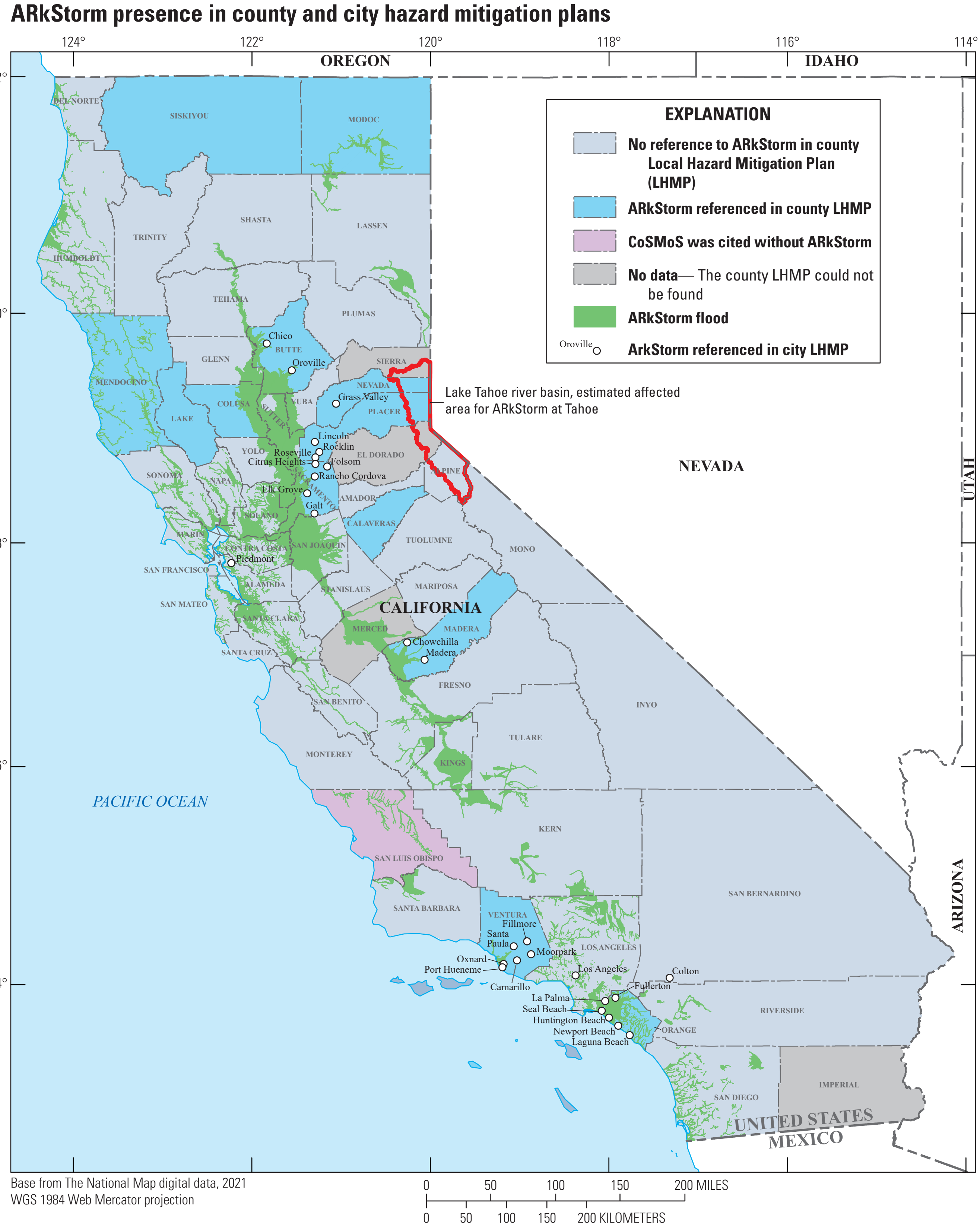

Figure 22. A map of references to ARkStorm in county and city Local Hazard Mitigation Plans (LHMP). Lake Tahoe basin outlined in red to identify ARkStorm@Tahoe region. Tahoe-Sierra Integrated Water Management (IRWN) boundary layer created by the Sierra Water Workgroup, California Department of Water Resources, and Kate Gladstein (available at https://services6.arcgis.com/MtSzpOZ2FMytnchL/ArcGIS/rest/services/TSDMS_Boundaries/FeatureServer/0). (CoSMoS, Coastal Storm Modeling System)

Tsunami Scenario

The map in figure 23 shows that San Francisco County is the only county to directly reference Tsunami Scenario in its LHMP. Some of the surrounding coastal counties and cities referenced the ABAG for their tsunami information. However, ABAG was a project partner in Tsunami Scenario, has used Tsunami Scenario map data and reports in tsunami information materials, and features Tsunami Scenario on their webpage (ABAG, 2021). Other coastal counties and cities referenced the State of California's HMP, which also used Tsunami Scenario to inform some of its tsunami risk assessments. Not all the LHMP that referenced ABAG or the State of California's LHMP are noted on the map.

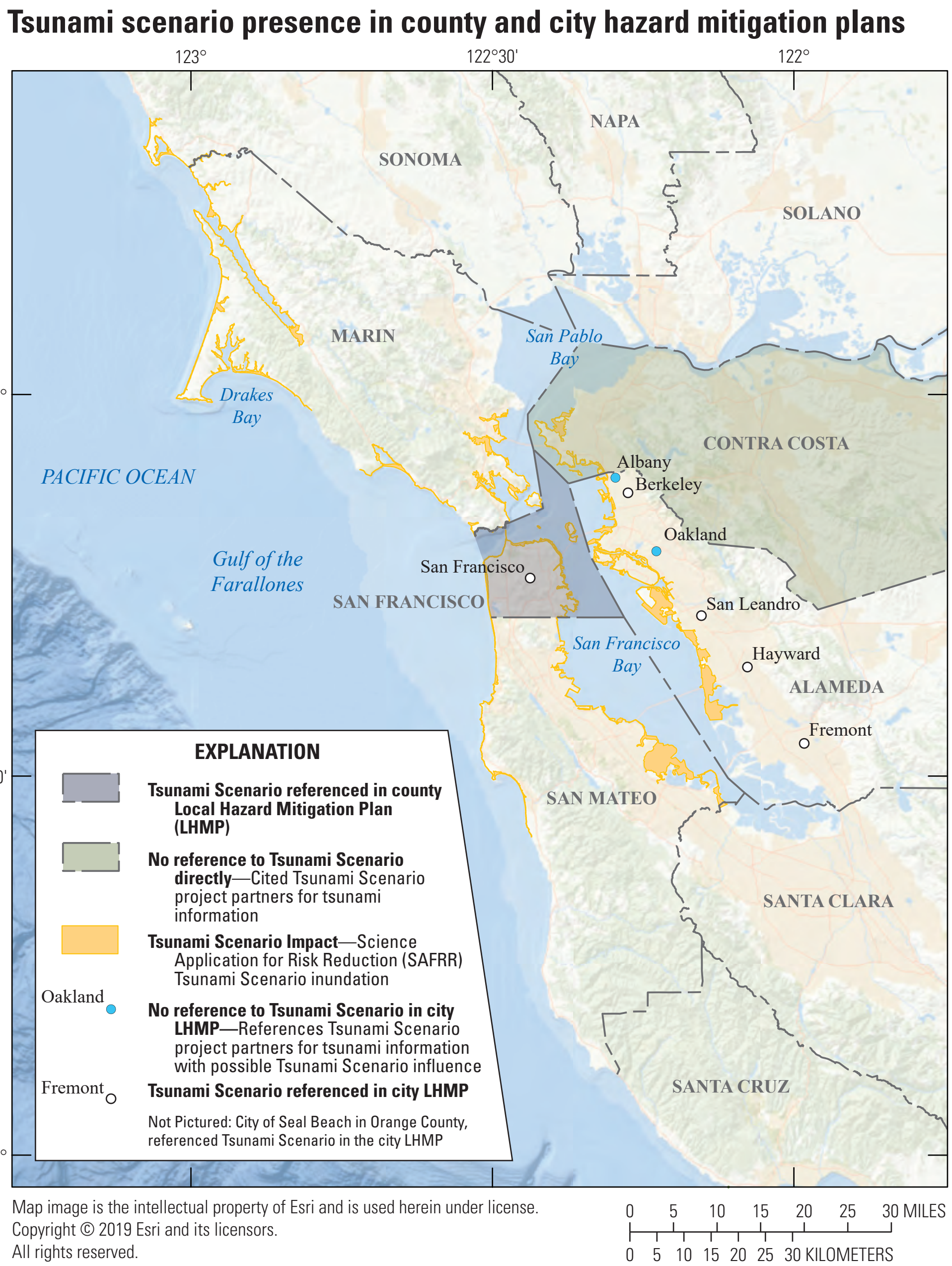

Figure 23. A map of references to Tsunami Scenario in county and city Local Hazard Mitigation Plans (LHMP). Science Application for Risk Reduction (SAFRR) Tsunami Scenario layer created by the U.S. Geological Survey and made available on ArcMap by the Association for Bay Area Governments (ABAG; available at https://services3.arcgis.com/i2dkYWmb4wHvYPda/arcgis/rest/services/tsunami_safrr_scenario/FeatureServer).

It is apparent that Tsunami Scenario has been integrated into different packages of tsunami information and initiatives through project partners (see app. 2), and the lack of direct references in the city and county LHMP is not an indicator of lack of use.

HayWired

HayWired is referenced in one county and eight cities (fig. 24), as it is the newest scenario and partially unpublished. The county and cities that reference the scenario are all in the scenario affect area. It is important to note that LHMP are updated every 5 years, and over two-thirds of the LHMP were written before HayWired was released. Additionally, many LHMP updates due over 2020 were delayed because of Covid-19. In some cases, county, or city LHMP mentioned Hayward Fault and scenarios but did not cite HayWired or the USGS for the information, or specify other sources, so it is unclear if the scenario was involved.

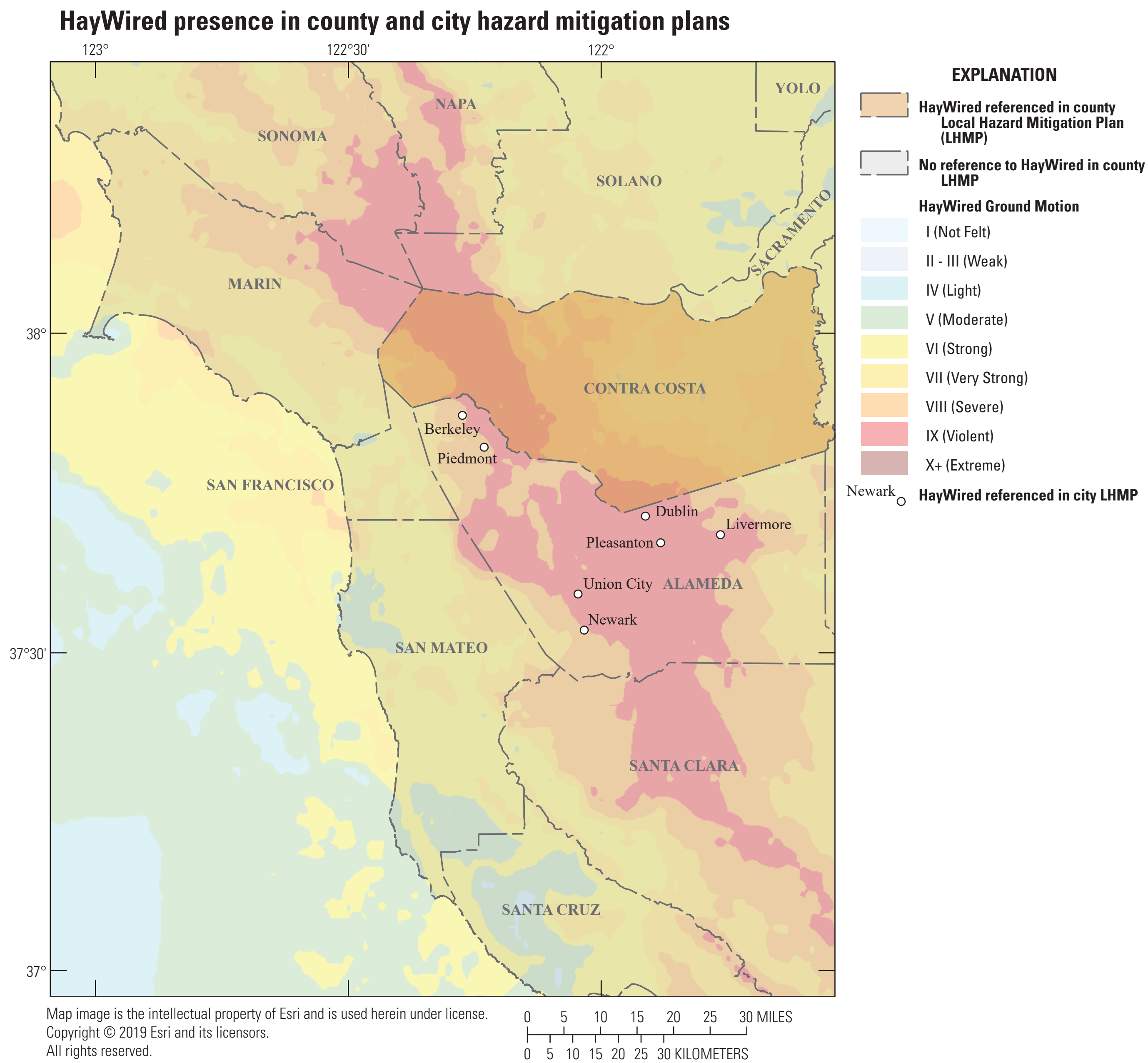

Figure 24. A map of references to HayWired in county and city Local Hazard Mitigation Plans (LHMP). HayWired ground motion provided by the California Integrated Seismic Network (available at https://services3.arcgis.com/i2dkYWmb4wHvYPda/arcgis/rest/services/eq_hayward_northsouth/FeatureSer).

Innovations

To answer RQ3 (have SAFRR scenarios stimulated the development of new technologies or innovations for disaster response preparedness?), information on innovations through the interviews and research was collected. The innovations listed here are organized by the categories outlined in figure 6, and some are described in more detail in the retrospective scenario histories in appendix 2. This is not an exhaustive list of scenario innovations; the following is a collection of examples that illustrate the scenarios' footprint in DRR innovation.

Many interviewees considered the scenarios themselves to be innovative. They experienced the multidisciplinary collaboration on new hazard science and procedure as innovative, as well as the focus on interdependencies and breaking down the silos between organizations. Interviewees also considered much of the science and technology made for the scenarios as innovative.

A common thread in the interviews among both users and developers was that the scenarios contained an unprecedented level of detail, both in the analysis, as well as in the data packages used to build the models. Users applied the scenario data to model their own regions and added factors to assess hazard risk. The academic sector and DRR planning practitioners have used the scenario's data and models to create new science, new models, and new policy in their fields.

ShakeOut

The development innovations included here for ShakeOut are categorized by scenario processes, science and technology, and marketing. Innovations in use are categorized under policy innovations and systemic innovations.

Development Innovations

Scenario processes—ShakeOut was the most comprehensive earthquake scenario ever made according to the ARkStorm OFR (Porter and others, 2011).

Scenario Processes—A paper on the lifeline interdependency panels described them as a novelty (Porter and Sherrill, 2011). This paper posits that emergency planning involving lifelines had previously been dominated by consultants and experts who were not themselves involved in the lifelines in question, and the inclusion of lifeline representatives was credited for much of the detail, credibility, and use of ShakeOut.

Science and technology—One example of ShakeOut's innovative level of detail is the liquefaction model. One interviewee discussed how liquefaction damage calculations had previously involved some assumptions about soil susceptibility and a percentage of failure, but for ShakeOut, the calculations were done using a highly detailed water table analysis created by a ShakeOut developer.

> "Liquefaction ends up being a very small percentage of the ShakeOut damage because of this really innovative work"
>
> Interview 12, 2020, on why ShakeOut is an innovative product.

Marketing—Creating a brand-like identity for ShakeOut by making a distinctive name to use for promotion in a public campaign was considered innovative for a USGS product. The brand is credited for The Great ShakeOut's international success by three interviewees. Branding also allowed for name recognition in the news media cycle, placing ShakeOut in headlines when disasters occur.

Use Innovations

Policy—The USGS created a technical assistance partnership with the Mayor's Office of Los Angeles, using ShakeOut as a blueprint for earthquake resilient policy design. This was responsible for a massive retrofitting policy push called "Resilient Design," and multiple retrofitting ordinances being approved in the city. For more information on Resilient Design, see appendix 2.

Systemic—While not the first earthquake drill, The Great ShakeOut earthquake campaign has internationally standardized the "drop, cover, and hold on" earthquake drills. The ShakeOut website drill registrations demonstrate widespread adoption in school districts, businesses, and municipalities across the world, and it is the most widespread earthquake drill in the United States (Adams and others, 2017).

ARkStorm

The ARkStorm innovations listed here consist of development innovations in science and technology, and use innovations in Administrative or Organizational and Service Delivery.

Development Innovations

Science and Technology—The study of atmospheric rivers was a relatively new field when ARkStorm started.

> "I think the most innovative thing definitely early on was the fact that—first of all, I think it put atmospheric rivers on the map, and figuring out how to model them and develop these kinds of scenarios."
>
> Interview 19, 2020, on why ARkStorm is innovative.

This interviewee noted that academic papers on atmospheric rivers dramatically increased after the publication of the scenario.

Science and Technology—ARkStorm was also the first to calculate losses from highway flood damage due to storms based on real life data.

> "nobody'd ever put that together in terms of from a storm."
>
> Interview 12, 2020, on the innovative highway flood damage estimates of ARkStorm.

Interview 12 noted that for two California Department of Transportation (Caltrans) districts, interns working on ARkStorm went to Caltrans offices and went through every contract for road repair, determined if it was for rain damage, tabulated the costs, and then extrapolated the cost information to all the road systems affected by ARkStorm.

Science and Technology—CoSMoS, a new modelling system for the California coastline, was developed for ARkStorm to see how the precipitation would impact coastal areas. CoSMoS continues to do innovative work with coastal flooding and climate change, including virtual reality simulations to communicate the science (Barnard and Erikson, 2021). CoSMoS is described in appendix 2.

Science and Technology—A new predictive flood modelling program named FloodCast is currently in development. Like ShakeCast, Caltrans' earthquake damage prediction model, use of FloodCast is expected to aid decision makers in anticipating where road flooding will occur during precipitation events in California so that Caltrans response and repair crews can be efficiently deployed. The idea for FloodCast was inspired by ARkStorm from information an interviewee learned at the ARkStorm Summit. For more information, see appendix 2.

Use Innovations

Administrative or Organizational and Service Delivery—The California Water/Wastewater Agency Response Network (CalWARN) developed, through ARkStorm and the ShakeOut, an emergency response protocol called the water desk, a position that centralizes water emergency response and recovery efforts, as multiple agencies and organizations respond to a disaster and multiple mutual aid contracts are navigated. CalWARN is working to get this position in every county Emergency Operations Center (Porter and Sherrill, 2011; Sturdivan, 2011).

> "This position was activated after the 2010 Northern Baja earthquake and worked well. This real event helped the water and wastewater agencies to educate State and local officials about industry challenges in a disaster and how the industry can support affected agencies in response and recovery." (Porter and Sherrill, 2011, p. 454)

Tsunami Scenario

The Tsunami Scenario innovations listed here consist of development innovations in science and technology, and use innovations in policy.

Development Innovation

Science and Technology—Tsunami Scenario's depth of modelling and analysis was innovative for a developer and user interviewee.

> "I think that everything that I did was new and groundbreaking, from my perspective this is the first time that we were ever able to get a look at what the damage could be from a tsunami. * * * this is more comprehensive, clearly. It called out what the environmental impacts would be, and so it's going to be broader and deeper than just a simple software tool and then get a lot of—all of the thousand pages of analysis and material descriptions of the impacts and implications are valuable."
>
> Interview 9, 2020, on the depth of damage analysis in Tsunami Scenario.

Use Innovation

Policy—Interviewee 9 also discussed the Tsunami Scenario's policy recommendations contributing to the additions of tsunami requirements to the Seismic Hazard Mapping Act (Public Resources Code, chap. 7.8, sec. 2690–2699.6), which directs the California Geologic Survey to identify and map areas prone to earthquake hazards (CGS, 2021b).

> "Seismic Hazard Map Act—has a tsunami component that's being implemented now, and so those policy implications and how that policy is going to affect how construction can happen on the coast is something that we're looking at even now. The catalyst for some of the recommendation came out of [Tsunami] Scenario. The Tsunami Scenario Policy Implications chapter outlines over 40 public policy implications and recommendations, some of which have reportedly contributed to the implementation of California's Seismic Hazards Mapping Act by requiring the State to create tsunami sone maps (initial maps to be completed in the summer of 2021) identifying tsunami impact areas that counties will have to use for their construction permitting process."
>
> Interviewee 9, 2020, on Tsunami Scenario's policy influence.

HayWired

The HayWired innovations listed here are comprised of development innovations in scenario processes and science and technology, and use innovations in policy, marketing, and administrative or organizational.

Development Innovation

Scenario Processes—Interviewee 1 considered HayWired's level of detail is a large step beyond the previous SAFRR scenarios.

> "This is a big evolution. [HayWired] is not just a macro model. We went to spatial and micro."
>
> Interview 1, 2020, on the innovative scope of HayWired.

Interviewee 16 noted that though there were dozens of different scenarios for hazard planning in their region, none of them were close to the level of detail in the parcel level data packages, which the interviewee was able to use in their own hazard planning models.

Science and Technology—The HayWired publications feature new methods, models, and scientific conclusions, some of which are described in appendix 2, such as mathematizing how earthquake early warning could give people time to complete “drop, cover, and hold on.” Other innovations are documented in a conference paper from the 11th National Conference in Earthquake Engineering (Wein, 2018).

Science and Technology—Creating a telecommunications lifeline model is a first on this scale. Interviewee 1 noted that it had not been done before, partially because telecommunications infrastructure is owned by hundreds of private companies, making it extremely difficult to collect data on cell towers, broadband, internet exchange points, and other forms of infrastructure. Interviewee 4 called HayWired the first internet age disaster.

Use Innovation

Marketing—HayWired had been involving the private sector in the models for economic impacts, enabling developers working on the Outsmart Disaster campaign to recognize that there was a gap in how emergency management was communicated to small businesses. Outreach of Outsmart Disaster was tailored to the smaller, locally owned private sector (BCSH, 2021). appendix 2 has more information on Outsmart Disaster.

Policy—ABAG used HayWired extensively in their regional plan, resulting in a policy directive to retrofit over 300,000 seismically deficient buildings over the next 30 years. For more on this plan, see appendix 2.

Administrative or Organizational—Building an organization, like the HayWired Coalition, is an innovative way for the SAFRR project to harness stakeholder engagement not just for scenario input and workshopping, but to take ownership of the scenario and continue to promote its use (Wein, 2018). See appendix 2 for more details on the HayWired Coalition.

Actionable, Longitudinal, Educational, Relevant, and Thorough Evaluation Tool

The ALERT Evaluation tool prototype consists of the following series of checklists (tables 7–12), with a leading checklist titled “Overall Scope” for project design and organization. The indicators for this prototype align with region-scale, strategy-driven natural hazard scenarios, and can be altered depending on the specific goals of other projects. The indicators listed are the product of this evaluation’s findings and are therefore not an exhaustive list of indicators for a successful scenario planning method.

The following subsection “ALERT Evaluation Tool SAFRR Scenario Totals” contains a table with totals for each ALERT subcategory. This helps inform what methods different scenarios prioritized during development and deployment. The totals are not scores indicating quality but are intended to bring attention to the methods the scenarios did or did not use. While this tool has been used as a retrospective analysis for this evaluation, it can be used at any time during the scenario planning process to help set measurable goals, check progress, and help scenario planners create a methodology for their project. This tool offers a first step towards developing a model for project design, as well as process and outcome evaluations by the scenario planners themselves.

Key Findings:

- Each subsequent SAFRR scenario increased in thoroughness and detail.
- All four scenarios show opportunities for growth in longitudinal, as a primary category, and accessibility, as a subcategory.
- The highest score in actionable was ShakeOut, due to a campaign and multiple public events.
- HayWired’s relevance and actionable totals may change with the publication of its third volume, and its longitudinal score may decrease as time passes after publications and rollout.

Table 7. Science Application for Risk Reduction (SAFRR) Evaluation Tool—Overall Scope.

[–, placeholder for number that user will enter; NA, Not Applicable; --, no check]

Overall Scope						
Check Number	**Project Design**	**0=No 1=Yes**	**Team Preparation**	**0=No 1=Yes**	**Stakeholder Engagement**	**0=No 1=Yes**
Check 1	Does the project have a mission statement?	–	Has the project developed a clear, elevating purpose with the scenario planning team?	–	Did the project engage all major lifeline industries?	–
Check 2	Does the project have clearly outlined short-term and long-term goals?	–	Were the scientists building the source modelling briefed in the need for a generalizable model?	–	Did the project engage community leaders from large language/race minority groups?	–
Check 3	Are the project goals quantifiable, to measure progress and success?	–	Has the development team developed a consensus about the balance between highly precise science and timeliness?	–	Did the project engage multiple levels of local government?	–
Check 4	Did the project outline target users and how they are expected to use the scenario?	–	Were the scientists building the source modelling engaged in the planning process for deliverables to secondary impact modelers?	–	Did the project engage partners that are aligned in the same goal/hazard work?	–
Check 5	Does the project have a logic model?	–	Were the scientists building the source and secondary impact modelling engaged in the planning process for deliverables to lifeline and infrastructure engineers?	–	Did the project include community partners in a needs assessment?	–
Check 6	Does the project have a workflow diagram?	–	Were the infrastructure and lifeline damages modelers engaged in the planning process for deliverables to economic and social impacts modelers?	–	Did the project include lifeline industries in a needs assessment?	–
Check 7	Does the project have plans for level of detail required in each sequence?	–	Were development team members a part of developing the schedule and timeline for product completion?	–	Did the project include local government in a needs assessment?	–
Check 8	Is there a person assigned to recording how and why decisions were made about project design and development?	–	--	–	Did the project leadership review organization charts of partners to ensure they were leveraging the full expertise of community partners?	–
Check 9	Is there an authority to enforce the deadlines?	–	--	NA	--	NA
Check 10	Does the project have a schedule with deadlines?	–	--	NA	--	NA
Subsection Totals	--	**0**	--	**0**	--	**0**
Category Total	**0**					

Table 8. Science Application for Risk Reduction (SAFRR) Evaluation Tool—Actionable.

[–, placeholder for number that user will enter]

Actionable				
Check Number	**Tools**	**0=No 1=Yes**	**Accessibility**	**0=No 1=Yes**
Check 1	Are stakeholders involved in all stages (before, during, after) of developing scenario tools?	–	Are there preparedness actions that are financially accessible to most stakeholders?	–
Check 2	Do the actions required for mitigation, adaptation, or preparedness have clear lines of jurisdiction?	–	Are the preparedness actions within stakeholder capacity?	–
Check 3	Are the drills, practice, and planning tools usable without expert guidance?	–	Are the preparedness actions targeted to stakeholders within their jurisdictions?	–
Check 4	Are the tools transferable to different levels/ intensities/locations for the same hazard?	–	Are the preparedness actions easily available to stakeholders without rigorous searching through a report?	–
Check 5	Are the tools transferable to different hazards?	–	Are the preparedness messages appropriately modified for the comprehension level of target stakeholders?	–
Check 6	Did the scenario-based tool development incorporate usability/user-centered design?	–	Have preparedness messages been reviewed by diverse stakeholder groups?	–
Check 7	Are the scenario's base scientific data and models organized and clearly labelled for release to users?	–	Are preparedness action instructions and preparedness messaging available in multiple languages?	–
Subsection Totals		**0**		**0**
Category Total	**0**			

Table 9. Science Application for Risk Reduction (SAFRR) Evaluation Tool—Longitudinal.

[USGS, U.S. Geological Survey; –, placeholder for number that user will enter; --, no check; NA, Not Applicable]

Longitudinal						
Check Number	**Internal Longevity**	**0=No 1=Yes**	**External Longevity**	**0=No 1=Yes**	**Follow through**	**0=No 1=Yes**
Check 1	Is there a USGS liaison for community partners to contact regarding the scenario after project completion?	–	Are stakeholders demonstrating buy-in and continuing to disseminate scenario information independent of scenario leadership?	–	Has the project identified community partners that are able to carry out preparedness actions?	–
Check 2	Is there a USGS employee assigned to track scenario use and engagement after project completion?	–	Is authority delegated to a community partner to continue outreach efforts past publication and project completion?	–	Is local government involved in oversight surrounding preparedness actions?	–
Check 3	Is there a USGS liaison to connect community partners with each other when appropriate?	–	Does the scenario have an outreach coordinator among project partners to continue working on messaging and efforts with a disparate group of stakeholders?	–	Is there a plan to check in about follow-through of community partner's preparedness actions?	–

Table 9. Science Application for Risk Reduction (SAFRR) Evaluation Tool—Longitudinal.—Continued

[USGS, U.S. Geological Survey; –, placeholder for number that user will enter; --, no check; NA, Not Applicable]

Longitudinal						
Check Number	**Internal Longevity**	**0=No 1=Yes**	**External Longevity**	**0=No 1=Yes**	**Follow through**	**0=No 1=Yes**
Check 4	Is there a USGS employee assigned to update the scenario's pages on the USGS website, including modernizing the pages, or reorganizing for usability?	–	If project partners have a high turnover in leadership, does the scenario planning team have tools for a transfer of knowledge to the new leadership?	–	--	NA
Subsection Totals		**0**		**0**		**0**
Category Total	**0**					

Table 10. Science Application for Risk Reduction (SAFRR) Evaluation Tool—Educational.

[–, placeholder for number that user will enter; --, no check; NA, Not Applicable]

Educational								
Check Number	**Inclusive and Diverse**	**0=No 1=Yes**	**Multiple Techniques**	**0=No 1=Yes**	**Awareness and Outreach**	**0=No 1=Yes**	**Accessibility**	**0=No 1=Yes**
Check 1	Did the scenario impacts development process include representatives from the affected region's demographics?	–	Is there a fact sheet detailing the scenario?	–	Is there a unifying brand name and symbol that can be easily recognized on all products?	–	Did the scenario source developers engage with secondary impact modelers to ensure understanding of their material?	–
Check 2	Did the outreach development process include representatives from the affected region's demographics?	–	Are there informative and engaging visuals available about the scenario and preparedness initiatives?	–	Is there a unifying message that is clear, straightforward, and contains preparedness actions or an indication there are preparedness actions available?	–	Did the scenario developers engage with emergency management and decision makers to ensure understanding of their material?	–
Check 3	Is the scenario information available in the primary languages of the target population?	–	Did the scenario team tailor presentations to target stakeholder groups?	–	Were media/ campaign/ outreach developers briefed in disaster risk reduction messaging best practices?	–	Did the scenario source & hazard modelers engage with target industry representatives to ensure understanding of their material?	–

Table 10. Science Application for Risk Reduction (SAFRR) Evaluation Tool—Educational.—Continued

[–, placeholder for number that user will enter; --, no check; NA, Not Applicable]

Educational								
Check Number	**Inclusive and Diverse**	**0=No 1=Yes**	**Multiple Techniques**	**0=No 1=Yes**	**Awareness and Outreach**	**0=No 1=Yes**	**Accessibility**	**0=No 1=Yes**
Check 4	Were representatives of marginalized communities present in the development phase?	–	Are there multi-media detailing the scenario?	–	Were community partners involved in outreach to their own sectors/groups?	–	Is the scenario publication hosted on a navigable website?	–
Check 5	--	NA	Is there a plain language summary of the information available in the scenario report?	–	Did the scenario team travel to different forums for outreach?	–	Are the fact sheets readily available and searchable?	–
Check 6	--	NA	Did scenario planners host informational sessions in public forums?	–	Is the outreach information available on a navigable website?	–	Is there a video detailing the scenario information and best practices readily available and searchable?	–
Check 7	--	NA	Does the outreach package include different levels of educational material?	–		NA	Does the video have comprehensive subtitles or text?	–
Check 8	--	NA		NA		NA	Is there an audio (for the visually impaired) informational product to the scenario?	–
Subsection Totals		**0**		**0**		**0**		**0**
Category Total	**0**							

Table 11. Science Application for Risk Reduction (SAFRR) Evaluation Tool—Relevant.

[–, placeholder for number that user will enter; --, no check; NA, Not Applicable]

			Relevant					
Check Number	**Stakeholder Needs**	**0=No 1=Yes**	**Credible**	**0=No 1=Yes**	**Structured for Scenario Planning**	**0=No 1=Yes**	**Timeliness**	**0=No 1=Yes**
Check 1	Were stakeholders of different sectors involved in designing the project mission?	–	Is the scenario science based?	–	Is the scenario improbable?	–	Has there been a review of stakeholder schedules to time product release?	–
Check 2	Were stakeholders of different sectors involved in designing the project scope?	–	Is the scenario plausible?	–	Is the scenario toolbox applicable/adaptable to hazards that are not identical to the scenario?	–	Has the sequential process of data transfer been planned and mapped out?	–
Check 3	Were stakeholders of different sectors involved in designing the decision-making tools?	–	Is there internal continuity in the scientific findings of each section?	–	Is the damages section generalizable, so that all stakeholders can consider their infrastructure susceptible, and prepare accordingly?	–	Have all developers been briefed on the timeline?	–
Check 4	Were stakeholders of different sectors involved in designing the level of detail of the project?	–	Are the sections sequentially accurate?	–	Are the tools transferable to different levels/intensities/origins for the same hazard?	–	Has time been budgeted for data and model transfer between different disciplines?	–
Check 5	Did scenario project planners review stakeholder programs working on the same subject? For example, winter storm flood mitigation.	–	Are the findings peer reviewed?	–	Is the level of hazard impact and destruction within the boundaries of stakeholder capacity for action?	–	Is there a plan for supporting authors and contributors who fall behind on deadlines?	–
Check 6	Did scenario project planners review stakeholder programs working on the same subject for scenario outreach? For example, Tsunami awareness.	–	Non-probabilistic hazard planning is a difficult concept—are stakeholders briefed in the need to prepare for probable and improbable events?	–	--	NA	If contractors and consultants have been engaged, are the start and stop dates of their contracts and when they will need data or models accounted for in deadline planning?	–
Check 7	Were community watchdog groups present and able to make comments to scenario developers during the impact development stages?	–	Is there scientific consensus?	–	--	NA	Were contractors budgeted enough time to review and revise from peer review?	–

Table 11. Science Application for Risk Reduction (SAFRR) Evaluation Tool—Relevant.—Continued

[–, placeholder for number that user will enter; --, no check; NA, Not Applicable]

Relevant								
Check Number	**Stakeholder Needs**	**0=No 1=Yes**	**Credible**	**0=No 1=Yes**	**Structured for Scenario Planning**	**0=No 1=Yes**	**Timeliness**	**0=No 1=Yes**
Check 8	--	NA	--	NA	--	NA	Has the scenario been on schedule?	–
Subsection Totals		**0**		**0**		**0**		**0**
Category Total	**0**							

Table 12. Science Application for Risk Reduction (SAFRR) Evaluation Tool—Thorough.

[–, placeholder for number that user will enter; --, no check; NA, Not Applicable]

Thorough						
Check Number	**Stakeholder Sectors**	**0=No 1=Yes**	**Sector Workshop Opportunities**	**0=No 1=Yes**	**Depth of Narrative Development**	**0=No 1=Yes**
Check 1	Did the development process include representatives from the local electric companies?	–	Was there a workshop for impacts on the electric system?	–	Were lifeline representatives given opportunities to workshop interdependencies with each other?	–
Check 2	Did the development process include representatives from the local water/sewer organizations?	–	Was there a workshop for impacts on the water/sewer systems?	–	Was there a workshop/exercise for response?	–
Check 3	Did the development process include representatives from the local telecommunications industries?	–	Was there a workshop for telecommunications impacts?	–	Was there a workshop/exercise for short term recovery?	–
Check 4	Did the development process include representatives from the local first responders?	–	Was there a workshop for transportation impacts?	–	Was there a workshop/exercise for long term recovery?	–
Check 5	Did the development process include representatives from the local government?	–	Was there a workshop or exercise for local government to practice coordination of the lifeline industries?	–	Was there a workshop/exercise for long term resilient rebuilding?	–
Check 6	Did the development process include representatives from the local transportation department?	–	Were small business representatives present some lifeline workshops?	–	Does the scenario address impacts to region-specific industries? For example, timber, fishing, or agriculture.	–
Check 7	Did the development process include representatives from environmental or community watchdog groups?	–	Were large corporate representatives present at some lifeline workshops?	–	Does the scenario impact include vulnerability assessments for the affected regions?	–
Check 8	Did the development process include representatives from local business groups?	–	Were region-specific industries present at lifeline workshops? For example, fishing, mining, or timber.	–	--	NA

Table 12. Science Application for Risk Reduction (SAFRR) Evaluation Tool—Thorough.—Continued

[–, placeholder for number that user will enter; --, no check; NA, Not Applicable]

			Thorough			
Check Number	Stakeholder Sectors	0=No 1=Yes	Sector Workshop Opportunities	0=No 1=Yes	Depth of Narrative Development	0=No 1=Yes
Check 9	Many lifeline industry representatives are not able to share their facilities' vulnerabilities for liability reasons - did the scenario planning team work to accommodate liability concerns?	–	--	NA	--	NA
Subsection Total		**0**		**0**		**0**
Category Total	**0**					

ALERT Evaluation Tool SAFRR Scenario Totals

Table 13 lists the category and subcategory totals for the four scenarios. All four scenarios were assessed including scenario use and activities up to May 2021. For example, ARkStorm was not just assessed for the ARkStorm OFR and summit rollout but also the ARkStorm@Tahoe and Ventura County exercises that occurred years after publication. Factors such as the outreach campaigns were also factored in, as well as HayWired's Outsmart Disaster campaign, though only for the Outsmart Disaster activities that related to HayWired. The percentages are not analogous to educational grades—below 75 percent is not below average. Since these scenarios are unique among hazard scenarios for their level of detail and stakeholder engagement, there is no average score to compare them to. These totals are guidelines to see where the scenario planners have prioritized different aspects to reach their goals.

Overall, the totals show that the scenarios became increasingly thorough and detailed from ShakeOut to HayWired, while becoming less timely in product development and publication. The levels in the educational category fluctuated mostly based on outreach strategies and accessibility of the information and outreach. One category that appears to be an opportunity to expand the usability of the scenarios would be actionable, perhaps by producing clear toolkits for preparedness action and posting them in a clearly accessible document alongside the scenario OFRs. ShakeOut does stand out in the actionable category due to the public awareness campaign for "drop, cover, and hold on," the week of earthquake events during ShakeOut's rollout, and the fact that the scenario was designed for the 2008 Golden Guardian exercise. Nevertheless, the nature of the USGS as an institution limits the ability for USGS products to recommend action, making actionable a difficult category. Another category that may represent an opportunity would be project design in overall scope. However, many of the planning tools used to design the projects are not available to the evaluation team, and the totals from this subcategory underrepresent the actual project organization efforts made by the scenario planners. As of this evaluation, HayWired is still ongoing, so the project's products that support actionable (such as a policy implications chapter) may not have been published or disseminated among project partners.

HayWired's active status as of July 2021 also results in higher totals for internal longevity, due to the USGS scenario authors working as coordinators and liaisons among community partners to support the use of the scenarios, thereby creating a higher score in internal longevity. Both ARkStorm and Tsunami Scenario have primary authors and organizers still using scenario products therefore increasing their internal longevity score, though not to the same extent. Because ShakeOut has been managed primarily by external partners and has not continued to be used as a foundation for current USGS projects, it did not score in internal longevity, resulting in the lowest score of the four scenarios. The longitudinal category does not necessarily score for how many years the scenario has been in use, but rather whether there are mechanisms in place for continued use both by internal and external partners.

The evaluation tool totals are a product of the information available to the evaluation team, through the interviews, the scenario publications, and papers written by the scenario authors about their experiences working on the scenarios. This information is limited. The evaluation tool would be more accurate if it was filled out by the scenario authors, who would be in the best position to answer questions like whether the scenario planning team made workflow diagrams to organize the flow of information from the scenario source to the social impacts. Not being able to access information about project design and many of the scenario planning processes limited the level of detail included in the checklist. A potential next step in the evaluation tool's development would be to have a focus group of scenario planners, to expand on the checklist

Table 13. Science Application for Risk Reduction (SAFRR) Evaluation Tool Totals for ShakeOut (yellow), ARkStorm (blue), Tsunami Scenario (gray), and HayWired (red).

[The scenarios are marked by colors that correspond to their branding. The grayscale gradient for the percentage scores is to provide a visual cue of the difference between the numbers. %, percent; --, not applicable]

	ShakeOut	ARkStorm	Tsunami Scenario	HayWired	
	Overall Scope Totals				Out of
Project Design	4	3	6	5	10
Team Preparation	3	7	6	6	7
Stakeholder Engagement	5	3	4	4	8
Total Category Score	**12**	**13**	**16**	**15**	**25**
Percentage Score	48%	52%	64%	60%	--
	Actionable Totals				Out of
Toolbox	4	3	2	3	7
Accessible	6	4	4	3	7
Total Category Score	**10**	**7**	**6**	**6**	**14**
Percentage Score	71%	50%	42%	42%	--
	Longitudinal Totals				Out of
Internal Longevity	0	2	2	2	4
External Longevity	3	3	2	4	4
Follow-through	2	1	2	2	3
Total Category Score	**5**	**6**	**6**	**8**	**11**
Percentage Score	45%	54%	54%	72%	--
	Educational Totals				Out of
Inclusive and Diverse	2	1	2	2	4
Multiple Techniques	6	6	6	7	7
Awareness/Outreach	6	4	3	5	6
Accessible	5	5	4	7	8
Total Category Score	**19**	**16**	**15**	**21**	**25**
Percentage Score	76%	64%	60%	84%	--
	Relevant Totals				Out of
Stakeholder Needs	4	3	4	3	7
Credible	6	7	7	7	7
Structured for Scenario Planning	5	5	5	5	5
Timeliness	6	6	4	2	8
Total Category Score	**21**	**21**	**20**	**17**	**27**
Percentage Score	77%	77%	74%	62%	--
	Thorough Totals				Out of
Stakeholder Sectors	6	7	8	8	9
Sector Workshop Opportunities	4	5	6	8	8
Depth of Narrative Development	3	6	7	5	7
Total Category Score	**13**	**18**	**21**	**21**	**24**
Percentage Score	54%	75%	87%	87%	--
	Scenario Totals				Out of
Scenario Total	**80**	**81**	**84**	**88**	**126**
Total Percentage Score	63%	64%	66%	69%	--

and provide input into weighing the importance of different factors. Further, the system of 0=No and 1=Yes ignores much of the nuance and complexity of the scenario development and use. This system does not measure the extent of outreach efforts or how effective the outreach was. A more complex number system, for example, 0–5, combined with more precise questions to be checked off at different stages of scenario development and use would capture a better assessment of the scenario's efforts.

Discussion

This Science Application for Risk Reduction (SAFRR) retrospective covered three research questions, using multiple methods and perspectives to gather information and create a narrative of the scenario development and use. The following discussion is divided by research question, though the information gathered throughout this process was often used to inform the approach to all three questions.

RQ1: What are the barriers and enablers to developing and deploying the SAFFR scenarios?

Over the course of the interview process, three overarching barriers emerged from both developers and users: project delays, navigating multidisciplinary collaboration, and unclear project design. Of all the barriers discussed, delays in the project development were the most common. Most interviewees talked about delays deterring downstream analyses and user engagement, though many of the source developers also talked about adherence to strict deadlines being a barrier as well. While deadlines were used to enable the timely production of scenario materials, they also limited the level of precision science and stakeholder input that makes these scenarios unique. This conflict between deadlines for scenario product development and scientific rigor became a primary theme for all four of the SAFRR scenarios.

Multidisciplinary collaboration and project design are interrelated with project delays, as each barrier can lead to another. Difficulties in translating technical expertise across multidisciplinary sectors slowed progress on the technical development of the scenarios. Representatives of these different sectors also brought in multiple perspectives on scenario products and analyses, contributing to an unclear project design as it changed with stakeholder input. In contrast, not getting multidisciplinary input was also a barrier, as the scenario planning team required information and expertise on infrastructure, utilities, or private businesses to accurately depict potential damages, and without that input the analyses lacked potentially important information, or scenario developers needed to take extra time to find the necessary information themselves. Strategy-driven scenarios rely on multidisciplinary collaboration, and both stakeholder engagement and the lack thereof can cause delays in project progress or change the project design. Multiple perspectives brought by stakeholders can reveal areas of inquiry that the project design did not anticipate, and as a result the scenario planning process does not always fit into traditional project planning tools and timelines.

Though multidisciplinary collaboration created difficulties in scenario development, the primary enabler that emerged from the interviews is stakeholder engagement. Discussions on stakeholder engagement revealed indicators of coproduction of knowledge because of the collaboration. Stakeholders were more comfortable understanding and using the science, the products fit their needs, and they felt an ownership of the scenarios that enabled them to continue endorsing and using the scenarios independently of primary scenario authors (Wall and others, 2017). Effective communication of science was enabled by engaging multiple sectors; participating in multidisciplinary and multi-jurisdictional scenario development required specialists to generalize their communications about their work so others could use the information for subsequent analyses. Passing data from physical scientists to engineers to economists to decision makers required a common language of hazard science among developers and users.

Interviewees felt that, without this coproduction of scenario products, the scenarios would not have (1) accessible action items, (2) long-term use by dedicated stakeholders, (3) scenario-based education and awareness tools, (4) relevant information and products available to multiple groups, and (5) a thorough depth and breadth of analyses of potential damages. These characteristics defined the ALERT framework—actionable, longitudinal, educational, relevant, and thorough—five main enablers for the development and deployment of SAFRR scenarios, all of which were made possible through stakeholder engagement (fig. 7).

Project Delays as Both a Barrier and Enabler

Allowing for delays did have some beneficial tradeoffs. Allowing more time to work on the different components created more opportunities for the highly detailed or innovative science that makes these scenarios unique. Delays in the SAFRR scenarios offered opportunities for more stakeholders to join the project, adding their own insights or pushing for new research directions, which then created more delays but also created more thorough, user-designed products. Allowing for more time to collaborate, and more stakeholders to join the development process, also created more opportunities for networks of hazard management personnel and scientists to develop. The increased time to practice working together with the networks built through SAFRR supported multidisciplinary communication and collaboration, which enabled interagency hazard preparedness and response efforts.

Some delays are out of scenario developers' control, such as the review and publishing process. Clarification of the project's goals and timelines will never be seamless either. Strategy-driven scenarios are an iterative process, where the scenario narrative is built piece by piece based on the input of multiple sectors over long periods of time. Working with so many different disciplines will create inevitable miscommunications of the means by which the scenario takes form and the intended uses. For the SAFFR scenarios, creating the hazard source data before engaging project partners has been one method for limiting the impacts of project delays. Adherence to deadlines is another, though without realistic deadlines created with the developers, this method risks losing some of the high level of detail and variety of analysis that user's value in the SAFRR scenarios.

RQ2: Have the SAFRR scenarios changed Cultures of Preparedness?

For the second research question, a definition was created based on the literature review: Cultures of Preparedness are groups united by vulnerability to one or more hazards, sharing risk and common knowledge, norms, and communications that guide the conceptualization and behavior of preparedness. Data were gathered to determine the extent to which groups or sub-groups of affected regions used the scenarios to create or alter common knowledge, norms, behaviors, or communications regarding preparedness. The selected indicators to represent changes in Cultures of Preparedness were based on social resilience indicators, DRR best practices, and scenario theory. These indicators were used to construct the outcomes of the logic model shown in figure 8.

Interview results and the work done by the previous studies and evaluations summarized in the "Evaluation Findings" section of this report demonstrate awareness. Awareness campaigns, outreach, and stakeholder workshops were considered effective and relevant, as well as increasing awareness of interdependencies among lifelines, businesses, and the population. For ShakeOut, ARkStorm, and HayWired, the media uses the scenarios to raise awareness and inform readers about hazards and preparedness. The second outcome category in the logic model, education, is supported by the examples of stakeholders using the scenario science for policy and planning described in the scenario histories in appendix 2, as well as in the media usage in "Media Mentions" from the "Secondary Data Collection" section. Previous studies and evaluations also demonstrated that the scenario planning process was educational for stakeholders, and interviewed developers also reported learning more about hazards and their impacts when working on the scenarios. The scenario histories also support the third outcome, application. Expanded networks of stakeholders have worked together to apply the scenarios to policy and regulation. All four scenarios have been used in State, county, and city LHMP. Application is also seen through the academic engagement, demonstrating use of the scenario narratives and data to innovate DRR science and technology. Finally, many institutions are still using the scenarios, promoting them, featuring them, and creating preparedness initiatives based on the scenario findings, providing evidence for longevity.

The ALERT framework (fig. 7) became the foundation for a strategy-driven scenario evaluation tool prototype that captures many of the barriers and enablers identified by interviewees, as well as DRR best practices and scenario theory. While this tool was initially created to capture the lessons learned from users and developers, it became a tool to assess how the scenarios approached their intended outcomes and goals. In applying the tool, the totals in the longitudinal category were consistently the lowest across the four scenarios. This was also a theme with scenario developers, as they reported inconsistent long-term scenario use. To be embedded in a culture implies that a group has taken ownership of a scenario and applies it to their norms, behaviors, or knowledge, with continuous use over time, growing and changing to meet the group's evolving needs. Inspiring buy-in from stakeholders is in the theory for strategy-driven scenarios. This can be partially attributed to the natural inclination to assign a higher valuation to things we create or participate in, partially to a belief in the mission of the scenario itself, and partially to the connections created among developers working on the project. This is a built-in mechanism that enables scenario integration into cultures by the way of the stakeholders who participated in development. However, without active mechanisms in place by the core scenario leadership team, the continuity of scenario use is dependent on the inclinations and positions of individuals. Scenario development participation may inspire some long-term use by those involved in the development process, but that can be sporadic and inconsistent. An intentional long-term use and follow-through strategy might be considered to keep these scenarios active in the preparedness cultures of stakeholders.

RQ3: Have SAFRR scenarios stimulated the development of new technologies or innovations for disaster response preparedness?

There are many innovations associated with the SAFRR scenarios. The scenario OFRs record scientific innovations in their methods of hazard science. They have been used to produce or promote new policy and stakeholders are continuing to find new ways to apply them to hazard management. What this evaluation came to find is that the scenarios themselves as USGS products are innovative. They represent a unique face of the USGS in terms of public outreach, stakeholder engagement, and communicating hazard science.

Over the course of the interviews, reflections on the educational nature of the scenarios matched common pedagogic theory, whether the interviewees were aware of education theories or not. Modern pedagogic theories focus on creating opportunities for the pupil to shape their own education, using multiple techniques to transmit information, creating an inclusive and diverse learning environment, accessibility, and building on the existing schema (essentially the mental models and knowledge base) of the pupil (Aubrey and Riley, 2015). Developers utilized these methods, knowingly or unknowingly, to shape the scenario as a learning tool.

Stakeholder engagement from the beginning of the scenarios meant that stakeholders were shaping the information and format of the scenarios. By engaging with target groups, or being in a target group, developer interviewees endeavored to create a scenario that worked for a diverse population, which increased the accessibility of the information to different sectors. Interviewees discussed using multiple techniques to transmit information, including videos, fact sheets, awareness campaigns, and direct outreach. What seemed most important to the interviewees, was the interactive learning process of building and communicating the scenario narrative. The scenarios were not just educational tools for the scientists, engineers, and economists to transmit information down to stakeholders. Working with multiple disciplines created two-way communication with project partners, coproducing knowledge and a shared language of hazard science and preparedness.

Scientific communication and coproduction, on this scale, was considered unique for the USGS by the developers and users interviewed. The SAFRR scenarios seem to be innovative educational tools, science communication tools, network building tools, and DRR tools for the USGS. They create lasting partnerships with external and internal partners, break down silos between sectors, and are used in tangible disaster risk reduction efforts. For many of the scientists that worked on these projects, the scenarios changed the way they would produce and communicate science for the rest of their careers.

Many of the activities, or even subjects, of the scenario development process seem to be outside of the USGS' traditional role as a federal scientific agency based in the geological sciences. However, throughout the interviews many users reiterated that the USGS as a federal science agency was able to create a centralized scientific project that facilitated collaboration with multiple jurisdictions and levels of government. For users, the USGS brought its reputation as a deeply respected scientific organization to the scenario building process, allowing stakeholders to trust the reality of the hazards and begin working on preparedness with minimal pushback about the plausibility of the scenario. This was substantiated by the level of precision science that the SAFRR scenarios offered. The USGS also has many existing partnerships with agencies, community partners, and organizations through a vast network of projects, missions, and community partnerships. Bringing these disparate groups to the table may be easier for the USGS than for a regional group, and the USGS may also be able to partially fund some of the project partners. Bringing in media is another benefit of being a federal level science agency; the scenario rollouts garnered media attention, which boosted the awareness and resilience campaigns, alerted other stakeholders to the products on offer, and put the USGS science in the headlines. The USGS is uniquely positioned to provide high-visibility and high-engagement to scientific endeavors, and in doing so provided the opportunity to work with project partners on innovating the use of science in hazard risk reduction.

Conclusion

Strategy-driven scenario planning has traditionally been a practitioner tool, meaning it has largely been developed and used by decisionmakers to explore potential futures. Frameworks and measurement tools for evaluating the efficacy of these efforts are not well established. Many of the intended outcomes of scenario planning, such as flexible thinking and alignment of participant mental models, are difficult or impossible to quantify and measure. Combining this inexact practice of strategy-driven scenario planning with the deeply rigorous and exact practice of U.S. Geological Survey (USGS) scientific research requires a complex balance of many conflicting needs. In this way, the Science Application for Risk Reduction (SAFRR) scenarios have worked to be many things for many users—groundbreaking scientific risk analyses, but also accessible damage narratives for tabletop exercises, providing both parcel-level data and generalized summations. They are expected to be accessible, readable, understandable, and usable for emergency managers that have many demands on their time, but also scientifically sound, peer reviewed, and diligently reported scientific publications. Creating this balance accounts for the size of these projects, for the conflict between deadlines and scientific rigor, the differing opinions about project scope and responsibilities, and other challenges throughout the development and deployment of these projects. And, as these scenarios go back as far as 2006 and involve hundreds of collaborators and authors and millions of intended users, capturing that complex balance and analyzing it requires building an evaluation protocol that is a mosaic of methodologies. Like the scenarios, this retrospective attempts to be many things to many different audiences, and contains a mix of process evaluation, outcome evaluation, and impact evaluation methodologies. The evidence reported here and the ALERT evaluation tool provide a starting point, but not a comprehensive assessment.

That said, conclusions can be drawn about the outcomes of SAFRR scenarios. All four scenarios have increased hazard knowledge with regard to both public perceptions and within the emergency and hazard practitioner communities. The scenarios have also added to the scientific literature of hazard sources, mitigation, preparedness, and management. The scenarios contribute to hazard planning, study, and preparedness activities for multiple agencies and sectors, and have connected participants across those sectors in networks of shared risk. The scenario planning process provided opportunities to innovate hazard science, preparedness, and outreach, with the potential for future innovations as the scenarios continue to be used in disaster risk reduction efforts. Moreover, the USGS was uniquely positioned to achieve these goals with scenario planning; the SAFRR project provided funding, credibility, centralization, and resources that enabled collaboration on such a large scale.

Glossary

Atmospheric rivers: Large currents of warm moist air that result in prolonged precipitation when they make landfall.

Barriers: The social, institutional, physical, or intellectual obstacles that affect the ability to access, design, or use the Science Application for Risk Reduction (SAFRR) scenarios.

Community resilience: While there is no set definition of community in this context, the general definition of community resilience is the sustained ability of a diverse group of individuals that share a geographic area to withstand and recover from adverse events, including the adaptation and growth of said group after a disaster (Sharifi, 2016).

Cultures of Preparedness: Cultures of Preparedness are defined by the evaluation team as groups united by vulnerability to one or more hazards, sharing risk and common knowledge, norms, and communications that guide the conceptualization and behavior of preparedness.

Deploying: Any form of use of the scenarios, including publishing and distribution to an audience; use in a model; revision and adaptation to appeal to a specific audience; and end use as a participant in a drill or exercise based on the scenarios.

Developing: Any activity involved in the scenario planning process, including providing expert opinions; building scientific models or tools to support the narrative; workshopping the narrative, model, or tool usability; using the scenario to create a drill or disaster plan; writing the scenario methods and reports; or other forms of collaboration.

Disaster literacy: “An individual's ability to read, understand, and use information to make informed decisions and follow instructions in the context of mitigating, preparing, responding, and recovering from a disaster” (Brown and others, 2014, p. 267).

Enablers: The social, institutional, physical, or intellectual supporting factors that affect the ability to access, design, or use the SAFRR scenarios.

Eponym: An eponym is when the name of something, such as a brand, or someone is used as a generic description for all concepts in the same category. An example would be Newtonian physics, named after Isaac Newton.

Exploratory scenarios: Also called projective or descriptive scenarios.

Forecasts: Assessments of the most likely given future, called forecasts, are not to be confused with scenario planning. Weather predictions, for example, can inspire scenario planning, but are not actually scenarios.

Futures theories: Studies on social, technological, and environmental trends, often extrapolating on current trends to explore potential outcomes.

Futurist: A person who studies the future and makes predictions about it based on current trends

Implementation: The widespread adoption of an innovation within an organization, or widespread use of the innovation within a group.

Lifeline: Lifelines include infrastructure and services necessary for a population, such as potable water, sanitation, electricity, and transportation infrastructure.

Lifeline infrastructure: Lifeline infrastructure refers to utilities and transportation infrastructure that, when interrupted, cause major interruptions to the safety and health of a society. Clean water, waste management, transportation, electricity, etc.

Organizational learning theories: The study of the creation, use, and retention of knowledge within an organization.

Resilience: “The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions” (UNDRR, 2021).

Risk communication: the dissemination of information to the public about hazards and risks, such as tornado warnings or evacuation orders.

Silos or siloed: When groups within a system are isolated from each other, and do not share information or resources.

Systems theories: The interdisciplinary study of systems as they relate to each other within a larger, more complex system.

Theory-based evaluation: A method of evaluation that explores the relationships between the inputs, activities, and outputs of a program or project, and how they achieve the intended outcomes of that project. Inputs → Activities →Outputs →Short-term Outcomes →Long-term Outcomes →Project Goal

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Appendix 1. Evaluation Methodology

This appendix has supporting information for the Evaluation Methods and Data Methodology sections of this report. The following two tables and figure were used during the development of this retrospective report.

Disaster Risk Reduction Logic Model

Not a standard logic model, the following table (table 1.1) describes the Science Application for Risk Reduction (SAFRR) scenarios' inputs, process, outputs, outcomes, and impacts in a finer detail than displayed in the more illustrative logic model in figure 5. This logic model can be generalized to large-scale strategy-driven hazard scenarios.

Table 1.1. A disaster risk reduction scenario logic model table developed to support this retrospective report.

[DRR, disaster risk reduction]

DISASTER RISK REDUCTION SCENARIO PLANNING LOGIC MODEL		
COMPONENTS	**Indicators**	**Description**
INPUTS	I.1 Source science	Define the origin of the hazard.
	I.1.A Geology and (or) meteorology Fieldwork	Determine the composition of the affected area.
	I.1.B Modelling	Create models of the effects of the hazard on the area of interest.
	I.2 Secondary hazards	Identify the immediate effects of the source hazard, such as a tsunami caused by an earthquake.
	I.3 Physical damages	Estimate damages to area based on source hazard and secondary hazard impacts.
	I.3.A Infrastructure damage	Damages to buildings and lifelines.
	I.3.B Ecological impacts	Damages to ecosystems and climate.
	I.3.C Restoration cost and time	Estimations to restore lifeline infrastructure, factoring in interdependencies.
	I.4 Social and economic impacts	Estimate social and economic impacts based on damages and restoration timeline.
	I.4.A Health impacts	Estimate deaths, injuries, and secondary health hazards such as issues arising from being unable to access potable water due to earthquake shaking compromising.
	I.4.B Business interruption	
	I.4.C Vulnerability	
	I.4.D Restoration time	
	I.5 Policy considerations	Identify policy issues.
	I.6 Personnel	Affected sectors are represented in development team.
	I.6.A Scientists	
	I.6.B Engineers	
	I.6.C Lifeline experts	
	I.6.D Community representatives	
	I.6.E Decisionmakers	
	I.7 Purpose and goal	Project goals are outlined.

Table 1.1. A disaster risk reduction scenario logic model table developed to support this retrospective report.—Continued

[DRR, disaster risk reduction]

DISASTER RISK REDUCTION SCENARIO PLANNING LOGIC MODEL		
COMPONENTS	**Indicators**	**Description**
PROCESS	P.1 Scenario planning	Scenario planning is the process of positing informed, plausible future narratives in which decisions may be played out for the purposes of planning or altering current trajectories.
	P.1.A Plausible and improbable futures planning	Choosing a future narrative that is between forecasts or predictions and speculation.
	P.1.B Collaborative stakeholder engagement	Utilize stakeholder input for needs assessment, expertise, perspectives, and focus of planning process.
	P.1.C Multi-disciplinary collaboration	Interdependencies workshops, diverse planning teams, affected demographics are represented by planning team.
	P.2 Project management	
	P.2.A Project planning	Timelines, workflow diagrams, logic models, process mapping.
	P.2.B Stakeholder outreach	Work to capture the input of more stakeholders.
	P.2.C Stakeholder assessments	Review stakeholder org charts to ensure appropriate representatives. Perform consistent needs assessments for products and processes.
OUTPUTS	OP.1 Scientific tools and reports	Geographic and atmospheric models, maps, reports, estimates.
	OP.2 Products, simulations, communications tools	Scenario narratives, products that enable end users to utilize the scenario findings, communication toolkits.
	OP.3 Emergency response exercises	Products for DRR organizations and institutions to perform drills, tabletop exercises, and other planning/practice actions.
SHORT TERM OUTCOMES	OC.1 Coproduction of knowledge	
	OC.1.A Stakeholder ownership	Because stakeholders were involved in production, they have established “buy-in” of scenario products and use.
	OC.1.B Stakeholder use	Because stakeholders were involved in production, they are familiar with products and how to use them.
	OC.1.C Stakeholder relevance	Because stakeholders were involved in production, products are more relevant to stakeholders.
	OC.2 Scenario planning outcomes	
	OC.2.A Relevance	Stakeholders understand relevance of improbability hazard planning.
	OC.2.B Networks	Networks of stakeholders from different sectors practice communicating and planning together.
	OC.2.C Exposed vulnerabilities	Multi-disciplinary teams workshopping interdependencies and stakeholder input from multiple sectors reveals vulnerabilities.
	OC.2.D Non-probabilistic planning	Stakeholders and decisionmakers plan for events outside probabilistic patterns—increases flexibility in response.
	OC. 3 Application	
	OC.3.A Use	Use of scenario narratives, tools, findings, or models.
	OC.3.B Strategy	Preparedness strategies for scenario developed.
	OC.3.C Innovation	Use of scenario to innovate DRR science and technology.
	OC.3.D Practice	DRR networks work together on scenario tabletops or exercises.
	OC.3.E Policy and regulation	Use of scenarios to develop hazard policy and (or) regulations.

Table 1.1. A disaster risk reduction scenario logic model table developed to support this retrospective report.—Continued

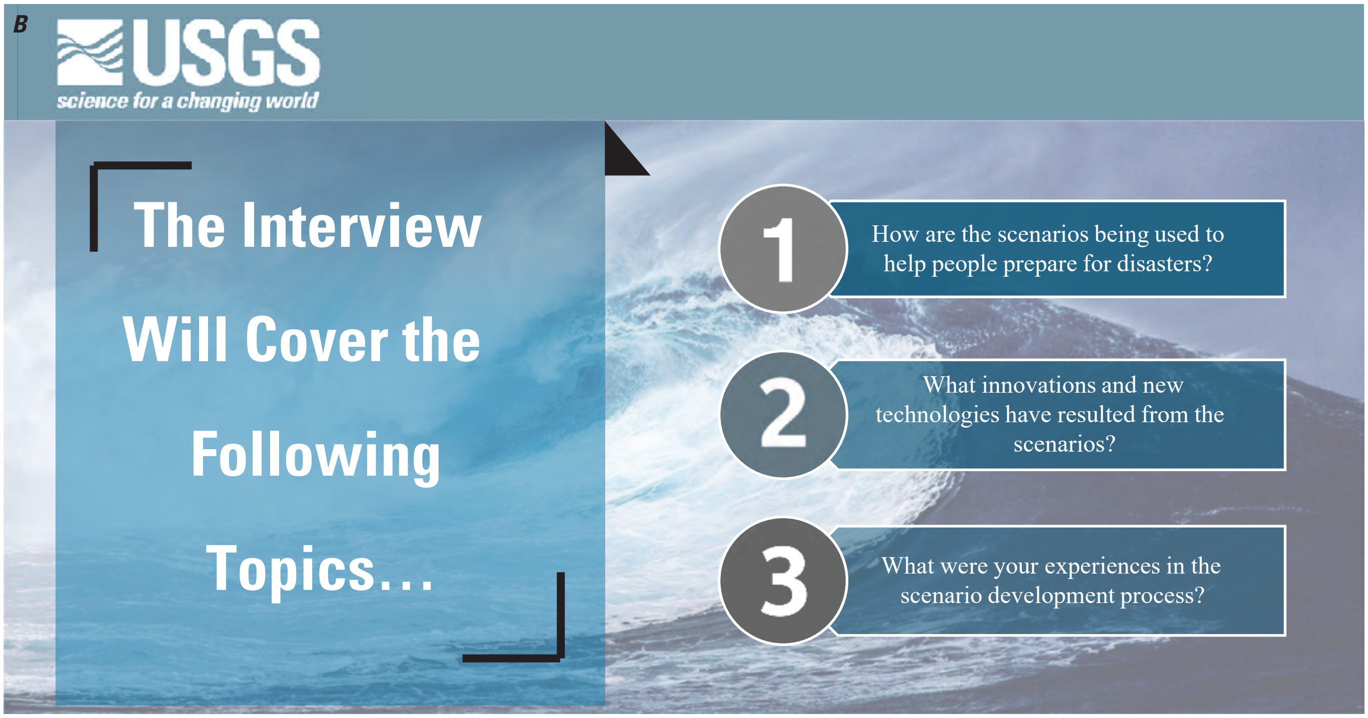
[DRR, disaster risk reduction]

DISASTER RISK REDUCTION SCENARIO PLANNING LOGIC MODEL		
COMPONENTS	**Indicators**	**Description**
IMPACTS	IM.1 Awareness	Use of scenarios for hazard awareness and outreach.
	IM.1.A Public recognition	News coverage of scenarios—news uses scenarios as examples.
	IM.1.B Institutional recognition	Scenario tools used institutionally—drills, exercises.
	IM.2 Education	
	IM.2.A Public knowledge	Public knows preparedness and response actions for hazard.
	IM.2.B Institutional knowledge	Organizations have processes in place to maintain hazard awareness and preparedness procedures.
	IM.3 Preparedness	Mitigation and planning action.
	IM.3.A Infrastructure	Infrastructure is developed, retrofitted, and maintained to withstand the hazard.
	IM.3.B Population	The public has performed preparedness actions.
	IM.3.C Cross-sector	Multiple sectors consistently communicate on preparedness and response plans.
	IM.4 Longevity	Follow-through and long-term use.
	IM.4.A External	Project partners and end-users continue preparedness planning and follow-through of scenario findings.
	IM.4.B Internal	Primary authors provide central organization, connec tions, and monitoring of scenario use over time.
	IM.4.C Networks	Stakeholder cross-sector networks are maintained over time.

Interview Flyer

Figure 1.1 details the purpose of the SAFRR retrospective project, and the outline of the interview process for potential interviewees.

Figure 1.1. *A–B* A flyer provided by email to potential interviewees to inform them about the interview process.



Definitions

Terms That Will Be Used in the Evaluation and Interviews

Scenario Planning— Also called scenario analysis or scenario thinking, this term is used for the process of creating and using one or more plausible alternative future stories for planning or brainstorming purposes.

Barriers and Enablers — The social, moral, physical, or intellectual obstacles or supporting factors that affect your ability to access, design, or use the SAFRR scenarios.

Scenario Use—Any reference to the scenarios, planning process based on the scenarios, or utilization of the tools or models developed for the scenario.

Scenario Development — Any activity involved in the scenario planning process, including providing expert opinions, building scientific models or tools to support the narrative, workshopping the narrative, model, or tool usability, using the scenario to create a drill or disaster plan, writing the scenario methods and reports, or other forms of colaboration on the scenario.

Innovation —Any new or significantly improved concept, tool, or process that is associated with scenarios.

Preparedness —Actions taken to plan, organize, equip, train, and exercise to build and sustain the capabilities necessary to prevent, protect against, mitigate the effects of, respond to, and recover from hazards.

Risk—The exposure, susceptibility, coping capacity, and adaptive capacity of a population to one or more hazards.

Hazard— A potentially damaging physical event, that can cause social or economic disruption, environmental degradation , or other major interuptions to a system.

Disaster Risk Reduction — the concept and practice of reducing disaster risks through systematic efforts to analyse and reduce the causal factors of disasters.

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In Partnership with Dale Cox, Project Manager of SAFRR

Figure 1.1. *A–B* A flyer provided by email to potential interviewees to inform them about the interview process.—Continued

Interview Codebook

Table 1.2 shows the code labels, with higher-level codes that became themes, and the lower-level codes that supported those themes. Each code has a description, detailing what the analyst considered for these descriptions. Many passages were coded with multiple codes to identify the complexities of interview statements.

Table 1.2. Interview Codebook used by the Science Application for Risk Reduction Project.

[Lower-level codes are indented and nested under top-level codes. USGS; U.S. Geological Survey; SAFRR, Science Application for Risk Reduction; DRR, Disaster Risk Reduction]

Name	Description
Barriers	The social, moral, physical, or intellectual obstacles that affect the ability to access, design, or use the SAFRR scenarios.
Multidisciplinary interactions	Difficulties in working with multiple disciplines.
Consultants and contractors	Restrictions and standards can be different when working with different groups.
Incompatible models	Example, the models used by seismologists not translating to the models used by engineers.
Not getting stakeholder input or expertise or buy-in	Issues in the projects that could have been solved/avoided by engaging stakeholders
Liability	This code is for difficulties in getting stakeholders to divulge potential weaknesses, mismanagement, or illegal activities that endanger themselves and others and will be an issue in a disaster. If they divulge, they could potentially be liable for damages.
Silos	When groups within a system are isolated from each other, and do not share information or resources
Institutional structure and limits	Often, institutional design was a barrier. For example, the USGS, as a Federal government institution, had many rules and regulations limiting action
Cannot recommend policy	This has come up frequently as a frustration, that scenario creators (as members of the USGS) cannot recommend policy action based on their work.
Financial problems	Anything to do with money: funding difficulties, money management, and budgeting.
Project delays	Any delays in the SAFRR scenario planning process
Precision science	The need to refine and perfect the scenario models throughout the planning process sometimes caused delays. Scenario planning, generally, is a generalized and hypothetical practice that does not necessarily use detailed scientific models.
Sequential process	Since each level of scenario development requires input from the previous stage, any delays or incompatibilities can create delays and difficulties in the project timeline and the ability for downstream scientists to do their jobs.
Project organization	Barriers created from project organization issues.
Lack of usability	Criticisms of the scenarios' usability. This would include user reports that the tools are not what they needed, the science was difficult to understand, or other issues.
Solutions	This code is for anecdotes of barriers that are solutions, as well.
Deadlines	Deadlines come up frequently—it's a deeper conversation about leadership styles and the balance between scientific rigor and thoroughness versus time.
Enablers	The social, moral, physical, or intellectual supporting factors that affect the ability to access, design, or use the SAFRR scenarios.
Actionable	(*A*) Has instructions: Clear, simple, straightforward, comprehensive. There is clear jurisdiction/responsibility (*B*) Drills/practice/training: Low cost and repeatability (*C*) Transferable actions and tools (*D*) Toolbox for practitioners
Drills or planning sessions	Specific outlines or descriptions of actions like drills or planning sessions that people have undertaken
Targeted tools to specific stakeholders	Mentions of specifically creating or targeting tools to stakeholders. Tools being scenario tabletop exercises, lists of preparedness activities determined by the scenario tabletop exercises, or other tangible products.

Table 1.2. Interview Codebook used by the Science Application for Risk Reduction Project.—Continued

[Lower-level codes are indented and nested under top-level codes. USGS; U.S. Geological Survey; SAFRR, Science Application for Risk Reduction; DRR, Disaster Risk Reduction]

Name	Description
Educational	Pedagogic Theory: (1) pupil (stakeholder) voice, (2) clearly stated long term and short-term goals, (3) build on prior knowledge base, (4) multiple techniques, (5) focus on critical thinking & metacognition, (6) embedded assessment for learning, (7) scaffolding for pupils, (8) inclusive and diverse.
Awareness	Techniques to raise or spread awareness of the scenarios to stakeholders.
Messaging	Conversations about how communications were structured to convey a specific message in a specific way.
Outreach	How the scenario developers got the message out - what actions and processes were in place to communicate the science to stakeholders
Piggybacking	Using other disasters to spread awareness and inspire action. Disasters tend to inspire belated disaster preparedness efforts.
Rollout	Specific activities launching the scenario.
Pedagogy	Structured educational initiatives.
Accessibility	(*A*) Inclusive and diverse in language, products, outreach, representation, (*B*) multiple techniques used in language, products, outreach, representation, (*C*) involve stakeholders in solutions, (*D*) account for barriers: social, moral, physical, intellectual, (*E*) made available to stakeholders not involved in scenario development.
Diverse team to build or play the scenario	The different people and sectors involved in creating, developing, and (or) exercising the scenario.
Variety of messaging or outreach strategies	Discussion or examples on using multiple communication formats for messaging or outreach.
Longevity	This code is for products and processes that enable the scenarios to continue to be used after they are published, and rollout activities have ceased.
External stakeholder longevity	How people have kept these scenarios active, independent of developer or SAFRR organizational involvement.
Internal USGS longevity	USGS employees continuing to work with the scenarios.
Staff turnover	This is a barrier to personnel-dependent long-term preparedness strategies.
Project organization	Mirroring the project organization code in “Barriers”—examples of project organization as an enabler. Some of the concepts here are also in “Scenario Theory—Basics” and “Scenario Scope.”
Leadership	How leadership enabled scenario development and (or) deployment.
Connections	Leadership brings or creates a network that was useful.
Diplomacy	When leadership enabled scenario development and (or) deployment by using diplomacy and balancing needs and voices of stakeholders.
Making space	Leadership makes or creates safe spaces for co-authors, especially new or young developers, to do something with the scenarios, enabling innovation, trust and partnership.
Power	Leadership or champions had a status in the system that enabled them to cut through barriers that others did not have the influence or ability to push through.
Relevance	Markers of relevancy of the scenarios: (*A*) credible, (*B*) plausible, (*C*) designed with stakeholder input, (*D*) timely, for example, ShakeOut drills are more effective at the beginning of school year instead of the end, (*E*) applicable/adaptable, (*F*) structured logically.
Plausible and credible	Scenario narratives need to be plausible to be useful - here is how scenario developers consider plausibility. Credibility is included here as well.
Consensus	Scientific consensus on the plausible disasters in the scenario narratives gave credibility and believability to scenario users.
Historical determinism	Historical determinism cited as a reason the scenario is considered credible.
Precision science	This was initially listed as a barrier, but interviewees also talk about how much precision science has helped credibility (see codes Consensus, Relevant to Other Disasters).

Table 1.2. Interview Codebook used by the Science Application for Risk Reduction Project.—Continued

[Lower-level codes are indented and nested under top-level codes. USGS; U.S. Geological Survey; SAFRR, Science Application for Risk Reduction; DRR, Disaster Risk Reduction]

Name	Description
Relevant to other disasters	How the scenarios have been relevant to other disasters outside of their primary focus or location. For example, HayWired being used to plan for fire regardless of earthquake.
Relevant to whom	Discussions about the worth of the scenarios, but the interviewee considers them not particularly applicable/relevant to themselves or their own organization.
Timeliness	Timeliness is a subcode of Relevance because for city planners, publishers, practitioners, and other users, having the scenario information in a timely manner impacted how relevant the scenarios were considered.
Stakeholder engagement	Stakeholder engagement may be one of the most important aspects of a successful scenario—it is an aspect of multiple codes.
Clear and elevating purpose	Pride in the hazard work being done, a call to help or go the extra mile, keeping stakeholders engaged and inspired.
Co-production of knowledge	A growing area of research interested in creating usable or actionable science through collaboration between scientists and decision makers
Multi-disciplinary	Conversations about positive experiences working across sectors or silos.
Ascertain needs	Ascertaining target population needs before or during development.
Collaboration	Multidisciplinary collaboration—working together on a tangible product.
Communication	Multidisciplinary communication—specifically how the different sectors have developed strategies to communicate effectively.
Problem-solving with stakeholders	Collaborating with stakeholders to develop a solution.
Stakeholder connections and expertise	By engaging stakeholders, scenario development teams can access a wider range of people/sectors. Ripple effect of communication and collaboration.
Thorough & creative	Identification of as many secondary, tertiary, quaternary disasters as possible. This is often done by involving stakeholders from as many different sectors (multiple perspectives) as is reasonable to (1) identify as many aspects of the scenario as possible and (2) inform each other about potential disasters identified due to their various perspectives, and then workshop interdependencies. Thorough also includes identifying disasters that are not probable but are plausible.
Exposing vulnerabilities	One of the goals for Multi-Hazards Demonstration Project and SAFRR was to expose vulnerabilities by discovering them or making stakeholders aware of them.
Scenario scope	The breadth of the scenario—what does it cover? Did it cover enough topics?
Veterans	Team members or self who had worked on previous scenarios—knew how to navigate around barriers or where various limits were.
Getting involved	How do these different sectors of people come together to start work on the scenario? This will partially inform enablers, partly reveal DRR network connections, potentially reveal patterns in recruiting talent that leadership may want to consider. If nothing else, it helps seat the interviewee chronologically in their memories.
Network	Connections to the core SAFRR leadership is how this person got involved.
Prior experience with SAFRR scenarios	The interviewee had previously worked on a SAFRR scenario, which led to their involvement in another.
Opt in	Subject heard about the program and made a point to involve themselves to get their voice heard in the project
Subject expertise	The interviewee was pulled into this project (headhunted) because of expertise in a particular field needed for the scenarios.
Interesting anecdote	Repository for notable things that may not be relevant to the study. Something to review periodically, to see if any new codes change how we look at these anecdotes.
Personalities	Anecdotes for how different personalities impacted scenario development.
Preparedness	Preparedness activities resulting from scenario involvement. Preparedness includes actions taken to plan, organize, equip, train, and exercise to build and sustain the capabilities necessary to prevent, protect against, mitigate the effects of, respond to, and recover from hazards.
Culture of preparedness	Preparedness activities that match the culture of preparedness theory.

Table 1.2. Interview Codebook used by the Science Application for Risk Reduction Project.—Continued

[Lower-level codes are indented and nested under top-level codes. USGS; U.S. Geological Survey; SAFRR, Science Application for Risk Reduction; DRR, Disaster Risk Reduction]

Name	Description
Links in a chain	Many interviewees talked about the scenarios being part of a group of initiatives that inspired or supported them in their preparedness efforts.
Networks strengthened	Strengthened or enlarged DRR networks from developing/deploying scenarios.
Use	Examples of ways the scenarios have been or are being used.
Impact	Anecdotes of scenario impact, or downstream effects of the scenarios being developed and (or) used.
Innovation	Innovation is any new or significantly improved concept, tool, or process that is implemented.
Deployment	Innovations due to scenario deployment or use.
Development	Innovations that occur because of or to enable scenario development.
New Policy	Whenever people mention policy, follow up on the actual laws, regulations, or policies that were inspired by SAFRR scenarios.
Quotable	Quotable phrases.
Scenario Development	Scenario theory in general goes under this tag, and some conversations about the development, makeup, or nuts and bolts of the SAFRR scenarios.
Lifeline panel organization	Information about the lifeline panels.
Tips for the future	Lessons learned about scenario development.
Workshops	Information about the workshops.

Appendix 2. Retrospective of Science Application for Risk Reduction (SAFRR) Scenarios Use and Development

The following sections detail the origins of the SAFRR scenarios, and how the projects grew from approximately 2008. It is not a complete history, but rather an illustrative one, showing how the scenarios were developed and many of the effects they had. Specifically, how Urban Earth became the Multi-Hazards Demonstration Project (MHDP), which then became the Science Application for Risk Reduction (SAFRR) Project.

In 2000, Interior Secretary Bruce Babbitt wanted the U.S. Geological Survey (USGS) to have a more unified presence and get the different scientific disciplines working together on projects. One manifestation of this directive was Urban Earth, a multidisciplinary exploration of the interactions between the natural world and human development headed by Dale Cox, who was with the California Water Science Center. Cox brought in Dr. Lucy Jones, who had previously been Scientist-in-Charge for the Southern California USGS Earthquake Hazards Team (U.S. Congress, House Committee on Appropriations, 2005; Thorwaldson, 2010). The program grew over several years before becoming large enough to require additional Federal funding. To obtain funding allocations from the House Appropriations Committee, Urban Earth was renamed and redesigned as the Multi-Hazards Demonstration Project (MHDP) to emphasize the fact that it was multidisciplinary and addressed multiple hazards, but it was also not a permanent project and a whole new program (Jones and others, 2007).

The MHDP was organized to integrate multiple USGS agencies and resources to focus on multidisciplinary, collaborative solutions for risk in Southern California (Jones and others, 2007; National Academies and Sciences, Engineering, and Medicine, 2008). Jones and others (2007) chose Southern California because of their familiarity and connections in the region, as well as the fact that the eight counties are subject to fires, earthquakes, tsunamis, and floods that cost billions per year in damages (U.S. Congress, House Committee on Appropriations, 2008). MHDP partners include local emergency responders, other federal agencies, such as Federal Emergency Management Agency (FEMA), the United States Forest Service, and the Bureau of Land Management, private enterprises, and city and state government agencies, among others (U.S. Congress, House Committee on Appropriations, 2008). The overarching mission of the MHDP was to help communities reduce losses from natural hazards, and to increase the use of science in hazard management practices (Jones and others, 2007). At that time, “MHDP organized focus groups consisting of potential end users—emergency response professionals, public officials, and resource managers—and found a strong need and interest in scenarios that would increase preparation for catastrophic natural disasters.” (Perry and others, 2011, p. 263). While scenario planning is not the only tool used by the MHDP, scenarios are what the project became known for.

In 2011, the MHDP was made a permanent USGS project, which necessitated a name change to reflect the permanent mission of the program. Thus, the MHDP became the Science Application for Risk Reduction (SAFRR) Project, with a focus to innovate the application of hazard science to preparedness. Today, SAFRR has projects dealing with tsunamis, earthquakes, floods, winter storms, volcanoes, wildfires, and debris flows. The program works in risk perception and communication, develops tools for risk analysis and decision-making, and is a partner to many different community groups all working towards hazard resilience and preparedness (SAFRR, 2020).

> “Our SAFRR team focuses on building partnerships to improve the use of natural hazards information. We identify information needs and gaps and develop new products that make our science more available to users such as emergency managers, community members, or decision makers. These efforts increase public safety and reduce economic losses caused by natural hazards.”
>
> (SAFRR, 2020)

ShakeOut Scenario

In April of 2006 leadership in the MHDP attended the 100th Anniversary 1906 San Francisco Earthquake Conference, which was attended by thousands of emergency management professionals, researchers, academics, local and State government representatives, and private business partners (EERI, 2006). There Jones and Cox worked across multiple sectors to start conversations around what local governments, businesses, and nonprofits needed in terms of earthquake preparedness endeavors (Becker, 2009). Scenarios were not the initial goal of MHDP’s work, the idea developed out of the conference and during three strategic planning workshops throughout February and March 2006 at the USGS Pasadena office. These workshops included external stakeholders, like first responders, who asked specifically for planning scenarios, improved hazard mapping in urban areas, access to monitoring networks, and a general increase in hazard information (Jones and others, 2007).

The San Andreas Fault was chosen because of the number of populated areas on the fault, the amount of strain the fault had accumulated, and the risk of it rupturing (Perry and others, 2008). The scenario needed to be large enough to be taken seriously, but not implausible, and near enough to population centers to expose multiple vulnerabilities to highly developed areas (Jones and others, 2008). Its most immediate use was to be in the November 2008 Golden Guardian exercise—a large, multifaceted emergency response exercise organized by Governor Schwarzenegger to allow for a collaborative training opportunity for the State's numerous disaster response entities. The MHDP team studied many previous earthquake scenarios and scenario planning guidelines and wanted to expand on what had been done before by increasing the level of detail and interactivity in the development process. Most notably, the team expanded the extent to which social science was incorporated into the scenario by involving the intended end users in the scenario development (Perry and others, 2011).

The project formed a partnership with the Southern California Earthquake Center (SCEC), a research entity that provided research and data for the earthquake simulations. SCEC hosted two workshops with San Andres Fault experts in November 2006 and January 2007 to compile the data for potential ruptures (Jones and others, 2008). At that time, SCEC's Mark Benthien (SCEC Director for Communication, Education, and Outreach) joined the scenario development team. They chose a magnitude 7.8 earthquake on the southernmost segment of the San Andreas Fault, between the Salton Sea and Lake Hughes. Previous ground motion models factored in magnitude and distance to estimate shaking, but the ShakeOut team chose to build a model that factors in soil conditions, interactions of ground motion waves coming from different directions, and the radiation pattern of energy distribution, creating a highly detailed and novel ground motion model (Jones and others, 2008).

As the project drew in more stakeholders and gained notoriety, California Institute of Technology, the University of California San Diego, and Carnegie Mellon University became involved. Different groups among those universities worked on creating accurate animations of the earthquake with SCEC. At that time, most animations for earthquakes consisted of a bullseye epicenter with concentric rings radiating out. The ShakeOut animation portrayed realistic ground movements that varied in different areas depending on the geological makeup of the area, creating an innovative display of how earthquakes really moved.

Much of the data and modelling on the physical damages to buildings and infrastructure were determined in partnership with representatives from the major lifeline industries. Workshops, called lifeline panels, comprised of approximately 100 engineers, operators, and emergency planners and covered water supply, wastewater, power, dams, mass transit, surface streets, and the Ports of Los Angeles and Long Beach. The lifeline experts participated in damage, response, and recovery projections (Porter and Sherrill, 2011). The economic interruptions worked from the damages found by these panels and consultant studies, factoring in business losses from direct damage and losses from lifeline interruptions (Jones and others, 2008). The lifeline panels contributed to the twenty overall studies that built the ShakeOut scenario (Porter and Sherrill, 2011).

The source and ground motion work were written up in Open-File Report (OFR) 2008–1150 titled "The ShakeOut Scenario," along with the models and estimates for damages, casualties, and economic impacts (Jones and others, 2008). Alongside the OFR, scenario leadership wrote a circular—a shorter report to describe the project and make the earthquake scenario accessible as a narrative "The ShakeOut Earthquake Scenario—A Story that Southern Californians are Writing" (Perry and others, 2008). Starting at 10 minutes before the quake, the piece sets the stage for millions of Californians, commuting, dropping children off at daycare, sending their kids to school, and starting their day, as seen in figure 2.1. This was a novel form of writing for USGS, because it was narrative driven and did not follow the model of standard reports (Perry and others, 2008).

The Great California ShakeOut Drill and ShakeOut's Earthquake Week

Since the 100th Anniversary 1906 San Francisco Earthquake Conference, ShakeOut's steering committee was considering a public outreach strategy for MHDP's projects (for a list of the ShakeOut steering committee members and their responsibilities, see the section "ShakeOut Steering Committee"). A day of earthquake awareness associated with the ShakeOut project seemed logical—something modeled after Earthquake Day in Japan, an annual commemoration of the devastating 1923 Kanto earthquake (Jones and Benthien, 2011). The committee happened to be meeting on the day of the Great American SmokeOut, an annual campaign put on by the American Cancer Society to raise awareness of tobacco related cancers. Inspired by the name "SmokeOut," the group brainstormed the name "ShakeOut," giving the scenario its unmistakable brand. Originally, the idea of a public campaign was just to raise awareness about earthquakes and did not yet have any design for a drill. SCEC then set up the shakeout.org website and created a registration process (Becker, 2009; SCEC, 2021).

Getting people registered was the next step, but how many was a reasonable goal? The campaign organizers jumped from two hundred thousand registrants originally to a goal of five million (one quarter of southern California's population). That was too big a goal to talk to people individually. The team decided to do outreach by counties, splitting up the ShakeOut leadership to go have meetings with emergency managers, county government, and school districts. The idea was to give community leaders materials for ShakeOut and have them get other people to sign up. It worked. The head of emergency management for Los Angeles Unified school district signed up, pledging 850,000 students and staff. Counties signed up for county staff, companies registered their employees, and the final count for drill participation was 5.23 million, all signed up within 3 months (Becker, 2009; Jones and Benthien, 2011).

The ShakeOut Scenario Narrative

Much like a movie script, the following fictional narrative will guide those participating in the ShakeOut Earthquake Scenario public drills and emergency response exercises on November 13, 2008. More effectively than any statistics, this narrative describes what this magnitude 7.8 earthquake would be like in southern California if no additional actions are taken for mitigation or preparedness.

November 13, 2008

Thursday 9:50 a.m. (… 10 minutes before the quake begins…)

By mid-morning on this workday, 200,000 commuters have made their way from Kern, Riverside, and San Bernardino Counties into the Los Angeles area. These drivers trade a lengthy commute for the lower cost of housing in fast-growing communities like Victorville and Lancaster, on the far side of the San Andreas Fault. Others cross the fault in the opposite direction, to employers in high desert communities. The commuters have joined 7.5 million other southern Californians in workplaces constructed of steel, concrete, brick, or wood. Of the many millions of homes and workplaces, only a fraction are covered by earthquake insurance.

A steady flow of trains crosses the San Andreas Fault at multiple locations, moving goods between cargo ships at the Ports of Los Angeles and Long Beach and the rest of the country. Trucks are also on the move nonstop, carrying goods through narrow passes cut in the San Gabriel and San Bernardino Mountains. These "lifeline corridors" are the veins and arteries that sustain economic life in southern California. Sharing these passes with cars, buses, trucks, and trains are pipelines carrying natural gas and fuels; water conveyance tunnels, pipes, and aqueducts; electrical transmission towers and lines; and the telecommunications cables that connect people by phone and Internet—connecting banks and clients, suppliers and providers, buyers and sellers, friends and families, headquarters and field offices. Like the commuters, they all cross the San Andreas Fault.

Figure 2.1. The scenario narrative opening from "The ShakeOut Earthquake Scenario—A Story That Californians Are Writing" (Perry and others, 2008).

Figure 2.2. The Drop, Cover, and Hold On earthquake response graphics.

Benthien and Jones had been personally going to the eight counties in Southern California, to engage the emergency managers, stakeholders, and decisionmakers in the ShakeOut drill and upcoming Golden Guardian event. In Orange County, July 2008, they were in a Red Cross center with nearly 30 emergency management personnel from the county. Jones was discussing the difficulty of making earthquakes salient. There had not been a major Southern Californian earthquake in a while, and people can discount the urgency to prepare if there has not been a recent event. Minutes later, the Chino Hills magnitude 5.4 earthquake hit (Jones and Benthien, 2011). Up until that point, the ShakeOut campaign was just to educate people about earthquakes and the upcoming ShakeOut events, but after watching Chino Hills news footage of people running outside buildings, Benthien and Jones realized they needed to have a drill (Jones and Benthien, 2011). The safest earthquake response is to drop to the floor, find cover under sturdy furniture, and hold on so the furniture is not shaken out from over you. While the emergency managers knew this, the population evidently did not. The "Drop, Cover, and Hold On!" drill, with a graphic shown in figure 2.2, was added to the campaign and shakeout.org website, and the ShakeOut leadership began to plan for a rollout event to introduce the report, the drill, and promote the Golden Guardian exercise.

By this time, the ArtCenter College of Design's socially focused design program, Designmatters, reached out to the ShakeOut steering committee, offering to create and support innovative hazard preparedness outreach and project design. Designmatters made a 4.5-minute animated video called "Preparedness Now," to be released with the OFR and rollout. The video follows the scenario narrative, starting with the standard commute activity just before 10:00 am, and then what happens when the earthquake hits, describing damage and loss. It then outlines preparedness behaviors that an average citizen could perform easily. Uploaded to YouTube on November 7, 2008, it had 37,561 views as of March 30, 2022, and has been embedded in presentations by ShakeOut leadership to promote the project (USGS, 2008).

During the planning period for Golden Guardian, a Los Angeles city councilman (from the 12th district that was hard hit by the Northridge and the 1971 San Fernando earthquakes) reached out to Jones to support the ShakeOut rollout with an earthquake conference (Becker, 2009). Specifically, the councilman was promoting an ordinance to retrofit nonductile concrete buildings. While the councilman was unsuccessful at that time, it was only 10 years later that Jones' work with the mayor's office helped get a retrofit ordinance through city council and construction is now underway (MSSTF, 2014). The conference invited international members of the earthquake community to Southern California from November 12 through 14, 2008, to take part in the ShakeOut events. The conference ended with the "Los Angeles Earthquake: Get Ready Rally," a street-fair style event created with the ArtCenter College of Design (Sterling, 2008; Becker, 2009; Jones and Benthien, 2011). Designmatters also developed a multiplayer earthquake game called "Aftershock," set to run on the Thursday of the ShakeOut drill for 3 weeks, prompting users to complete earthquake preparedness missions (Sterling, 2008).

The Earthquake Country Alliance also designed "Beat the Quake!" a free online game to be released for the earthquake week rollout. The game was designed to teach players how to safely secure a living space in the event of an earthquake, or at least be aware that everything from hanging pictures to lighting fixtures could drop with even slight shaking (USCNews, 2008). The game was featured in a study that indicate video games can promote learning for earthquake risk preparedness (Tanes and Cho, 2013). Later in 2016, California State University, Northridge created "Beat the Quake: An Earthquake Themed Puzzle Room" based on the online game, where teams of 4-5 students had to solve puzzles to secure the room before the earthquake buzzer. The escape room was recognized with a Silver Award from the California Emergency Services Association for its educational innovation (CSUN, 2016).

The 2008 Golden Guardian kicked off with the first Great California ShakeOut drill at 10:00 am on November 13, which signaled the multi-jurisdictional teams to jump into action (after they dropped, covered, and held on, of course). The ShakeOut team had created a series of county-specific summaries out of the ShakeOut loss data for the exercise, making the 300-page report less daunting for participants (CalEMA, 2008; Perry and Holbrook, 2008). Altogether, Golden Guardian, the International Earthquake Conference, the Get Ready Rally, the Aftershock game, and the first Great Southern California ShakeOut drill formed a week of planned activities geared towards informing the public on earthquake safety. Then there was the ArtCenter of Design's earthquake public service announcements that aired on television before the event, the "Beat the Quake" game, ShakeOut animations, the "Preparedness Now" movie, a USGS Circular, an OFR, and a triumphant ShakeOut steering committee (Perry and others, 2008; Jones and others, 2008). ShakeOut had multiple avenues to capture the public imagination and spread earthquake awareness. Additional activities are outlined in the Observations from the Great California ShakeOut report from the Institute of Geological and Nuclear Sciences (GNS Science; Becker, 2009).

In 2010, Cox, Jones, and many others received Shoemaker Awards for their work in science communication via ShakeOut, and ShakeOut remains the best known of the SAFRR scenarios.

ShakeOut Use

In July 2009, the Geological Society of America, American Geophysical Union, Incorporated Research Institutions for Seismology, and Seismological Society of America co-sponsored a congressional briefing on the 2008 ShakeOut events. Three ShakeOut developers met with congressional staff from the House, Senate, and select committees, as well as local fellow seismic community members (Astiz, 2009; Nishenko and Duffy, 2010).

The Los Angeles Department of Water and Power's (LADWP) exercise and panel contributions challenged the assumption that there would be a six-month water supply available to the southern San Andreas area after a disaster. This resulted in LADWP installing highly ductile pipe aqueducts for an emergency water supply to reach the area (Davis, 2010; Porter and Sherrill, 2011). LADWP also installed a seismic-monitoring system at the fault, in collaboration with the USGS. The water company held a series of meetings on seismic safety throughout 2009 and 2010, some of which were attended by hundreds of employees, and are credited as a direct result of LADWP's participation in the ShakeOut lifeline panel process (Porter and Sherrill, 2011). A paper on LADWP's seismic upgrades was included in the May 2011 ShakeOut special issue of the journal "Earthquake Spectra" along with articles from many of ShakeOut's main authors (Davis and O'Rourke, 2011).

In January 2014 Jones created a technical assistance partnership with the Mayor's Office of Los Angeles to support earthquake resilience using the ShakeOut scenario as a blueprint, focusing on buildings, water, and communications (Garcetti, 2014). The Mayor's Office published their plan for earthquake readiness called "Resilience by Design" in December 2014. By October 2015, Mayor Garcetti signed into law Ordinance 183893 which requires the retrofit for pre-1978 buildings and new cell tower design requirements that had been outlined in "Resilience by Design" (City of Los Angeles Department of Building and Safety, 2015; MSSTF, 2014; Garcetti, 2015). Also, at the mayor's request, a LADWP engineer who led the water company's efforts in seismic resiliency headed the "Water System Seismic Resilience and Sustainability Program," using lessons learned from ShakeOut with Jones and the Mayor's Office (Davis, 2015).

By 2015, LADWP began work on creating a seismic resilient water supply task force to create seismic resilient infrastructure and mutual aid, using ShakeOut damage estimates as a guide. The task force consisted of LADWP, the Metropolitan Water District of Southern California, and the California Department of Water Resources (DWR), all of which provide water to Los Angeles. At this point, LADWP had already performed a seismic risk assessment of the Los Angeles aqueducts system and written a preliminary plan for fire following earthquake water supply, and a dam safety program incorporating ShakeOut's findings (Davis, 2015). The ShakeOut drill continues to occur annually, with millions of registrants from all over the world.

ARkStorm Scenario

By 2008, current events in California were increasingly urgent around flooding, infrastructure, and state responsibility. In 1986, a levee failure in Yuba County killed two people and destroyed nearly 3,000 homes. Trials and appeals around responsibility for the disaster lasted until 2003, when the California Supreme Court heard Paterno v. the State of California and affirmed in part that the state was liable for levee management and upkeep (Court of Appeal, Third District, California, 2003). In 2005, the Department of Water Resources issued a document to the legislature identifying $30 to $40 billion dollars of economic damage from potential flooding in California's Central Valley. Finally, after noting the infrastructure failures of Hurricane Katrina, the Association of Civil Engineers began issuing their first Statewide infrastructure report cards, and the first "F" they ever gave was to California for their flood management and a "D" for the levee system in 2006 (ASCE, 2012). Following these warnings, Governor Schwarzenegger declared a State of Emergency for California's levee system in 2006 and signed Executive Order S-01-06, the Levee Repairs Program, directing the Department of Water Resources to repair critical levee sites. California voters also passed Propositions 1E and 84, Flood Management Provisions, propositions that provided nearly $5 billion in flood risk reduction (ASCE, 2012). California was focused on floods.

Meanwhile, pending the launch of ShakeOut, Cox did not want to let the momentum dissipate for scenario planning. On October 28, 2008, three weeks before the first Great California ShakeOut drill and the week of ShakeOut events, he called MHDP leadership and hydrologists to begin planning a winter storm scenario that would result in catastrophic flooding. One of the key hydrologists brought in was USGS' Mike Dettinger, who had been working on the growing field of atmospheric rivers (Cox and Jones, 2010). Also present and key to the development of the storm scenario was Marty Ralph, then the chief of the Water Cycle Branch in the National Oceanic and Atmospheric Administrations (NOAA) Earth System Research Laboratory, who would later write the book on atmospheric rivers (Ralph and others, 2020).

Atmospheric rivers were a relatively new field of study in atmospheric science, though they have been the reason for many of California's historic megafloods. The underlying concepts of the phenomenon were identified in the 1970s, though atmospheric rivers were not measured and recorded until the 2000s, when they were recognized as the source of extreme weather events all over the United States (Ralph and others, 2020). As their name suggests, atmospheric rivers are narrow formations of extremely moist air that travel like a river through the atmosphere. The atmospheric phenomenon occurs in winter for the northern hemisphere and has fueled many winter storms in recent Californian history. Between a new push to address catastrophic flooding, it was a clear choice for the MHDP team to develop an atmospheric river-fueled flood event in California (Ralph and others, 2020).

At that point in time, the period of record for California floods was 100 years, in which the worst flood that California had experienced was in 1938. A period of record is the length of time that continuous, reliable observations of any of the weather elements are available at a particular location. When estimating the "100-year flood," California was only including data from the last 100 years. An El Niño-driven series of storms washed out infrastructure in the Los Angeles area, flooding the Los Angeles River and killing at least 96 people (Harrison, 2018). Before the period of record there were the floods of 1861 and 1862, featuring precipitation that dwarfed 1938's 11 inches. From December 23, 1861, to January 22, 1862, it rained as much as 25.5 inches in California, covering five to six thousand square miles of the central valley with floodwater. The storms stretched from Oregon to Southern California, and as far east as Utah, destroying towns, railways, bridges, and killing people and livestock (Dettinger and Ingram, 2013). Sacramento was completely flooded under three meters of water for three months, during which California's new Governor, Leland Stanford, was elected and rowed to his own inauguration (Ingram, 2013). Because the 1861–62 storms were not in the period of record there was some consternation with using the 1861–62 event since flood probabilities for the state were only calculated in that 100-year period. Similar to ShakeOut, many flood preparedness models were based in a probabilistic approach, and it was a struggle for some to transition to an improbable event for the scenario. But the fact that the 1860s floods were indeed plausible won out, and the storm scenario that came to be known as ARkStorm was fashioned to resemble the magnitude of that event (Ralph and others, 2020)

Scenario Design

In order to make a model of the scenario storms, the developers needed existing data on wind speeds, air moisture content, and precipitation—data they did not have from the 1860s. They did not want to arbitrarily increase modern storm precipitation data, either (Dettinger and others, 2012). The ARkStorm source team decided to concatenate the data from two historical storms following a wet fall. The specific parameters and conditions for the end of a 1969 storm matched the beginning parameters for a storm from 1983, which allowed the team to stitch the data together back-to-back to create a massive, atmospheric river fueled month of rain, though with less total rainfall than the 1860s storms (Porter and others, 2011; Dettinger and others, 2012; Ralph and others, 2020).

While Ralph, Dettinger, and a team of hydrologists and meteorologists from the Scripps Institution of Oceanography, the National Weather Service, the California Extreme Precipitation Symposium, Golden Gate Weather, San Francisco State University, the Western Regional Climate Center, and the California Department of Water Resources lined up the hydrology information, the scenario was missing the key piece that translated the hydrology to the flood depths. Unfortunately, there was no State model, either through the DWR (California's flood plain management organization) or Federal Emergency Management Agency (FEMA), the leading authority on flood maps for property valuation and insurance purposes. At that time in 2010, neither the DWR or FEMA had the technology for the large-scale modelling necessary to calculate ARkStorm's flood boundaries (Porter and others, 2011). Of course, both

CoSMoS—Coastal Storm Modelling System

Patrick Barnard was just finishing his Mendenhall Research Fellowship Program when he was recommended as a good candidate to create the models for ARkStorm's impacts on the coasts. To do this, Barnard created the Coastal Storm Modelling System, CoSMoS, a dynamic modelling approach that can predict coastal flooding based on a variety of input parameters. Barnard took the ARkStorm force information (winds, precipitation, and atmospheric pressure) and translated those forces into the waves and total water levels along the entire Californian coastline. This was initially to identify the risk to the communities within the ARkStorm area, but CoSMoS revealed the equivalent of only a five-year-storm level impact to the coastal areas (Porter and others, 2011). ARkStorm's real destructive power remained in the inland floods. In 2007 the International Panel on Climate Change had put out their influential "Fourth Assessment Report," which highlighted the threat that sea level rise poses to coastal communities (IPCC, 2007). Barnard started inputting sea level rise parameters into CoSMoS and then running storm scenarios, creating detailed predictions of potential storm-induced coastal flooding, erosion, and cliff failures given various estimates of sea level rise. CoSMoS became a powerful tool for estimating climate change impacts on the west coast of the United States. Today Barnard is Research Director of the Climate Impacts and Coastal Processes Team for the USGS' Pacific Coastal and Marine Science Center, where CoSMoS supports coastal planning efforts for the San Francisco Bay area, fourteen municipalities, seven coastal counties, four major utilities, National Oceanic and Atmospheric Association (NOAA), and other federal and state agencies (Barnard and Erikson, 2021).

organizations had flood insurance maps that had been in use for years, but they were all paper maps at different scales, and could not just be stitched together. Creating a model of that size and scale was not feasible with time and financial constraints, so a group of hydrologists, FEMA mapping experts, and a U.S. Army Corps of Engineers representative took a printout of the overlay maps of FEMA's national flood hazard layer in California and, using a crayon, began developing a rough but reasonable estimate of runoff and drainage depths (Porter and others, 2011; Schaefer, 2010). The findings were refined using a series of different modeling techniques, and while there was some reasonable pushback on their findings for the flooding of Sacramento and the California delta, the statewide estimates were still more detailed than what the state had been working with previously (Porter and others, 2011; Schaefer, 2010). The proposed ARkStorm 2.0 project would be able to create detailed statewide flood maps.

At the time of ARkStorm, there was also not anything like a state-wide landslide susceptibility mapping system, or even techniques for estimating what are called "shallow landslides," landslides within the soil mantle or weathered bedrock (CEPSYM, 2010). Because landslides are a primary cause of damage during extreme precipitation, mapping them was a crucial step in estimating winter storm damages. Lacking models that related rainfall and landslide distribution, as well as records of landslide damages from past storms, the research team led by California Geological Survey (CGS) engineering geologist had to extrapolate existing maps of extreme landslide risk, past landslides, and the geologic nature of areas. In doing so, they created the first statewide landslide susceptibility maps with the greatest level of detail of any existing landslide mapping models (CEPSYM, 2010; Porter and others, 2011).

Using the innovative statewide flood and landslide damage maps, a series of twelve panels were held with representatives of the lifelines at risk in January and February of 2010. Meeting in Pasadena, Sacramento, Menlo Park, and San Francisco, the panels covered roads and highways; dams and levees; power; and water and wastewater. Participants totaled 85 people from 43 federal, state, local, and private agencies, and universities. Together they workshopped the potential damages to lifelines, as well as estimates for restoration given the interdependencies of the lifelines on each other for recovery (Porter and others, 2011). They outlined lists of action-items, as well, detailing potential resiliency actions tailored to each sector. Ironically, during this crucial development stage, particularly heavy rains were hitting the Pasadena area while the California Institute of Technology was hosting a lifeline workshop, and around a dozen members cancelled due to weather (Chang, 2010).

Throughout the development process, the MHDP once again partnered with Designmatters to facilitate the development of a communication strategy, a public awareness film, and the rollout summit. Designmatters hosted a workshop called "DesignStorm" in October 2010, bringing together emergency managers, structural engineers, meteorologists, business leaders, geologists, social scientists, and policy makers to develop communication between these key stakeholders and outline action-oriented goals and consensus in the design and rollout of ARkStorm (Designmatters, 2021). The DesignStorm consolidated stakeholder concerns and knowledge into five main categories that guided some of the design of ARkStorm for the following year: communication and awareness, owning storm mitigation, storm response, impact recovery, and long-term storm recovery (Designmatters, 2021).

Prior to the decision to name it ARkStorm, the media had been calling MHDP's winter storm scenario "Frankenstorm," as seen in this ABC article "Scientists create model of monster 'Frankenstorm'" found at https://abc13.com/archive/7237963/. It was with Designmatters that Cox came up with the name ARkStorm, where "AR" stood for Atmospheric Rivers and the "k" signified 1,000; meaning, the ARkStorm scenario exceeded precipitation that many places would only see once every 500 to 1,000 years (Cox and Jones, 2010). Despite reservations about the religious connotations, the name ARkStorm was agreed on. The ArtCenter team also created an opening film for the rollout event called "ARkStorm Summit," a two-day ARkStorm conference, and another film called "The ARkStorm, a short film" that introduced the scenario and narrative similar to the "Preparedness Now" ShakeOut film. Both films can be viewed on the Designmatters' ARkstorm website (Designmatters, 2021). The films were debuted during the ARkStorm Summit, which was scheduled to coincide with the release of the ARkStorm OFR "Overview of the ARkStorm Scenario," published January 13, 2011 (Porter and others, 2011). Altogether, the ARkStorm package was created by 118 researchers and practitioners from 56 agencies over the course of two years (Porter and others, 2011).

ARkStorm Summit

USGS presented the ARkStorm scenario to California Office of Emergency Services (Cal OES) and proposed doing a Statewide exercise series around it, similar to Golden Guardian. However, the scale of the scenario deterred local emergency managers, many of whom managed counties that could be devastatingly flooded, and Cal OES also declined (McKenna, 2011). Instead, USGS, FEMA, and CGS organized the ARkStorm Summit, a two-day conference in January 2011, at the California State University, Sacramento. After a viewing of the ArtCenter Summit video, around 250 stakeholder invitees from public and private sectors participated in preparedness planning. Their objectives were to workshop ideas for how to fix and update the levees, dams, and weirs, create more efficient connections between agencies, address financial consequences, and, if possible, create a ubiquitous storm scaling similar to hurricane categories (Designmatters, 2021). Speakers included ARkStorm leadership, as well as USGS Director Marcia McNutt. The full Summit program, as scanned by an attendee, is available in PDF at https://doi.org/10.3133/sir20235011. Project partner NOAA reported, "A significant outcome of the Summit was acknowledgment of the scientific realism and likelihood of the ARkStorm event" (NOAA, 2011). After the Summit, the inland regional administrator for Cal OES began work with FEMA on a catastrophic incident concept of operations for the San Joaquin Delta. This then prompted Cal OES to begin work with the U.S. Army Corps of Engineers developing county contingency plans modelled after the ones created for San Joaquin County (McKenna, 2011).

ARkStorm Use

In May 2011, the California Water/Wastewater Agency Response Network (CalWARN) teamed up with the California-Nevada Section of the American Water Works Association (AWWA), to plan an ARkStorm emergency response exercise. Collaborating with Arizona and Nevada's Water/Wastewater Agency Response Networks, the Environmental Protection Agency, and the California Department of Public Health, CalWARN scheduled the exercise to fall in the middle of the annual AWWA California/ Nevada conference. Their focus was to workshop flood management with potable water, wastewater, and build networks and mutual aid across California, Nevada, and Arizona (CalWARN, 2011). Present was AWWA member and Director of Emergency Management and Business Resiliency at San Jose Water Company, Jim Wollbrinck, who had collaborated on the development of ARkStorm and brought the ARkStorm lessons back to San Jose, incorporating the flood narrative into San Jose Water Company's emergency exercises and plans.

Through their work with ShakeOut and ARkStorm, CalWARN created the water sector-specific position, also called "the water desk," which was established to centralize water emergency response and recovery efforts, coordinating multiple agencies and organizations in disaster response, and navigating multiple mutual aid contracts. The water desk was activated after the 2010 Northern Baja earthquake, when CalWARN representatives were able to support Imperial County with obtaining temporary water treatment pumps (microfiltration plants) while earthquake damage to their water facilities was repaired (Porter and Sherrill, 2011; Sturdivan, 2011).

From July 18–21, Navy installations all along the west coast participated in the 2011 Citadel Rumble, an annual hazard exercise that tests navy operations to respond to a hazard, evacuate personnel and civilians, and organize relief and repair efforts. The 2011 regional exercise was based on ARkStorm, responding to hypothetical flooding of the Navy Region Southwest, where they identified vulnerabilities like underground transformers and sewer stations, and anticipated the fact that the communities surrounding the naval bases would likely be looking to them for help in a scenario like ARkStorm (DVIDS, 2011; Larson Lee, 2011). ARkStorm project partners The Metropolitan Water District of Southern California also ran a scenario simulation exercise in 2011, which focused on facility damage and compromised water quality due to flooding. With the State Department of Public Health, they also refined their boil-water advisories and subsequently updated the water district's emergency plan (MWDSC, 2011).

In 2013, Ventura County was selected as a pilot ARkStorm project, taking the ARkStorm conditions and impacts down to the county level and looking at the effects on the Santa Clara River in a major flood event. FEMA provided funding and worked with Ventura County and the USGS as a primary project partner. FEMA's involvement made Ventura participants nervous because FEMA's flood maps determine flood insurance rates, and ARkStorm is a major flood—residents did not want their flood insurance rates to increase. This sentiment was echoed by other municipalities that were confronted with flooding due to ARkStorm (Schaefer, 2010). Because the USGS was fronting the exercise, it allowed Ventura to bypass concerns of FEMA's involvement and think about floods outside of FEMA's valuation. This enabled Cox to negotiate the use of ARkStorm in their annual emergency response exercise (VCWPD, 2013; Suzette M. Kimball, USGS, written commun., 2015). Ventura's tabletop

California's Test of ARkStorm

In January and February 2017, after an extreme drought season for California, an atmospheric river rolled through the State and brought the same levels of precipitation as was estimated in ARkStorm's narrative, but over 80 days instead of 23 (Cox, Dettinger, and others, 2018). The news cycle recognized the connection immediately, and there was a spike in headlines that mentioned ARkStorm, as shown in the "Media Mentions Findings" section of this report. Included in that damage was (1) the Anderson Dam in San Jose overflowed flooding Coyote Creek and forcing the evacuation of 14,000 people, and (2) the Oroville Dam that burst a hole in an emergency spillway and threatened to flood the surrounding area, which prompted the evacuation of 188,000 residents in Oroville, California (Prodis Sulek and Gafni, 2017). These floods, landslides, and mudslides prompted Governor Edmund Brown Jr. to request a Presidential Major Disaster Declaration three times for different stages of the storms, alongside issuing two emergency proclamations across the State (Cal OES, 2017). In 2018, Nevada Water Resources Association, Fall Symposium hosted an "ARkStorm—Lessons Learned" panel where participants discussed mitigation efforts and considered the 2016–17 storms as a test of their ARkStorm preparedness and response efforts (TWSA, 2020).

exercise included all the local Public Works Administration Divisions, the Sheriff Office of Emergency Services, and Cities of Ventura, Oxnard, Santa Paula, and Fillmore, as well as FEMA and the USGS (Hosseinipour and others, 2013; VCWPD, 2013). The tabletop exercise's primary goal was to develop next steps for Ventura County and city emergency planners, which they used to host countywide technical floodplain training courses, joined FEMA's National Flood Insurance Program's voluntary Community Rating System, and implemented the Fresno Canyon Flood Mitigation Project. Through this program, the county also engaged in five cooperating technical partnerships to improve flood mapping accuracy. Work with Ventura Counties ARkStorm project went through October of 2012 and four of the five cooperating technical partnerships were completed by 2013 (Pratt, 2014).

Cox was then assigned to a project to investigate the decline of clarity in Lake Tahoe by the USGS Director Marcia McNutt. With a team of researchers from the USGS and the University of California Davis, they discovered Lake Tahoe's clarity was affected by the intensity of atmospheric river storms (Albano and others, 2014). This finding was presented to the Tahoe Science Consortium, who joined a partnership with the USGS, FEMA, and the University of Nevada, Reno Academy for the Environment to kickstart ARkStorm@Tahoe. The Lake Tahoe region (the Tahoe Basin; Truckee, California; and Reno, Sparks, and Carson City, Nevada) became the next site for series of ARkStorm workshops and exercises (Albano and others, 2014; Suzette M. Kimball, USGS, written commun., 2015). Over 300 participants from 138 public and private sectors engaged in 6 workshops from September 2013 to January 2014, details are in table 2.1. Following the stakeholder workshops, ARkStorm@Tahoe held a tabletop exercise on March 14, 2014, where approximately 130 participants from over 80 organizations were divided into small groups across different incident management categories. They responded to three different stages of the storm, day 8—preparedness, day 18—response, and day 35—recovery (Albano and others, 2016). A full version of the ARkStorm Summit program, as scanned by an attendee, is available in PDF at https://doi.org/10.3133/sir20235011. Stakeholders reported being able to engage in the extreme storm scenario more tangibly due to the scientific rigor of the narrative and the products that allowed them to respond as they would if the situation were actually happening (Albano and others, 2016).

In the ARkStorm@Tahoe stakeholder meetings, the topic of developing flood risk awareness programs for the public was broached. Since then, University of Nevada, Reno Cooperative Extension, with other partners, developed the Nevada Flood Awareness Committee in late 2013, that planned to host an annual week of flood awareness events starting November 2014 (Albano and others, 2014; Nevada Floods, 2014). Project partners from California-Nevada Climate Applications Program (of whom Dettinger is a team member) cited ARkStorm@Tahoe as a source of new partnerships through ARkStorm@Tahoe project partners in their 2014 Annual Report (CNAP, 2014). These partnerships, according to California-Nevada Climate Applications Program, are how they are able to serve on the Tahoe Committee of Scientists, participate on the Water Sustainability and Climate project, and work on climate-centered issues for agriculture in the Great Basin (CNAP, 2014). In December 2015, author Linda Davies published "Ark Storm: A Novel" an ARkStorm based thriller that follows a meteorologist as she foresees the arrival of an atmospheric river fueled storm event (Davies, 2014).

Tsunami Scenario

As ARkStorm was approaching publication and rollout, MHDP leadership continued facilitating connections with Los Angeles organizations, including the Port of Los Angeles, one of the major ports of commerce in the United States.

FloodCast

One attendee of the ARkStorm Summit was Herby Lissade, P.E., then Supervising Transportation Engineer at California Department of Transportation (Caltrans) before becoming Chief of the Caltrans Office of Emergency Management. At that time Caltrans had been using the earthquake response tool ShakeCast, which they developed in partnership with the USGS to provide accurate assessments of earthquake damage to over 12,700 bridges and facilities so Caltrans can deploy repair crews where they are most needed (Caltrans, 2017). Lissade, struck by the destructive power of floods at the ARkStorm level, set about organizing the development of a similar tool that would predict flood damage to bridges, roads, and facilities during extreme precipitation events, called FloodCast. As a member of the Transportation Research Board and Chair of Transportation Research Board National Cooperative Highway Research Program panels on catastrophic transportation emergency management, Lissade got the project picked up by the National Cooperative Highway Research Program in 2014. FloodCast, created by Dewberry Consultants LLC, has been overseen by a panel including representatives from Caltrans, NOAA, USGS, Delaware's DOT, research universities, and private consulting firms (Caltrans, 2017; NCHRP, 2018). The project was primarily completed in 2018, though the crucial Phase IV (completing the flood data and hydrology inputs so flood forecasting is available nationwide) is still in progress (Dewberry Venner Consulting, 2018).

Table 2.1. The ARkStorm panels for the Lake Tahoe region (the Tahoe Basin; Truckee, California; and Reno, Sparks, and Carson City, Nevada), from Albano and others (2016).

Focal Topic Areas	Location	Date	Number of Registered Attendees	Organizations Represented
Public Utilities, Water Supply	Incline Village General Improvement District, Incline Village, Nevada	9/12/2013	31	22
Emergency Response, Health and Human Services, Business Community	Lake Tahoe Visitor's Authority, Stateline, Nevada	10/11/2013	63	43
State and Federal Coordination	Nevada Division of Emergency Management, Carson City, Nevada	11/12/2013	68	30
Truckee River Flood Management	Regional Emergency Operations Center, Reno, Nevada	12/5/2013	138	69
Tribal Impacts	Reno-Sparks Tribal Health Center, Reno, Nevada	1/13/2014	40	39
Natural Resource Impacts	Tahoe Regional Planning Agency, Stateline, Nevada	1/14/2014	63	39

Port emergency managers requested a worst-case tsunami scenario, something that the MHDP strategic plan had already outlined as an intended area of study (Jones and others, 2007; Ross and others, 2013a). The Port of Los Angeles, and soon the Port of Long Beach, became primary partners for the conception of the Tsunami Scenario, and plans to investigate potential tsunami impacts along the Southern California coast were started.

Finding a source location that would affect the ports and sizing it appropriately to the plausible but improbable standards was a challenge. The eastern side of the Pacific Rim is well protected from most potential direct tsunami sources (Jones and others, 2007; Ross and others, 2013a). Holly Ryan, a geologist and organizer for the team that would develop the source, pulled in geophysicist Stephanie Ross, given Ross' expertise in offshore earthquakes. Later, due to Ross' experience managing interdisciplinary projects, including roles that focused on communicating science, Jones asked Ross to lead the Tsunami Scenario as lead scientist and project manager.

The same week of ARkStorm's rollout in January 2011, development of the Tsunami Scenario formally kicked off. Having learned from ShakeOut and ARkStorm that delays in the source development can compound and cause difficulties for the engineering and economic analysis, Ryan and Ross' team decided to determine the source before engaging in any other scenario development stages, which ended up being fortuitous. A moderately strong earthquake source for Tsunami Scenario had been (more or less) agreed upon by the developers for Tsunami Scenario's project kickoff. However, the fourth biggest earthquake in recorded history, the Tōhoku earthquake (also known as the Great East Japan Earthquake and the Great Sendai Earthquake) hit off the coast of Japan on March 11, 2011. The Tōhoku 9.0–9.1 magnitude undersea megathrust created tsunami waves as high as 40.5 meters that travelled as far as 10 km inland of the Sendai area of Japan. The size and devastation of the Tōhoku earthquake put the original Tsunami Scenario source in perspective, and several members in the Tsunami Scenario source team realized that the scenario might need to be bigger to provide a more robust hazard preparedness and response tool (Real and others, 2014). While some disagreed, worried that they were overshooting believability of the scenario by making it seem implausibly large, the original source was changed, and increased in magnitude to match Tōhoku and set in the Aleutian Islands not far from Kodiak Island, Alaska. Ultimately, the Tsunami Scenario source took two years total to finalize (Ross and others, 2013a; Ross and others, 2014).

While the project scope had originally been more focused on the Ports of Los Angeles and Long Beach, the involvement of Cal OES and CGS pushed the scenario to encompass the whole coast of California (Real and others, 2014). Cal OES had recently reimaged and released their tsunami inundation maps in 2009, and when Tsunami Scenario was proposed not long after, there was a potential for the state 2009 maps and the Tsunami Scenario maps to be conflated for users. Tsunami experts in USGS, CGS, and Cal OES wanted to ensure a united front with California tsunami messaging and working groups, and to expand the scope of the project to look at tsunami impacts across the California coastline. The coordinating committee ultimately grew to 29 members from thirteen different organizations, including NOAA, multiple universities, and tsunami experts from New Zealand to Alaska (Ross and others, 2013a).

In the work to find a plausible, distance-sourced tsunami that would have a notable impact on the Ports of Long Beach and Los Angeles, but would also affect other coastline areas, CGS' Rick Wilson then coordinated the teams of scenario contributors from CGS, USGS, Humboldt University, California Department of Water Resources, University of New South Wales, and the Australian Nuclear Science and Technology Organization to survey the coastline of California for evidence of historical tsunamis. The diverse team collected data on tsunami deposits along the entire coast, and calculated place of origin and estimated date. This database of historical tsunami data enabled Wilson's team to create what was the most detailed and evidence-based probabilistic tsunami hazard analysis maps of any state, through probabilistic tsunami hazard analysis (Wilson, Hemphill-Haley, and others, 2014). The probabilistic tsunami hazard analysis products are currently used to update the statewide Tsunami Hazard Area maps and create new Tsunami Regulatory Zones under the California Seismic Hazard Mapping Act, as well as the Tsunami Design Zone maps under the California Building Code (Wilson and Miller, 2013; Wilson, Miller, and others, 2014).

Tsunami Scenario Rollout

"The SAFRR (Science Application for Risk Reduction) Tsunami Scenario" OFR 2013–1170 and California Geological Survey (CGS) Special Report 229 was published in September 2013, crediting 31 more authors from nine different organizations on the publication itself, which, along with the coordinating committee, totaled in 60 authors from 22 organizations (Ross and Jones, 2013). An additional 174 contributors from 50 more organizations were also credited in the report. The report contains highly detailed information about the source earthquake, inundation areas, debris flow and expected inundation currents, economic and social data, among many potential vulnerabilities and mitigation opportunities. Some highlights include hazard maps for harbors and offshore safety zones for potential boat evacuation that apply to a variety of distance-sourced tsunamis, playbook maps and guidance for running Tsunami Scenario exercises and drills, and cost estimates for damages that enable state and federal organizations to contextualize tsunami preparation costs (Ross and Jones, 2013). Also published on September 3, 2013, was the fact sheet "The SAFRR Tsunami Scenario—Improving Resilience for California" containing the highlights from the OFR (Ross and others, 2013b) and an animation of the tsunami propagation (Lynett, 2013). The USGS funded tsunami awareness video, titled "The First Sue Nami," was also released for the Tsunami Scenario rollout. The video features Sue Nami, a personification of a tsunami, instructing the viewers on warning signs and what to do if they think a tsunami is coming (Sandoval, 2014).

While Tsunami Scenario leadership considered a public campaign titled "The Next Wave," with prototypes for public awareness materials, SAFRR leadership decided against a public campaign (Designmatters, 2012). Instead, Tsunami Scenario leadership learned from ARkStorm's success on the local level and reached out personally to municipalities and targeted organizers and decisionmakers. For the initial rollout, Tsunami Scenario developers convened in partnership with the California Tsunami Hazard Mitigation Program to host a series of workshops with key stakeholders like harbormasters in affected regions. The workshops kicked off in the Cabrillo Aquarium in Los Angeles on September 4, 2013, with a small media presence. The workshops continued throughout 2013 in Santa Barbara County Office of Emergency Management (September 5), San Diego County Office of Emergency Management (September 6), Santa Cruz County Office of Emergency Management (September 9), and the Port of San Francisco (September 10). Each workshop had around ten Tsunami Scenario developers, to cover a wide range of the scenario's topics and answer questions in depth, and 40 to 100 participants (USGS, 2013; Ross and others, 2016).

Tsunami Scenario Use

Tsunami Scenario developers had identified a potential concern in the tsunami response protocol regarding the Seal Beach and Long Beach area. The scenario development team had worked with the National Tsunami Warning Center in Alaska to develop an exercise scenario to assess the warning system. For the exercise, the National Tsunami Warning Center developed a series of Tsunami Information Statements (TIS), which are the official statements of tsunami warning and guidance distributed to emergency management and the public in affected locations (Ross and Jones, 2013). Based on the potential tsunami's projected pathway, one area could receive an advisory TIS while another receives evacuation TIS. Through this exercise, the Tsunami Scenario team identified one TIS boundary (called a breakpoint) between Los Angeles and Orange County called the Alamitos Breakpoint, where Seal Beach and Long Beach are separated by a river and county boundary, but otherwise are an integrated and highly developed population. Having the north side of this area get a warning TIS, while the south side gets an evacuation TIS, at different times, would create potential for confusion, mixed messages, and failure to properly evacuate a population at risk (Ross and Jones, 2013). This discovery inspired the action to move this breakpoint boundary to the Orange County and San Diego County boundary, to ensure a seamless tsunami response to the Seal Beach and Long Beach residents (Miller and Long, 2013).

For the 2014 National Tsunami Preparedness Week (March 23 to 29) NOAA chose Tsunami Scenario for its annual PacifEX tsunami warning exercises on March 27, 2014, running tabletops in Marin County, San Mateo County, San Francisco, and the State of Washington (Ross and others, 2014). The San Francisco Department of Emergency Management expanded the PacifEX exercise, hosting a tabletop on March 5, and three days of functional exercises from March 26–28, focusing on alert and warning procedures, response coordination, and recovery operations. Ross and other Tsunami Scenario collaborators supported these exercises across California. Ross also represented the USGS at the San Francisco Tsunami Walk on March 29, 2014, simulating a tsunami evacuation for affected San Francisco residents (PCMSC, 2014; Ross and others, 2014).

In April 2014, the National Institute of Environmental Health Sciences conducted a tabletop exercise with emergency managers on State and local levels, focusing on Tsunami Scenario's impacts on the Port of Long Beach. Their simulation was comprised of electrical problems at a refinery located near the Port of Long Beach caused by tsunami inundation. The National Institute of Environmental Health Sciences added a simulated refinery explosion and fire, resulting in a toxic plume and an oil spill into the flood waters, and how this would affect the health of the surrounding communities (Ross and others, 2014; NIH, 2015).

Project partners in CGS and Cal OES brought the Tsunami Scenario into ongoing state tsunami organizations and programs. The California Tsunami Program, a collaboration between CGS and Cal OES, released "Tsunami Evacuation Playbooks," tsunami mitigation, response, and recovery products for harbors, and plans for maritime communities to prepare and recover. The California Tsunami Program also made plans to expand tsunami research and collaborate with groups like National Tsunami Hazard Mitigation Program (NTHMP). These products are based on information from the 2010 Chile tsunami, the Tōhoku tsunami in 2011, and historic tsunamis in California, along with analysis from the SAFRR and Cascadia Tsunami Scenarios (Wilson and Miller, 2013; Wilson, Hemphill-Haley, and others, 2014). The California Tsunami Program also identified that the Ports of Los Angeles and Long Beach were in the process of improving their tsunami response planning and considering long term infrastructure changes to reduce risk of tsunami impacts (Wilson, 2013)

In 2014 the California Tsunami Policy Working Group (CTPWG), a multidisciplinary group in California's Department of Conservation's Natural Resources Agency that advises the state on tsunami hazard risk, mitigation, and policy opportunities, released a comprehensive hazard report titled "California's Tsunami Risk: A Call for Action." The report heavily referenced SAFRR's Tsunami Scenario and presents a series of 47 recommendations to reduce tsunami risk along California's coast (CTPWG, 2014). Throughout development, Tsunami Scenario developers worked closely with CTPWG, as members of CTPWG worked on the Tsunami Scenario coordinating committee, and Tsunami Scenario members co-chaired positions in CTPWG, facilitating communication between the two groups. CTPWG took the findings of the Tsunami Scenario, assessed mitigation and preparation measures and their feasibility, and produced policy recommendations for the State of California (Real and others, 2014).

ABAG features the SAFRR Tsunami Scenario on its "Tsunami and Additional Hazards" page, where it is used in tandem with the 2009 State Tsunami Inundation Maps to inform municipalities throughout the San Francisco Bay Area. ABAG works with nine counties and ninety cities and is heavily cited in San Francisco Bay Area city and county Local Hazard Mitigation Plans (LHMP) for tsunami hazard assessment. ABAG's 2014 "Cascading Failures: Earthquake Threats to Transportation and Utilities" report and "San Francisco Bay Area Risk 2017 Profile" both use Tsunami Scenario to represent tsunami hazard in the region (ABAG, 2021c).

Much of the continued work done using Tsunami Scenario is made possible by the NTHMP. NTHMP is a partnership between NOAA, FEMA, USGS, the National Science Foundation, and Coastal States, Territories and Commonwealths, and focuses on providing guidance and funding for tsunami hazard programs in the affected states. The funding for the NTHMP comes from the Tsunami Warning and Education Act (33 U.S.C. 3201), which was reauthorized in 2017 as the Tsunami Warning Education and Research Act of 2017 (33 U.S.C. 3201), partially due to a coordinated effort between CGS and tsunami groups from Oregon and Washington to emphasize the importance of the funding and federal guidance of the Act (Lopes, 2017). CGS representatives provided information to support the reauthorization, using Tsunami Scenario findings and the probabilistic tsunami hazard maps to illustrate tsunami risk and the need for coordinated funding and support, writing letters to congress in support of the Act's reauthorization. The NTHMP's 2018-2023 Strategic Plan also utilizes Tsunami Scenario findings to justify preparedness and mitigation costs (NTHMP, 2018).

In fact, Tsunami Scenario has been used to emphasize the importance of the NTHMP and interagency coordination in tsunami response as early as April 14, 2011, when William Leith, Acting Associate Director for Natural Hazards, USGS, testified in the House Hearing of the 112th Congress "Tsunami Warning, Preparedness, Interagency Cooperation: Lessons Learned." Leith used the work in progress of the Tsunami Scenario to emphasize the potential danger to the West Coast of the United States for tsunami, and to illustrate what the interagency coordination through the NTHMP has been able to accomplish (U.S. Congress, House Committee on Oversight and Government Reform, 2011).

As of May 2021, Tsunami Scenario's lead author Stephanie Ross is leading a research coalition group through the John Wesley Powell Center for Analysis and Synthesis, called the "Tsunami Source Standardization for Hazards Mitigation in the United States" group, where six of the eight core team members are from the coordinating committee for the Tsunami Scenario (USGS, 2021). Ross is also one of the USGS representatives in the NTHMP, working alongside four other Tsunami Scenario co-authors.

HayWired Scenario

In the years since ShakeOut's 2008 publication, which included a supplemental study of telecommunications, California became the center of rapid technological advances. Silicon Valley grew as a dominant center of technological innovation, and by 2013, the area employed 250,000 information technology workers (JVSV, 2013). Smartphones had begun cornering the cellular market, and 88 percent of Americans owned a mobile device (Pew Research Center, 2021), while the number of households with a landline phone had dropped by 20 percent by the end of 2013 (Richter, 2021). Society's increasing reliance on internet and cellular devices changed the prospective risks involved in power outages, cell tower failures, and internet outages. California emergency management and DRR organizations would need to incorporate the growing telecommunications field into hazard studies and management procedures.

Meanwhile, SAFRR leadership and project partners had been discussing what to do after the publication of "Tsunami Scenario." A scenario on the Hayward Fault was proposed, due to the fault's location and high activity, commonly producing smaller earthquakes, but has an estimated major earthquake approximately every 100 to 220 years. The fault line runs through the densely populated and developed east San Francisco Bay Area, from San Jose and Silicon Valley at the southern point, through Oakland and Berkeley, to the northern point of the San Francisco Bay (Hudnut and others, 2017). In November of 2013, HayWired officially kicked off, with an intention to focus on the impact of telecommunications interruption on response and recovery. Anne Wein, who had led the social and economic impact chapters for ShakeOut, ARkStorm, and Tsunami Scenario became lead researcher for the project. The name HayWired was chosen to highlight that focus on the wired and wireless world (Hudnut and others, 2017).

HayWired Volume 1

Dale Cox rejoined SAFRR and the HayWired team in 2014 and was joined by geophysicist and ShakeOut veteran Ken Hudnut to work on the HayWired source. For the original earthquake rupture, the source team chose a simulation with a magnitude of 7.0 and an epicenter in Oakland, which was already partially modelled, among other faults, in Aagaard and others' (2010) paper. The scenario includes an initial fault slip during the rupture, and a longer-duration continued slip, called an "afterslip," that accompanies aftershocks for months after the main event (Aagaard and others, 2017). Liquefaction and landslide impacts were determined using recent, highly detailed work from the USGS and CGS partners, creating a highly detailed model for damage assessment.

While the source work was underway, Charles Scawthorn, who had written both ShakeOut and Tsunami Scenario's post-hazard fire analyses, began work on fire for HayWired. In October 2014, Scawthorn and project partners held a fire following earthquake workshop at the Richmond Field Station of the University of California at Berkeley. The workshop particularly focused on the reliability of a firefighting water supply in the San Francisco Bay Area, and what to do if water pipelines break from the ground shaking. After the workshop was a joint exercise, where four portable water-supply systems, belonging to the Berkeley, Oakland, San Francisco, and Vallejo Fire Departments, were tested together for the first time (Scawthorn, 2018).

HayWired leadership, aware of how project delays can create complications, but also wanting HayWired to have a more robust review process, chose to release the scenario in pieces—complete the source material, have a thorough review process, and then publish. Their goal was to engage project partners before the final volumes of the report were released (Wein, 2018). Publishing the source data as the first volume of HayWired enabled project partners to use the information right away and get involved with the development of the next volume (Cox, Kang, and others, 2018). Thus, the first volume for HayWired, Science Investigative Report 2017–5013–A–H, titled "The HayWired Earthquake Scenario—Earthquake Hazards" was published in 2017, and covered the Hayward Fault's history of earthquakes, as well as the scenario mainshock, landslides, and liquefaction data (Detweiler and Wein, 2018a). Also, in 2017, the USGS published an online geonarrative of HayWired Volume 1 called "The HayWired Scenario: An Urban Earthquake in a Connected World." The geonarrative presents interactive maps and information from ground shaking to liquefaction, with animations and easy-to-read summaries of the findings (Perry and Bruce, 2017).

HayWired Volume 2

The analysis of the engineering implications contains more detail in methodology and scope than previous scenarios. Instead of publishing a suite of supplemental studies where engineers and researchers filled in depth after the primary report was released, as with ShakeOut, HayWired leadership chose to contain all the highly specified engineering analyses in one document. For example, in ShakeOut, co-author Keith Porter estimated elevator failures from the mainshock and ground movement, but for HayWired, Porter calculated an estimated number of people trapped, and provided the math to do those calculations (Porter, 2018a). HayWired's developers not only outlined building failure, but also analyzed the current building codes against a more resilient set of building code standards, and included an estimated cost analysis (Porter, 2018c).

A notable advance in HayWired's earthquake impact and recovery modeling was Porter's new model (2018b) for water network resilience. Porter started with different kinds of pipe infrastructure, above and below ground, and modeled their vulnerability based on age and materials. This was built into equations to estimate damages and repairs, including factors for repair delays based on material availability and lifeline interactions from other damages due to the earthquake (such as road closure). HayWired's earthquake data was then applied to the model and run through earthquake risk estimation tool from Hazus, FEMA's nationally standardized risk modelling methodology program. Porter worked with the San Jose Water Company and the East Bay Municipal Utility District (EBMUD), using their data to present case studies of the model, and included estimates for Contra Costa and Alameda County (Porter, 2018b).

Another unique addition to engineering damages was Porter and Jones' chapter Q of HayWired Volume 2, estimating how many lives can be saved by earthquake early warning (Porter and Jones, 2018). They presented the results of studies on human behavior in earthquakes, including two studies on the efficacy of the ShakeOut drill, focusing on "drop, cover, and hold on." They used these results to estimate the efficacy of an earthquake early warning system, estimating the benefit of combining the two, giving people the seconds needed to complete "drop, cover, and hold on" even with initial hesitation or confusion. This chapter makes up HayWired's Volume 2: "The HayWired Earthquake Scenario–Engineering Implications," U.S. Geological Survey Scientific Investigations Report 2017–5013–I–Q, along with the fire following earthquake analysis, models for building failure, a deeper assessment of aftershock impacts, and a foray into surveying social expectations for building codes (Detweiler and Wein, 2018b).

HayWired Coalition

Meanwhile, HayWired project leads had been contacting partners across the region to begin forming what would become the HayWired Coalition. HayWired developers were working with the Pacific Earthquake Engineering Research Center (PEER), the Seismic Safety Commission, ABAG, the Metropolitan Transportation Commission, Joint Venture Silicon Valley (JVSV), and the Bay Area Center for Regional Disaster Resilience to communicate HayWired's results and make the scenario relevant across the State of California (Cox, Kang, and others, 2018). These groups became key collaborators in forming a coalition, as developers not only wanted to incorporate stakeholder feedback into HayWired's development, they also wanted to foster long-term relationships to continue to utilize HayWired's findings for earthquake preparedness and mitigation. In previous scenarios, engaging project partners was an organic process, with many connections made after the scenarios were finalized and published. For HayWired, the coalition was an intentional method for stakeholder engagement (Hudnut and others, 2017; Cox, Kang, and others, 2018).

The coalition formally began in April 2017, with the publication of HayWired Volume 1 "The HayWired Earthquake Scenario: Earthquake Hazards" (Detweiler and Wein, 2018a). The coalition kicked off with a meeting of over 60 HayWired collaborators and partners, and over the course of the year, the coalition collaborators engaged stakeholders across the State. PEER developed relationships with academic and engineering institutions, hosting workshops on the source data. ABAG and the Metropolitan Transportation Commission convened multiple briefings with over 60 San Francisco Bay Area jurisdictions, as well as with leadership in Alameda and Contra Costa Counties. JVSV also held HayWired workshops, but with internet and telecommunication providers, as well as businesses. JVSV's David Witkowski also joined Wein in the work on telecommunications impacts, and JVSV Institute for Regional Studies economists contributed to the HayWired economic impacts chapters (Cox, Kang, and others, 2018). The full list of HayWired Coalition partners as of 2017 can be found in table 2.2.

HayWired Campaign – Outsmart Disaster

The Seismic Safety Commission, at the time of HayWired's initial development, fell under the California Business, Consumer Services, and Housing Agency (BCSH), an agency responsible for business regulation and consumer protection. BCSH leadership, receiving reports on the Seismic Safety's Commission HayWired projections, saw an opportunity to translate HayWired's complex findings and engage a wide range of businesses in earthquake preparedness. In 2016, the BCSH started developing the HayWired Outsmart Disaster Campaign to target small and medium sized businesses, a sector that has not had a large presence in the SAFRR scenarios. BCSH was able to bring in a public relations and marketing firm to promote the hazard awareness and resilience campaign and create a vehicle for communication between SAFRR and thousands of San Francisco Bay Area businesses (BCSH, 2021). JVSV partnered with Outsmart Disaster, bringing in stakeholders like Pacific Gas & Electric, and helping develop materials for business recovery and continuity exercises (Cox, Kang, and others, 2018; JVSV, 2021).

Outsmart Disaster grew quickly and was working with many San Francisco Bay Area businesses through 2017 and 2018, when California experienced their most destructive wildfire seasons on record at that time. The campaign had been preparing materials for HayWired, including the fire following earthquake work. The campaign applied the fire-related HayWired materials and preparedness initiatives to the 2017–18 wildfires, including bringing in money from their major donors for wildfire resilience work (JP Morgan Chase, 2019). The wildfire response was the start of the campaign's pivot to multi-hazards, and away from HayWired as a specific foundation for preparedness. For a list of Outsmart Disaster's partners as of 2018, see table 2.3.

HayWired Rollout

By spring 2018, HayWired's first and second volumes were completed, and the Outsmart Disaster campaign was ready to formally launch their Resilient Business Challenge, an initiative to create goals for businesses to increase their resiliency to hazards. SAFRR, the HayWired Coalition, and Outsmart Disaster organized a rollout event with PEER for April 18, 2018, the anniversary of the 1906 San Francisco Earthquake. The event started with a media tour and presentations on the lifeline infrastructure impacts at the Fremont Community Center, where movement along the Hayward Fault caused a growing crack through the center (Cox, Kang, and others, 2018). Next was a press conference

Table 2.2. HayWired Coalition Partners in 2017 (Hudnut and others, 2017).

[LLC, Limited Liability Company]

Alameda County Mayors' Conference	Alameda County Sheriff's Office, Office of Emergency Services	American Red Cross
Art Center College of Design	Arup—Design and Engineering Consultants	Association of Bay Area Governments—Metropolitan Transportation Commission
Aurecon	Bay Area Center for Regional Disaster Resilience	Bay Area Council
Bay Area Rapid Transit Authority	Bay Area Urban Area Security Initiative	Bay Planning Coalition
Boston University	Business Recovery Managers Association	California Business, Consumer Services, and Housing Agency
California Department of Public Health	California Department of Transportation	California Earthquake Authority
California Earthquake Clearinghouse	California Geological Survey	California Governor's Office of Business and Economic Development
California Governor's Office of Emergency Services	California Independent Oil Marketers Association	California Independent System Operator
California Public Utilities Commission	California Resiliency Alliance	California Seismic Safety Commission
Carnegie Melon University	City and County of San Francisco	City of Berkeley
City of Fremont	City of Hayward	City of Oakland
City of Oakland, Fire Department	City of San Francisco, Department of Emergency Management	City of Walnut Creek
Contra Costa County Mayors' Conference	Earthquake Country Alliance	Earthquake Engineering Research Institute
East Bay Municipal Utility District	Federal Emergency Management Agency	Joint Venture Silicon Valley
Laurie Johnson Consulting/Research	March Studios	Marin Economic Consulting
MMI Engineering	Office of the Mayor, City and County of San Francisco	Pacific Earthquake Engineering Research Center
Pacific Gas and Electric	Palo Alto University	Price School of Public Policy and Center for Risk and Economic Analysis of Terrorism Events, University of Southern California
Rockefeller Foundation—100 Resilient Cities	San Jose Water Company	Southern California Earthquake Center
SPA Risk LLC	San Francisco Planning and Urban Research Association	Strategic Economics
Structural Engineers Association of Northern California	The Brashear Group LLC	University of California Berkeley Seismological Laboratory
University of Colorado Boulder	University of Southern California	U.S. Department of Homeland Security
U.S. Geological Survey	Wells Fargo	

in Berkeley's Memorial Stadium, a football stadium that straddles the Hayward Fault and despite recent renovations also has cracks resulting from fault creep. Later, scenario developers held more detailed lectures on HayWired's analyses in Berkeley classrooms (PEER, 2018). Coinciding with the rollout was the publication of the two HayWired volumes and "The HayWired earthquake scenario—We can outsmart disaster" Fact Sheet 2018-3016 (Hudnut and others, 2018). The HayWired team debuted a movie titled "The HayWired Scenario – Movie," where the scenario is described, from source through impacts, ending with preparedness initiatives and a link to outsmartdisaster.com (Cox and Cascio, 2018). Developers also released the source and engineering data packages for organizations that wanted to run their own analyses with HayWired's data, available through the USGS' website.

Table 2.3. Outsmart Disaster partners as of 2018 (Cox, Wein, and others, 2018).

[LLC, Limited Liability Company]

ARUP—Design and Engineering Consultants	Association of Bay Area Governments	Aurecon
Bay Area Center for Regional Disaster Resilience	Bay Area Rapid Transit Authority	Boston University
California Department of Public Health	California Department of Transportation	California Earthquake Authority
California Earthquake Clearinghouse	California Geological Survey	California Governor’s Office of Business and Economic Development
California Governor's Office of Emergency Services	California Public Utilities Commission	California Resiliency Alliance
California Seismic Safety Commission	Carnegie Melon University Silicon Valley	City of Berkeley
City of Oakland	City of San Francisco, Department of Emergency Management	City of Walnut Creek
Earthquake Country Alliance	Earthquake Engineering Research Institute	East Bay Municipal Utilities District
Federal Emergency Management Agency	Joint Venture Silicon Valley	Laurie Johnson Consulting
MMI Engineering	Pacific Earthquake Engineering Research Center	Pacific Gas and Electric
Palo Alto University	Red Cross	Rockefeller Foundation—100 Resilient Cities
San Jose Water Company	Southern California Earthquake Center	SPA Risk LLC
San Francisco Bay Area Planning and Urban Research Association	Strategic Economics	Structural Engineers Association of Northern California
University of California Berkeley Seismological Laboratory	University of Colorado Boulder	University of Southern California
U.S. Geological Survey		

HayWired’s Rolling Publications and Examples of Use

August 17, 2018, after the rollout, CGS and the California Earthquake Clearinghouse conducted a 1-day table-top exercise based on HayWired, coordinating 67 participants from NASA, USGS, California State and local governments, and earthquake research and response organizations. The exercise was preceded by three webinars, in April, June, and August, to prepare participants and familiarize the different groups with the others’ roles and abilities (CGS, 2018). That same fall, OutSmart Disaster pivoted from a San Francisco Bay Area focus to a statewide initiative and from HayWired to an all-hazards approach (BPC, 2018). HayWired was a strong foundation for their initial work.

Before “HayWired Volume 2” was published, EBMUD had been using their work with HayWired to perform seismic assessments and upgrades of their infrastructure, as well as entering into mutual assistance agreements with the LADWP and the Las Vegas Valley Water District. EBMUD recognized that local water agencies with which they had mutual assistance agreements would also be overwhelmed by an earthquake like HayWired, and these two water companies are geographically distant enough to provide aid (Terentieff and others, 2015; EBMUD, 2018). Since working with HayWired, the Alameda Water District has also increased their infrastructure’s resiliency by replacing the aging long-diameter water pipes with pipes redesigned to withstand the constant fault creep across the Hayward Fault (Hudnut and others, 2018). San Jose Water Company has evaluated their leak detection technology, stocked their facilities with repair materials, incorporated HayWired into their emergency planning exercises, and entered into mutual aid agreements (Porter and others, 2018). EBMUD is continuing to work with Keith Porter on optimizing their maintenance plan for replacing pipe with future earthquakes in mind.

As project delays were compounded into 2019 for HayWired’s development team, HayWired’s leadership chose to release the third volume’s chapters as they became available. The chapters involving social and economic impacts have been released individually starting October 2019. At the time of this evaluation, chapters T through W of Volume 3 are available from “The HayWired Earthquake Scenario: Societal Consequences,” covering lifeline damage and recovery interactions, demographic analysis of communities at risk, economic impacts, policy implications, and potential hazard mitigation actions (Detweiler and Wein, 2019). The delays did create opportunities for deeper analysis. Wein had been working directly with ABAG's chief economist, who ended up co-writing several chapters for HayWired's third volume, providing a detailed analysis of the San Francisco Bay Area's economic profile. The delays gave the chief economist the time needed to develop a more detailed economic analysis with Wein.

Having been deeply involved in HayWired throughout development, ABAG continued to incorporate HayWired into their hazard and resilience planning. During the Spring 2018 ABAG General Assembly and Business meeting, Hudnut presented on the HayWired earthquake, focusing on inventorying buildings for earthquake resilience and providing water for firefighting. The Spring 2018 General Assembly was attended by 150 representatives of local governments across the San Francisco Bay Area's nine counties (Rabari, 2018). ABAG also took the hard data provided by HayWired and incorporated it into their long-term planning program, creating three potential futures for the San Francisco Bay Area, all of which included the base data for a HayWired earthquake. Earthquake impact data was incorporated into ABAG's projections alongside demographic changes, changes in telecommunications technology, and climate change (ABAG, 2019). HayWired's data were then used for ABAG's long term planning to help identify over 300,000 seismically deficient buildings that would need retrofitting within the next 30 years (ABAG, 2021a). HayWired also informs multiple initiatives under the ABAG Resilience Program (ABAG, 2021b).

Examples of the use and impact of the later chapters may not have had time to be integrated into plans and policy at the time of this evaluation, though developers have been working on outreach to help translate these chapters to stakeholders. While the telecommunications chapter is in review as of May 2021, JVSV has been hosting online workshops with Witkowski and Wein on the social, economic, and telecommunications impacts of HayWired since November 2020, as the pandemic made online webinars, workshops, and outreach a necessity (JVSV, 2021). Recordings of the webinars can be found at https://jointventure.org/events/haywired-connection.

Supplementary Materials for the SAFRR Scenario Retrospective

The following are materials and information pertaining to the ShakeOut and ARkStorm scenarios. First is the steering committee table for ShakeOut, and then the ARkStorm Summit program and the ARkStorm@Tahoe tabletop schedule.

ShakeOut Steering Committee

Table 2.4 shows the ShakeOut steering committee members and their responsibilities within the ShakeOut development, taken from Jones and Benthien (2011).

ARkStorm Summit

The ARkStorm Summit was a two-day conference in January 2011, at the California State University, Sacramento. Around 250 stakeholder invitees from public and private sectors participated in preparedness planning and worked with ARkStorm developers and contributors for different aspects of the ARkStorm scenario. A version of the ARkStorm Summit program, scanned by an attendee, is available in PDF at https://doi.org/10.3133/sir20235011.

ARkStorm@Tahoe Tabletop Exercise Program

The ARkStorm@Tahoe project focused on the social and ecological impacts of an atmospheric river storm in the Lake Tahoe river basin. ARkStorm developers worked with over 300 individuals representing multiple sectors, from disaster response and planning to public utilities and businesses (Albano and others, 2014). The program for the tabletop exercise held at ARkStorm@Tahoe on March 14, 2012 (table 3 of Albano and others, 2016), is as follows:

- Phase One (day 8 of ARkStorm)—Priorities during preparedness phase
  - o Dissemination of information to the public
  - o Advance preparation of shelters and hospitals
  - o Activation of emergency plans
  - o Identifying locations of shelters, staging areas, and associated access routes
  - o Establishing a Unified Coordination Group
- Phase Two (day 18 of ARkStorm)—Priorities during response phase
  - o Prioritization of existing resources for maintaining roadways, utilities, lifelines, and other critical infrastructure necessary for evacuation and response
  - o Coordination of communications within the Incident Command System
  - o Coordination with dam operators and flood managers
  - o Maintaining a well-staffed, centralized Joint Information Center
  - o Continued warnings and communications with the public
- Phase Three (day 35 of ARkStorm)—Approaches to facilitate recovery and enhance resiliency
  - o Incorporate staging locations identifies in the exercise into existing plans and into future training and exercises

- o Expand and maintain interagency communications and have assistance agreements in place ahead of event
- o Conduct training and exercises to determine how to efficiently manage recovery resources, develop grant proposals, manage volunteer resources, and manage temporary housing
- o Maintain early and frequent communications with the public, particularly with at-risk, vulnerable, or remote populations
- o Engage with private industries that may be able to provide resources for response and recovery
- o Engage with policy makers to garner support for actions deemed necessary by operational staff
- o Document damages and elevate public and policy-maker awareness of storm impacts to stimulate flow of recovery resources
    - o Recognize (and act upon) opportunities to re-establish critical infrastructure and developments so that they are robust to future events

Table 2.4. The ShakeOut Steering Committee members and their roles (modified from Jones and Benthien, 2011).

[USGS, U.S. Geological Survey; SCEC, Southern California Earthquake Center; CBS, Columbia Broadcasting System]

Member	Organization and role	Activities
Lucy Jones	USGS, Chief Scientist for the Multi Hazards Demonstration Project, and for the ShakeOut scenario project	Interface with the scenario project
Mark Benthien	SCEC, Director for Communication, Education, and Outreach	Managed fundraising and media purchases. Developed registration system, all web pages, and promotional materials.
Monica Buchanan	State Farm Insurance, Executive. State Farm donated Ms. Buchanan's time to support the ShakeOut	Outreach to the business community and organization for ShakeOut
John Bwarie	City of Los Angeles; Deputy District Director for councilman Greig Smith	Organizer of the International Earthquake Conference
Captain Larry Collins	Los Angeles County Fire Department, Urban Search and Rescue Team	Coordination of Golden Guardian activities at the local level with the ShakeOut.
Dale Cox	USGS, Project Manager for the Multi Hazards Demonstration Project	Interface with the earthquake scenario and connections to the local government and military participants.
Kate Long	California Emergency Management Agency, Earthquake Program	Interface with the Golden Guardian exercise. Connections with Hollywood-based content developers. Drill Manual and Drill Broadcast development.
Ines Pearce	Pearce Global Partners	Connections to the business community and contingency planners
Jack Popejoy	CBS News Radio	Interface with local media.
Sohini Sinha	Art Center College of Design	Organizer of the Get Ready Rally
Steven Storbakken and Connie Lackey	Providence Health Care Hospitals Emergency Management	Connection to the healthcare community. Organized almost 200 hospitals in southern California to participate in ShakeOut
Margaret Vinci	California Institute of Technology, Director of Earthquake Research Affiliated	Interface between the business community and the earthquake monitoring network, California Integrated Seismic Network.
Auxiliary Members		
Ken Hudnut, Debbie Weiser, and Sue Perry	USGS	Members who provided expertise and connections to particular subsets of the activities
Mariana Amatullo	Art Center College of Design	
Peggy Brustche	American Red Cross	
Joanne McLaughlin	Illusion Factory	

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Appendix 3. Supplementary Findings

Local Hazard Mitigation Plan Table for California Counties and Cities

Table 3.1 shows the results of this evaluation's review of California's county and city local hazard mitigation plans (LHMP). The table is color coded to illustrate which scenarios appeared in the LHMP reviewed. A total of 72 cities and 3 counties did not have a LHMP available through their city of county websites at the time of this evaluation and were excluded from table 3.1. ShakeOut appeared in 34 LHMP, ARkStorm in 23, Tsunami Scenario in 7, and HayWired in 8. It is worth noting that Tsunami Scenario affects a smaller number of counties and cities (due to being a coastal disaster), and HayWired is the newest, with chapters published as recently as 2021, after data were collected by this evaluation.

Scenario Timeline

The timeline in table 3.2 comprises workshops, presentations, and publication dates that were significant to the Science Application for Risk Reduction (SAFRR) scenarios. This list does not contain all the activities related to the scenarios, but rather demonstrates examples of ongoing use and outreach.

Table 3.1. Local Hazard Mitigation Plans (LHMP) of California cities and counties.

[All excluded cities and counties did not have a Local Hazard Mitigation Plan LHMP available online during the time of this study. All blank spaces indicate the county or city did not use the scenario in the LHMP. The scenarios are marked by colors that correspond to their branding. SO, ShakeOut (yellow); AS, ARkStorm (blue); TS, Tsunami Scenario (gray); HW, HayWired (red)]

Region	SO	AS	TS	HW	Date
Alameda County					October 2016
Alameda City			■	■	June 2016
Albany City					January 2018
Berkeley City			■	■	December 2019
Dublin City				■	September 2018
Emeryville City					September 2019
Fremont City			■		January 2017
Hayward City			■		March 2016
Livermore City				■	September 2018
Newark City				■	August 2017
Oakland City	■				June 2016
Pleasanton City				■	September 2018
Union City				■	August 2017
Piedmont City		■		■	April 2019
San Leandro City			■		April 2017
Alpine County					August 2017
Amador County					January 2014
Butte County		■			October 2019
Calaveras County		■			October 2015
Colusa County		■			December 2018
Contra Costa County				■	January 2018
Pittsburg City					February 2017
Del Norte County					June 2019
Fresno County					April 2018

Table 3.1. Local Hazard Mitigation Plans (LHMP) of California cities and counties.—Continued

[All excluded cities and counties did not have a Local Hazard Mitigation Plan LHMP available online during the time of this study. All blank spaces indicate the county or city did not use the scenario in the LHMP. The scenarios are marked by colors that correspond to their branding. SO, ShakeOut (yellow); AS, ARkStorm (blue); TS, Tsunami Scenario (gray); HW, HayWired (red)]

Region	SO	AS	TS	HW	Date
Glenn County					September 2018
Humboldt County	■				January 2020
Inyo County					December 2017
Kern County					September 2012
Kings County					December 2012
Lake County		■			January 2018
Clearlake City					June 2019
Lakeport (county seat) City					July 2019
Lassen County					January 2019
Los Angeles County					October 2019
Los Angeles City	■	■			January 2018
Long Beach City					February 2017
Santa Clarita City	■				September 2015
Glendale City					December 2018
Lancaster City	■				September 2013
Palmdale City					April 2015
Pomona City					No Date
Torrance City					September 2016
Pasadena City	■				September 2018
West Covina City					No Date
Madera County		■			October 2017
Marin County					April 2018
Mariposa County					February 2015
Mendocino County		■			May 2014
Merced (county seat) City		■			March 2015
Modoc County		■			March 2016
Mono County					May 2019
Monterey County	■				June 2015
Napa County	■				March 2020
Napa (county seat) City					August 2016
Nevada County		■			August 2017
Orange County	■	■			November 2015
Anaheim City					April 2017
Buena Park City					November 2017
Fountain Valley City					April 2012
Fullerton City		■			March 2019
Garden Grove City	■				January 2020
Huntington Beach City	■	■			March 2017
La Palma City		■			October 2019
Laguna Beach City		■			August 2018
Laguna Woods City	■				December 2012

Table 3.1. Local Hazard Mitigation Plans (LHMP) of California cities and counties.—Continued

[All excluded cities and counties did not have a Local Hazard Mitigation Plan LHMP available online during the time of this study. All blank spaces indicate the county or city did not use the scenario in the LHMP. The scenarios are marked by colors that correspond to their branding. SO, ShakeOut (yellow); AS, ARkStorm (blue); TS, Tsunami Scenario (gray); HW, HayWired (red)]

Region	SO	AS	TS	HW	Date
Newport Beach City	■	■			January 2016
Orange City					October 2016
Rancho Santa Margarita City	■				December 2019
San Juan Capistrano City					August 2019
Seal Beach City		■	■		May 2019
Tustin City					July 2018
Placer County		■			March 2016
Plumas County					September 2014
Portolas City					November 2012
Riverside County	■				July 2018
Banning City					May 2017
Beaumont City	■				June 2012
Moreno Valley City					May 2017
Palm Springs City	■				January 2017
Riverside City					-January 2018
Sacramento County		■			October 2016
San Benito County					August 2015
San Bernardino County	■				July 2017
Apple Valley City	■				January 2017
Barstow City	■				January 2018
Big Bear Lake City					January 2020
Chino Hills City	■				October 2011
Colton City		■			September 2018
Fontana City	■				June 2017
Grand Terrace City	■				March 2017
Hesperia City	■				May 2017
Montclair City	■				June 2012
Ontario City	■				January 2018
Redlands City	■				April 2015
Rialto City	■				May 2013
San Bernardino City	■				May 2016
Yucaipa City	■				August 2016
San Diego County					October 2017
San Francisco City			■		November 2014
San Francisco County			■		November 2014
San Joaquin County					May 2018
San Luis Obispo County	■	■	■		October 2019
San Mateo County					July 2016
Santa Barbara County					June 2017
Santa Clara County					October 2017
Santa Cruz County					September 2015

Table 3.1. Local Hazard Mitigation Plans (LHMP) of California cities and counties.—Continued

[All excluded cities and counties did not have a Local Hazard Mitigation Plan LHMP available online during the time of this study. All blank spaces indicate the county or city did not use the scenario in the LHMP. The scenarios are marked by colors that correspond to their branding. SO, ShakeOut (yellow); AS, ARkStorm (blue); TS, Tsunami Scenario (gray); HW, HayWired (red)]

Region	SO	AS	TS	HW	Date
Capitola City					May 2013
Santa Cruz (county seat) City					July 2017
Watsonville City					September 2015
Shasta County					November 2017
Redding City					November 2015
Shasta Lake City	■				March 2014
Siskiyou County		■			August 2018
Solano County					January 2012
Sonoma County					October 2016
Healdsburg City					June 2018
Rohnert Park City					March 2018
Santa Rosa City					October 2016
Windsor City					February 2017
Stanislaus County	■				July 2017
Sutter County					August 2013
Tehama County					October 2018
Trinity County					August 2016
Tulare County					March 2018
Tuolumne County	■				January 2018
Ventura County	■	■			September 2015
Simi Valley City					May 2016
Yolo County					December 2018
Yuba County					March 2015
TOTAL	**34**	**23**	**7**	**8**	

Table 3.2. A timeline of major Science Application for Risk Reduction (SAFFR) Scenario events, as identified by this retrospective.

[The scenarios are marked by colors that correspond to their branding: ShakeOut (yellow), ARkStorm (blue), Tsunami Scenario (grey), and HayWired (red). CalWARN, California Water/Wastewater Agency Response Network; AWWA, American Water Works Association; USGS, U.S. Geological Survey; NOAA, National Oceanic and Atmospheric Association; NIH, National Institutes of Health; EBMUD, East Bay Municipal Utility District; PEER, Pacific Earthquake Engineering Center; ABAG, Association of Bay Area Governments; SPUR, San Francisco Planning and Urban Research Association; JVSV, Joint Venture Silicon Valley; PG&E, Pacific Gas and Electric; ICT, Information and communications technology]

Date	Scenario	Activity	Detail
May 23, 2008	ShakeOut	Publication	"The ShakeOut Scenario" Open-File Report (Jones and others, 2008)
July 16, 2008	ShakeOut	Exercise	Los Angeles Department of Water and Power
July 17, 2008	ShakeOut	Exercise	Los Angeles Department of Water and Power
November 12, 2008	ShakeOut	Conference	International Earthquake Conference, Day 1
November 13, 2008	ShakeOut	Drill	First Great California ShakeOut Drill
November 13, 2008	ShakeOut	Exercise	Golden Guardian 2008 Day 1
November 13, 2008	ShakeOut	Conference	International Earthquake Conference, Day 2
November 14, 2008	ShakeOut	Exercise	Golden Guardian 2008 Day 2
November 14, 2008	ShakeOut	Event	Los Angeles Earthquake: Get Ready Rally street fair
November 14, 2008	ShakeOut	Conference	International Earthquake Conference, Day 3
November 15, 2008	ShakeOut	Exercise	Golden Guardian 2008 Day 3
November 17, 2008	ShakeOut	Exercise	Golden Guardian 2008 - Recovery Phase
November 18, 2008	ShakeOut	Exercise	Golden Guardian 2008 - Regional Recovery Seminar
June 24, 2009	ARkStorm	Presentation	ARkStorm Introduced at the 2009 California Extreme Precipitation Symposium
August 4, 2009	ShakeOut	Presentation	ShakeOut presented to Congress by Lucy Jones, Gary Sturdivan, and Stephen Sellers
October 15, 2009	ShakeOut	Drill	Great California ShakeOut Drill, New Zealand joins
February 23, 2010	ARkStorm	Presentation	California Water and Environmental Modeling Forum 2010 Annual Meeting
June 8, 2010	ARkStorm	Conference	Consortium for Integrated Climate Research on Western Mountains 2010 Conference
June 23, 2010	ARkStorm	Conference	California Extreme Precipitation Symposium | ARkStorm: Examining a Potential California Flood Disaster
October 21, 2010	ShakeOut	Drill	Great California ShakeOut Drill
November 2, 2010	ARkStorm	Presentation	Floodplain Management Association 2010 Annual Conference
January 13, 2011	ARkStorm	Publication	"Overview of the ARkStorm Scenario" Open-File Report (Porter and others, 2011)
January 13, 2011	ARkStorm	Conference	ARkStorm Summit - Day 1
January 14, 2011	ARkStorm	Conference	ARkStorm Summit - Day 2
January 25, 2011	ARkStorm	Policy	Natomas Basin Flood Protection Improvements Act of 2011 is introduced by Matsui
January 26, 2011	ShakeOut	Drill	Great British Columbia ShakeOut
March 21, 2011	ARkStorm	Presentation	Western States Water Council-California Department of Water Resources Climate Workshop - Ralph and Dettinger
March 22, 2011	ARkStorm	Presentation	Western States Water Council-California Department of Water Resources Climate Workshop - Ralph and Dettinger
March 23, 2011	ARkStorm	Presentation	Western States Water Council-California Department of Water Resources Climate Workshop—Ralph and Dettinger—San Diego
March 29, 2011	ARkStorm	Exercise	Wastewater Agency Response Networks Emergency Response and Recovery Exercise—CalWARN and AWWA

Table 3.2. A timeline of major Science Application for Risk Reduction (SAFFR) Scenario events, as identified by this retrospective.—Continued

[The scenarios are marked by colors that correspond to their branding: ShakeOut (yellow), ARkStorm (blue), Tsunami Scenario (grey), and HayWired (red). CalWARN, California Water/Wastewater Agency Response Network; AWWA, American Water Works Association; USGS, U.S. Geological Survey; NOAA, National Oceanic and Atmospheric Association; NIH, National Institutes of Health; EBMUD, East Bay Municipal Utility District; PEER, Pacific Earthquake Engineering Center; ABAG, Association of Bay Area Governments; SPUR, San Francisco Planning and Urban Research Association; JVSV, Joint Venture Silicon Valley; PG&E, Pacific Gas and Electric; ICT, Information and communications technology]

Date	Scenario	Activity	Detail
April 28, 2011	ShakeOut	Drill	Great Central United States ShakeOut
May 1, 2011	ShakeOut	Publication	Journal "Earthquake Spectra" Special ShakeOut edition
May 12, 2011	ARkStorm	Presentation	2011 National Hydrologic Warning Council Training Conference and Exposition - Marty Ralph presents in San Diego
July 18, 2011	ARkStorm	Exercise	2011 Navy Citadel Rumble—ARkStorm induced flooding
July 19, 2011	ARkStorm	Exercise	2011 Navy Citadel Rumble—ARkStorm induced flooding
July 20, 2011	ARkStorm	Exercise	2011 Navy Citadel Rumble–ARkStorm induced flooding
July 21, 2011	ARkStorm	Exercise	2011 Navy Citadel Rumble–ARkStorm induced flooding
October 20, 2011	ShakeOut	Drill	Great California ShakeOut Drill More than 9.5 million people participated
November 7, 2011	ARkStorm	Policy	Natomas Basin Flood Protection Improvements Act of 2011 is introduced by Feinstein
November 14, 2011	ARkStorm	Presentation	International Association of emergency Managers 59th Annual Conference - ARkStorm Scenario breakout session
December 15, 2011	ARkStorm	Conference	California Governor's Conference on Extreme Climate Risks and California's Future
February 7, 2012	ShakeOut	Drill	Great Central United States ShakeOut
March 9, 2012	ShakeOut	Drill	Japan holds ShakeOut Drill
April 17, 2012	ShakeOut	Drill	Great Utah ShakeOut
May 10, 2012	ARkStorm	Presentation	63rd Annual Highway Geology Symposium
August 1, 2012	ShakeOut	Exercise	Golden Guardian 2012
September 26, 2012	ShakeOut	Drill	First nationwide New Zealand ShakeOut
October 18, 2012	ShakeOut	Drill	The Great California ShakeOut Drill. 14.5 million worldwide participants
October 25, 2012	ARkStorm	Exercise	Ventura ARkStorm II exercise
February 7, 2013	ARkStorm	Partnership	ARkStorm Ventura River Watershed Council by the Ventura County Watershed Protection District
February 17, 2013	ShakeOut	Drill	Great Central United States ShakeOut
April 17, 2013	ShakeOut	Drill	Great Utah ShakeOut
September 3, 2013	Tsunami Scenario	Publication	"Tsunami Scenario" Fact Sheet (Ross and others, 2013b)
September 3, 2013	Tsunami Scenario	Publication	"The SAFRR (Science Application for Risk Reduction) Tsunami Scenario" Open-File Report (Ross and Jones, 2013)
September 4, 2013	Tsunami Scenario	Publication	"The First Sue Nami" (Sandoval, 2014)
September 4, 2013	Tsunami Scenario	Workshop	Long Beach and Los Angeles (120 participants)
September 4, 2013	Tsunami Scenario	Presentation	The Tsunami Scenario in Los Angeles and Orange Counties
September 5, 2013	Tsunami Scenario	Workshop	Santa Barbara (45 participants)
September 6, 2013	Tsunami Scenario	Workshop	San Diego (70 participants)
September 9, 2013	Tsunami Scenario	Workshop	Santa Cruz (65 participants)
September 10, 2013	Tsunami Scenario	Workshop	San Francisco (60 participants)
September 12, 2013	ARkStorm	Workshop	ARkStorm@Tahoe Public Utilities/Water Supply

Table 3.2. A timeline of major Science Application for Risk Reduction (SAFFR) Scenario events, as identified by this retrospective.—Continued

[The scenarios are marked by colors that correspond to their branding: ShakeOut (yellow), ARkStorm (blue), Tsunami Scenario (grey), and HayWired (red). CalWARN, California Water/Wastewater Agency Response Network; AWWA, American Water Works Association; USGS, U.S. Geological Survey; NOAA, National Oceanic and Atmospheric Association; NIH, National Institutes of Health; EBMUD, East Bay Municipal Utility District; PEER, Pacific Earthquake Engineering Center; ABAG, Association of Bay Area Governments; SPUR, San Francisco Planning and Urban Research Association; JVSV, Joint Venture Silicon Valley; PG&E, Pacific Gas and Electric; ICT, Information and communications technology]

Date	Scenario	Activity	Detail
September 26, 2013	ShakeOut	Drill	ShakeOut Grande Secousse de Charlevoix, Quebec, Canada
October 11, 2013	ARkStorm	Workshop	ARkStorm@Tahoe Emergency Response, Health and Human Services, and Business Community
October 11, 2013	ARkStorm	Conference	Are You Ready for ARkStorm? Expert Panel Discussion hosted by Tahoe Science Consortium
October 17, 2013	ShakeOut	Drill	Great California ShakeOut Drill
November 12, 2013	ARkStorm	Workshop	ARkStorm@Tahoe State and Federal Coordination
December 5, 2013	ARkStorm	Workshop	ARkStorm@Tahoe Truckee River Flood Management
January 13, 2014	ARkStorm	Workshop	ARkStorm@Tahoe Tribal Impacts
January 14, 2014	ShakeOut	Partnership	Los Angeles Mayor's Office partners with USGS, Lucy Jones organizes earthquake preparedness plans
January 14, 2014	ARkStorm	Workshop	ARkStorm@Tahoe Natural Resource Impacts
March 5, 2014	Tsunami Scenario	Exercise	San Francisco Tabletop
March 14, 2014	ARkStorm	Exercise	ARkStorm@Tahoe Tabletop exercise in Reno, Nevada
March 24, 2014	Tsunami Scenario	Presentation	Disaster Research Response Project Tabletop Exercise Webinar
March 26, 2014	Tsunami Scenario	Exercise	San Francisco Department of Emergency Management Day 1. Alert and Warning
March 27, 2014	Tsunami Scenario	Exercise	NOAA's PacifEx Tabletop
March 27, 2014	Tsunami Scenario	Exercise	San Francisco Department of Emergency Management Day 2. Response and Policy
March 28, 2014	Tsunami Scenario	Exercise	San Francisco Department of Emergency Management Day 3. Recovery
March 29, 2014	Tsunami Scenario	Drill	San Francisco Tsunami Walk
April 7, 2014	Tsunami Scenario	Exercise	NIH 2014 Los Angeles Tsunami Tabletop Exercise - Disaster Research Response Tabletop Report
October 29, 2014	HayWired	Workshop	Fire Following Earthquake workshop and exercise
December 1, 2014	ARkStorm	Publication	"ARkStorm@Tahoe—Stakeholder Perspectives on Vulnerabilities and Preparedness for an Extreme Storm" (Albano and others, 2014). Event in the Greater Lake Tahoe, Reno and Carson City Region
December 8, 2014	ShakeOut	Policy	Los Angeles Mayor releases Resilience by Design an earthquake retrofit initiative
October 9, 2015	ShakeOut	Policy	City of Los Angeles passed Ordinance 183893, earthquake retrofit plans from Resilience by Design
October, 10 2015	ARkStorm	Publication	"Application of an extreme winter storm scenario to identify vulnerabilities, mitigation options, and science needs in the Sierra Nevada mountains, United States" (Albano and others, 2016)
October 15, 2015	ShakeOut	Drill	Great California ShakeOut Drill, 43,929,156 participants worldwide
February 24, 2016	HayWired	Workshop	USGS HayWired Aftershock Workshop
February 25, 2016	HayWired	Workshop	USGS HayWired Aftershock Workshop
August 25, 2016	HayWired	Presentation	The Uses and Development of the HayWired Scenario—Hosted by Business Recovery Managers Association at EBMUD

Table 3.2. A timeline of major Science Application for Risk Reduction (SAFFR) Scenario events, as identified by this retrospective.—Continued

[The scenarios are marked by colors that correspond to their branding: ShakeOut (yellow), ARkStorm (blue), Tsunami Scenario (grey), and HayWired (red). CalWARN, California Water/Wastewater Agency Response Network; AWWA, American Water Works Association; USGS, U.S. Geological Survey; NOAA, National Oceanic and Atmospheric Association; NIH, National Institutes of Health; EBMUD, East Bay Municipal Utility District; PEER, Pacific Earthquake Engineering Center; ABAG, Association of Bay Area Governments; SPUR, San Francisco Planning and Urban Research Association; JVSV, Joint Venture Silicon Valley; PG&E, Pacific Gas and Electric; ICT, Information and communications technology]

Date	Scenario	Activity	Detail
October 13, 2016	ShakeOut	Drill	Great California ShakeOut Drill, 55,958,912 participants worldwide
February 23, 2017	HayWired	Workshop	Earthquake Country Alliance Bay Area Regional Workshop
April 24, 2017	HayWired	Publication	“HayWired Volume 1” (Detweiler and Wein, 2018a)
October 19, 2017	ShakeOut	Drill	Great California ShakeOut Drill
November 29, 2017	HayWired	Workshop	Earthquake Country Alliance Bay Area Regional Workshop
January 17, 2018	HayWired	Workshop	PEER - HayWired Scenario: Practical Uses of and Research Needs for Physics-Based Modeling of Ground Motion
January 17, 2018	HayWired	Workshop	PEER - The HayWired Scenario & Research Needs for Resilient New Buildings
March 1, 2018	HayWired	Workshop	Earthquake Country Alliance Bay Area Regional Workshop
March 1, 2018	Tsunami Scenario	Workshop	Earthquake Country Alliance Bay Area Regional Workshop
April 18, 2018	HayWired	Publication	Detweiler and Wein, 2018b)“HayWired Volume 2” (
April 18, 2018	HayWired	Publication	“HayWired” Fact Sheet (Hudnut and others, 2018)
April 18, 2018	HayWired	Event	HayWired Rollout - Berkeley's Memorial Stadium and Lawson Lecture Series
May 31, 2018	HayWired	Presentation	Spring 2018 ABAG General Assembly and Business Meeting
June 28, 2018	HayWired	Conference	Session: Innovations of the HayWired Scenario—11th National Conference on Earthquake Engineering
August 10, 2018	HayWired	Workshop	Earthquake Country Alliance Southern California Regional Workshop
August 10, 2018	ShakeOut	Workshop	Earthquake Country Alliance Southern California Regional Workshop
August 15, 2018	HayWired	Workshop	Earthquake Country Alliance Bay Area Regional Workshop
August 15, 2018	ShakeOut	Workshop	Earthquake Country Alliance Bay Area Regional Workshop
August 17, 2018	HayWired	Exercise	Tabletop - California Earthquake Clearinghouse HayWired Exercise
October 16, 2018	HayWired	Presentation	The Next Earthquake and the South Bay - SPUR & JVSV, sponsored by PG&E
October 18, 2018	ShakeOut	Drill	Great California ShakeOut Drill
November 2, 2018	HayWired	Workshop	Outsmarting Disaster: The Planning Professional’s Role in Disaster Preparedness and Recovery at the Bay Area Planning Directors Association Fall General Membership Meeting
January 7, 2019	ARkStorm	Presentation	32nd Conference on Climate Variability and Change
October 17, 2019	ShakeOut	Drill	Great California ShakeOut Drill
October 18, 2019	HayWired	Publication	“HayWired Volume 3” (Detweiler and Wein, 2019)
November 13, 2019	HayWired	Workshop	Earthquake Country Alliance Bay Area Regional Workshop
October 15, 2020	ShakeOut	Drill	Great California ShakeOut Drill—“Hold Your Own” initiative for 2020 Encourages home earthquake preparedness
October 22, 2020	HayWired	Webinar	HayWired: An Economic Disaster?
November 2, 2020	HayWired	Webinar	Wired: A Call to Action
November 19, 2020	HayWired	Webinar	Modeling Economic Impacts of Earthquakes: Research and Practice

Table 3.2. A timeline of major Science Application for Risk Reduction (SAFFR) Scenario events, as identified by this retrospective.—Continued

[The scenarios are marked by colors that correspond to their branding: ShakeOut (yellow), ARkStorm (blue), Tsunami Scenario (grey), and HayWired (red). CalWARN, California Water/Wastewater Agency Response Network; AWWA, American Water Works Association; USGS, U.S. Geological Survey; NOAA, National Oceanic and Atmospheric Association; NIH, National Institutes of Health; EBMUD, East Bay Municipal Utility District; PEER, Pacific Earthquake Engineering Center; ABAG, Association of Bay Area Governments; SPUR, San Francisco Planning and Urban Research Association; JVSV, Joint Venture Silicon Valley; PG&E, Pacific Gas and Electric; ICT, Information and communications technology]

Date	Scenario	Activity	Detail
March 17, 2021	HayWired	Webinar	Alameda County focus—The HayWired Connection: Telecommunications & ICT hosted by Joint Venture
March 31, 2021	HayWired	Webinar	San Mateo County focus—The HayWired Connection: Telecommunications & ICT hosted by Joint Venture
April 14, 2021	HayWired	Webinar	Santa Clara County focus—The HayWired Connection: Telecommunications & ICT hosted by Joint Venture
April 28, 2021	HayWired	Webinar	Contra Costa County focus—The HayWired Connection: Telecommunications & ICT hosted by Joint Venture
May 12, 2021	HayWired	Webinar	Napa & Sonoma Counties focus—The HayWired Connection: Telecommunications & ICT hosted by Joint Venture

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ShakeOut

ARkStorm

Tsunami Scenario

HayWired

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