Science for a Risky World—A U.S. Geological Survey Plan for Risk Research and Applications

Circular 1444

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

Cover:

Images, clockwise from top left:

A wildfire burns vegetation.

An earthquake caused road and structural damage to houses.

Flooded road in Louisiana. Photograph by James Fountain, U.S. Geological Survey, August 15, 2016.

A breach in the coastline of Rodanthe, North Carolina, caused by Hurricane Irene in 2011.
Photograph by Karen Morgan, U.S. Geological Survey, August 29, 2011.

North Fork Stillaguamish River and SR530 Landslide near Oso, Washington; flow is from right to left.
Photograph by Scott W. Anderson, U.S. Geological Survey, January 29, 2015.

Cracks in sediment during a drought.

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By Kristin A. Ludwig, David W. Ramsey, Nathan J. Wood, Alice B. Pennaz, Jonathan W. Godt, Nathaniel G. Plant, Nicolas Luco, Todd A. Koenig, Kenneth W. Hudnut, Donyelle K. Davis, and Patricia R. Bright

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Aerial photograph of Hurricane Sandy storm damage at Mantoloking, New Jersey coastline. Photograph by Greg Thompson, U.S. Fish and Wildlife Service, November 2, 2012.

U.S. Department of the Interior
RYAN K. ZINKE, Secretary

U.S. Geological Survey
James F. Reilly II, Director

U.S. Geological Survey, Reston, Virginia: 2018

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Case Studies

Conversion Factors

International System of Units to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
	Volume	
cubic meter (m^3)	0.0002642	million gallons (Mgal)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
	Flow rate	
meter per second (m/s)	3.281	foot per second (ft/s)

Abbreviations

BAER	Burned Area Emergency Response
3DEP	3D Elevation Program
CDI	Community for Data Integration
CVO	Cascades Volcano Observatory
DOI	Department of the Interior
DOT	U.S. Department of Transportation
EDGE	Equipment Development Grade Evaluation
FEV	Flood Event Viewer
FEMA	Federal Emergency Management Agency
FIM	Flood Inundation Mapping Program
GIS	Geographic Information System
HERA	Hazard Exposure Reporting and Analytics
MHDP	Multi-Hazards Demonstration Project
NEHRP	National Earthquake Hazard Reduction Program
NHMA	Natural Hazards Mission Area
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NSHM	National Seismic Hazard Maps
NSHMP	National Seismic Hazard Modeling Project
NWIS	National Water Information System
OFDA	Office of U.S. Foreign Disaster Assistance
ORCID	Open Researcher and Contributor ID
PAGER	Prompt Assessment of Global Earthquakes for Response
RGE	Research Grade Evaluation
SAFRR	Science Application for Risk Reduction
SAFRR CORE	SAFRR Cadre of Relevant Experts
SSP	Science Strategy Plan
STAR	Special Thanks for Achieving Results Award
IT	Information Technology
USAID	U.S. Agency for International Development
VASW	Volcanism in the American Southwest
VDAP	Volcano Disaster Assistance Program
WTC	World Trade Center

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Executive Summary

Natural hazards—including earthquakes, tsunamis, volcanic eruptions, landslides, hurricanes, droughts, floods, wildfires, geomagnetic storms, and pandemics—can wreak havoc on human communities, the economy, and natural resources for years following an initial event. Hazards can claim lives and cause billions of dollars in damage to homes and infrastructure as well as lost or compromised economic activity and threats to national security. They also can have adverse environmental, social, economic, and health effects that extend well beyond the immediate area, sometimes with global implications. Changes in population growth, climate, and urbanization may exacerbate hazard impacts.

Because of the potential severity of a single hazard event, reducing risk—the potential loss of societally important assets caused by these hazards—is a high priority for everyone, including policy makers, community members, emergency managers, resource managers, utility operators, business owners, and planners. These stakeholders demand usable, user-centric information to support decisions for planning a resilient future and for responding to and recovering from unanticipated events in more adaptable and cost-effective ways.

Meeting this demand requires maximizing the use of environmental observations; hazards science; and research on communications, social stressors, and human behavior to deliver risk information in forms that are accessible by decision makers and the public alike. To achieve this, scientists and stakeholders must collaborate to match community needs with actionable insights, research, products, and tools, using advances in technology to improve information discovery and delivery.

A Plan for U.S. Geological Survey Risk Research and Applications

The confluence of the new demand on the scientific community for risk research and applications, growing public expectations, and technological advances creates an opportunity for the U.S. Geological Survey (USGS) to contribute to empowering the Nation to prepare for and cope with hazards using scientific data and research. In recognition of this opportunity, the USGS developed this Plan for building internal capacity to advance its development and delivery of actionable information for risk reduction. Although this Plan primarily is intended for USGS scientific staff, managers, and leadership, it also identifies new opportunities for collaboration with external partners pursuing a broad range of risk reduction efforts.

USGS risk research and applications include hazard assessments, operational forecasts and warnings, vulnerability assessments, risk assessments, risk communication, decision-support systems, and post-event assessments. The objective of USGS risk research and applications is to serve as the analytical foundation upon which decision makers can integrate their information, assets, abilities, and priorities to make science-based decisions.

Developing USGS risk products is an iterative process that relies on three USGS core competencies—(1) partner engagement and outreach, (2) research, and (3) tool and product development. Each of these elements uses contributions from USGS physical and social scientists, analysts, engineers, programmers, communications and public affairs specialists, and managers. Notably, collaboration with partners *from the beginning* of research and product development *through to* message delivery and *continuing during* product evaluation is necessary to provide partners with information that can support actionable decisions for risk reduction.

Plan Goals

This Plan aims to initiate and maintain a community of practice focused on risk research and applications to improve internal communication, collaboration, and resource sharing across the USGS. This community of practice would allow USGS scientists and staff involved in risk research and applications from across the Bureau (spanning mission areas, programs, and science centers) to overcome existing geographic and disciplinary barriers to collaboration. Importantly, this Plan provides specific recommendations for addressing mechanisms to ensure that risk research and applications are supported, prioritized, and incorporated in USGS work. These recommendations range from identifying new pathways for connecting and coordinating expertise and resources across the Bureau to articulating new opportunities for training, mentoring, and regularly convening scientists and stakeholders for product development. The recommendations also draw attention to the need for improved capacity and capabilities in areas including technical expertise, product delivery, and expanding information technology capacity.

Throughout this Plan, case studies highlight how USGS risk research and applications show meaningful ways to connect with stakeholders, to leverage existing investments, to overcome challenges, and to capitalize on new opportunities. A collection of new project ideas envisions how the goals of this Plan could be embodied in future investments, including tools to assess multiple hazards and exposure at neighborhood, regional, and national scales; risk assessment on public lands; and products to improve situational awareness following events with multiple cascading consequences.

This Plan builds on priorities outlined in the U.S. Geological Survey Natural Hazards Science Strategy—Promoting the Safety, Security, and Economic Well-Being of the Nation (Holmes and others, 2013), with a specific focus on risk, where hazards and societal values intersect. The goal of this work is not for USGS scientists and staff working in risk research and applications to make decisions for their partners. USGS scientists and staff instead would serve as listeners, translators, facilitators, and scientific guides to provide the objective, unbiased scientific knowledge needed to address the societal consequences of hazards within a dynamic world.

Introduction

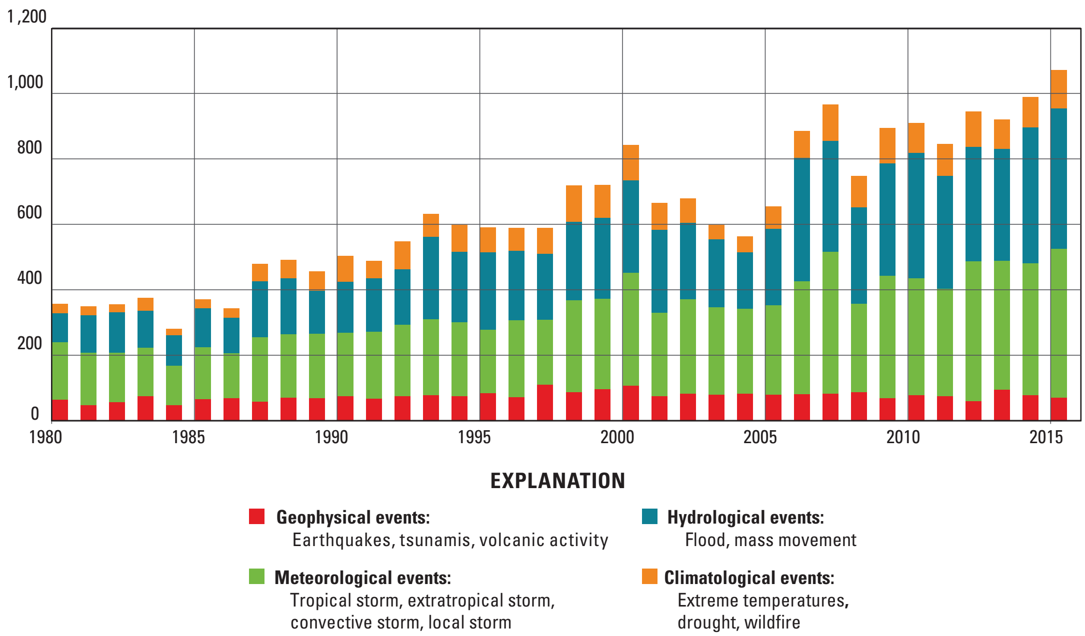
Overview and Motivation

The number of disasters and related losses resulting from extreme natural events continue to show an increasing trend (Munich RE, 2016; fig. 1). New challenges arising from a growing global population, increasing urbanization, and climate change are exacerbating hazard-related losses. At the same time, loss of biodiversity, changes in natural resources, and disruptive events such as geohazards, emerging diseases, and anthropogenic disasters create a high-risk environment. Together, these forces threaten lives, property, economic vitality, and cultural and natural resources. Improving the resilience of our built and natural environment systems relies on integrating multiple sources of information—including scientific analyses, environmental conditions, and socioeconomic data—to inform decision making in the near- and long-term.

Addressing these challenges requires new approaches to conducting and applying scientific research in **hazards**—dangerous processes or phenomena that may cause damage—to enhance the reduction of **risk**—the potential for societally relevant **losses** caused by hazards (terms in bold underline are defined in section, "Glossary"). Maximizing the use of environmental data and our understanding of earth processes to reduce risk depends on delivering risk information in forms that are accessible and easily understood by decision makers and the public alike. This requires strong collaboration between scientists, community members, business owners, emergency managers, and policy makers, where ongoing dialogues influence the assessment of community needs and, in turn, the communication of actionable insights to improve situational awareness and mitigate the adverse consequences of hazards. Emphasis on the co-creation of knowledge and products would enable U.S. Geological Survey (USGS) scientists to incorporate user needs in hazard and risk assessments and to develop risk reduction tools, and would improve the societal value of scientific research. These opportunities are bolstered by advances in technology, such as near-real time data collection, collaborative information sharing, and hazard notifications to be incorporated into risk models and decision making.

The confluence of new demands on the scientific community, growing public expectations, and technological innovations create an exciting opportunity for USGS scientists to contribute to empowering the Nation to prepare for and cope with natural hazards. In response to this opportunity, the USGS has developed this Plan for advancing its development and delivery of actionable information to improve risk reduction.

Number of loss events 1980–2015



Overall and insured losses 1980 to 2015 (in US$ bn)

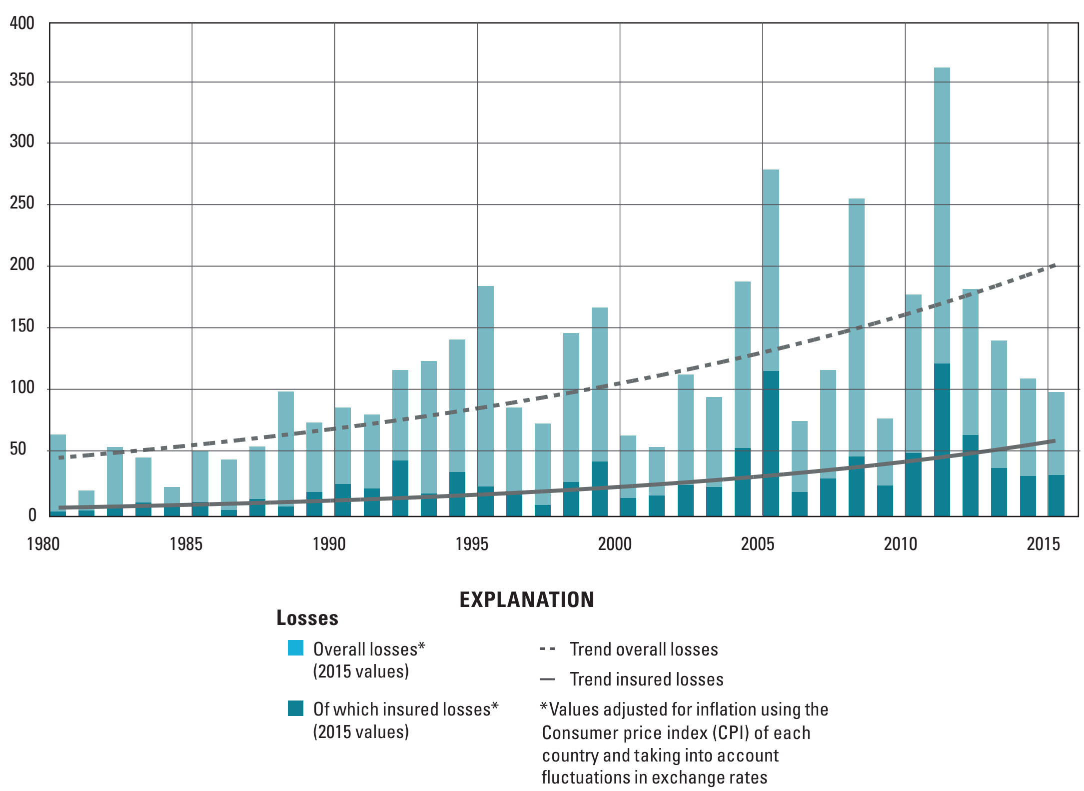


Figure 1. World natural catastrophes and losses, 1980–2015. (Source: Munich RE, 2016).

USGS Hazards Mission

The USGS serves the Nation by providing reliable scientific information to describe and to understand the Earth; to reduce loss of life and property from natural disasters; to manage water, biological, energy, and mineral resources; and to enhance and protect our quality of life. The natural hazards mission of the USGS is to develop and apply science to help protect the safety, security, and economic well-being of the Nation.

Specifically, the USGS is responsible for providing assessments and warnings for multiple types of hazards nationwide. USGS seismic networks are used for issuing public earthquake alerts and support the National Oceanographic and Atmospheric Administration (NOAA) tsunami warnings. USGS volcano monitoring provides timely warnings of volcanic activity and informs the Federal Aviation Administration and U.S. Air Force of dangerous volcanic ash clouds. USGS streamgages and storm surge sensors support NOAA flood and severe weather (including hurricane) warnings. Along and offshore of the Nation’s coasts, USGS coastal and marine research supports assessments of earthquake and tsunami hazards, coastal impacts from major storms, and sea level rise. USGS landslide hazard assessments support response to landslide emergencies and public information products. USGS geomagnetic observatories inform NOAA and the U.S. Air Force 557th Weather Wing of geomagnetic storm forecasts. Additionally, the USGS plays a key role in tracking chemical and biological threats, including acting as the eyes and ears for the Nation in monitoring diseases transmitted from animals to humans. USGS geospatial information coordination, collection, and archiving support response operations for flooding, wildfires, and many other disasters. USGS-developed vulnerability assessments, scenarios, and decision-support tools are used to improve preparedness, prevention, mitigation, response, and recovery on public and private lands across the Nation. On an international scale, the USGS supports capacity building, sharing technical expertise, and monitoring of hazards overseas, often in partnership with the U.S. Agency for International Development (USAID) Office of U.S. Foreign Disaster Assistance (OFDA).

The USGS hazards mission is championed by the Natural Hazards Mission Area (NHMA), which is responsible for long-term planning across the full USGS hazards portfolio, including activities supported by programs in all USGS mission areas (Holmes and others, 2013). These activities are undertaken by science centers across the country and through collaborations with scientists, engineers, emergency managers, and planners from the public and private sectors at Federal, State, and local levels.

Long-term planning for the USGS hazards mission is guided by the U.S. Geological Survey Natural Hazards Science Strategy—Promoting the Safety, Security, and Economic Well-Being of the Nation (Holmes and others, 2013; hereinafter referred to as the “Hazards Science Strategy”), which identifies risk as “an integral part of hazards science.” One outcome of the Hazards Science Strategy describes the USGS commitment to ensure that its hazards information is incorporated into **vulnerability** and risk analyses, and that it is delivered in forms that can be used by decision makers to improve situational awareness and mitigate adverse consequences. The following excerpt from the Hazards Science Strategy identifies this issue:

> “… A particular challenge was how to address the need for information about vulnerability and risk, not just hazard. Hazard is the physical process that is independent of the impacts on humans. Vulnerability studies draw on physical science, engineering, and social and behavioral sciences to determine what aspects of human society are vulnerable to damaging processes. Risk assessment combines the hazard with vulnerability to evaluate the probability of losses. Thus, risk assessment requires the physical sciences that are a core hazard mission strength to be combined with engineering, and social and behavioral sciences that reside in different parts of the USGS, or are completely external. A message from many stakeholders was for the USGS to take a larger role in ensuring that hazards information results in accurate risk assessments that have broader use in the community. Recognizing that many aspects of vulnerability and risk analysis can be done by others or in partnership with others, this report treats risk as an integral part of hazards science and includes the research and development of risk assessments as one of the many types of assessment that are needed.” (Holmes and others, 2013, p. 9)

Recognizing that the expertise required to fully address risk would not reside solely within USGS science centers funded by programs under the NHMA, the Hazards Science Strategy leaves open whether and how this work is conducted by these centers, or through collaborations with other mission areas, centers, and external public and private partners better equipped or positioned to complete such assessments. The appropriate mechanisms for conducting relevant fundamental research and delivering risk information likely would vary over time, across hazards, at various scales, and as multiple stakeholders are engaged. However, every effort requires the

USGS to ensure that the translation of its science into products that fulfill the needs of decision makers and that the best available science is used. This Plan was developed to advance this element of the Hazards Science Strategy.

The USGS has been successful in developing products used for a broad range of risk reduction measures, ranging from humanitarian response after earthquakes to community planning in tsunami-hazard zones. USGS scientists and their products play increasingly important roles in multiple dimensions of risk research and applications as hazards persist and as human populations expand into hazard-prone areas (for example, expansion of the wildland-urban interface), or in some cases, as new hazards emerge (for example, induced seismicity). These activities include researching and observing natural processes and human land use to advance our fundamental understanding of hazards and their cascading consequences, generating warnings to provide critical situational awareness, developing scientific assessments of the hazards and potential losses, and communicating the results in meaningful and timely ways to different audiences in accessible and easily understood formats.

Although the USGS excels in its work on hazards and has created various useful risk products, the Bureau must continue to seek out new opportunities to further explore the development and application of its research to reduce risk and to leverage the already-successful activities it pursues in this arena. These products directly contribute to disaster mitigation and response efforts and have proven critical for implementing appropriate recovery measures. As a result of these efforts, stakeholders are requesting additional support and products, which motivates the USGS to work in new areas such as community resilience.

About This Plan

Charge and Development Process

In November 2015, the USGS "Translating USGS Science to Risk Products Workshop" (appendix 1) convened 38 USGS scientists and managers to identify key elements of and priorities for translating USGS science into effective risk products and to develop a draft framework for a natural hazards risk reduction implementation plan. Following the workshop, a writing team composed of USGS hazard and risk scientists and managers was gathered to address the following charge:

> *Develop an actionable plan to ensure that USGS hazards information is delivered and incorporated into risk assessments and other products that can be used by decision makers to reduce loss.*
>
> *The plan should address observations from the November 2015 "Translating USGS Science to Risk Products" workshop and should consider using the components of the Hazards Science Strategy (monitoring, science research/expertise, assessments, situational awareness, communication) as a guide for addressing the different components of risk translation. The plan should include a section highlighting case studies; suggestions for mechanisms and organizational structures to ensure that risk translation is supported, prioritized, and incorporated in USGS work; and recommendations for measureable milestones. The plan should define the "space" of risk translation and the role of the USGS in this arena.*

The writing team combined its expertise with insights collected from the 2015 workshop, peer reviews provided by USGS and external partner colleagues, and published documents including journal articles and the Science Strategy Plans (SSPs) from all USGS mission areas.

Intended Audience and Purpose

This Plan primarily is intended for internal stakeholders, including USGS scientists, staff, managers, and leadership. Internally, this Plan is intended to:

- Provide resources, guidance, and inspiration for scientists, managers, and staff interested in pursuing risk research, applications, and product development at the intersection of hazards and society;
- Demonstrate, using case studies, meaningful ways to connect with stakeholders, leverage existing investments, and capitalize on new opportunities when conducting risk research and applications;
- Lay a foundation for a **community of practice** in risk research and applications;
- Identify how existing projects, tools, products, technologies, programs, and collaborations can be used to advance USGS success in risk research and applications;
- Describe USGS needs (that is, expertise and technological resources) and chart a course forward to conduct work in risk research and applications; and,
- Complement USGS SSPs (appendix 2) as well as program-specific plans for implementing the Hazards Science Strategy.

For external stakeholders, including scientists, planners, emergency managers, and decision makers at Federal, State, and local agencies, academia, and community and non-governmental organizations, this Plan highlights USGS activities, assets, and capabilities that support risk reduction, describes areas where the USGS may benefit from partnerships in conducting future risk research and applications, and identifies new opportunities for collaboration in risk research and applications.

Organization

This Plan defines risk and the role of USGS in risk research and applications. It identifies the Bureau's core competencies in this arena and includes background on and specific recommendations for building institutional capacity for creating sustained partnerships, supporting professional staff, and improving product delivery. Case studies are used throughout the Plan to showcase existing products and highlight lessons learned in risk research and applications to date; these case studies are a selection of activities from across USGS programs and do not represent an exhaustive compilation of USGS work in risk research and applications. This Plan concludes with ideas for projects that would build on existing USGS expertise while advancing specific elements identified in this Plan and meeting long-standing stakeholder needs.

Section 1. Role of USGS in Risk Research and Applications

Defining the Concept of Risk

Risk is a part of everyday life, given the dynamic and often unpredictable nature of the Earth and the complexity of human endeavors (fig. 2). Decisions are constantly being made by individuals and organizations under conditions of uncertainty that require weighing benefits against potential negative consequences. These decisions range from individual and inconsequential (such as whether or not to bring an umbrella on a cloudy day) to more complex with far-reaching implications for many (such as deciding on design standards or where to locate critical infrastructure).

Risk is perceived in many ways by individuals and societies based on experience, culture, and other factors. Likewise, risk is defined in many ways by various fields of research and practice depending on emphasis, needs, and objectives. Risk often is used to describe a hazard, a probability of occurrence of an event or adverse outcome, the probability of failure of a specific asset, or the larger societal impacts if an adverse event or outcome occurs, or as a cost-benefit analysis of a proposed course of action.

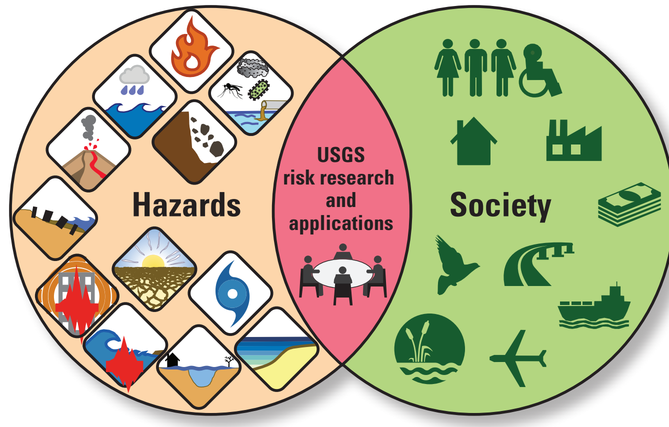


Figure 2. Intersection of multiple hazards and coupled human-natural systems that create risk. Through collaboration across the Bureau and with external partners, U.S. Geological Survey (USGS) risk research and applications improve our understanding of risk and support risk reduction decisions.

The Hazards Science Strategy describes risk as the likelihood of a hazard causing losses based on the probability of the hazard occurring and the value of assets in harm's way. Although useful in certain contexts (for example, insurance decisions), this probability-based construct of risk can be limiting in other situations. For example, a probabilistic perspective of risk is less useful in situations where probabilities of a hazardous event occurring, of an asset being damaged, or of a larger system failing are unknown or unknowable. A probabilistic perspective may not be useful or appropriate for certain risk reduction strategies, such as raising awareness of tsunami threats in a community, avoiding exposure to potential contaminated floodwaters, evacuation training, or preparedness and response efforts. Quantification of asset value in societally relevant or acceptable ways, such as the value of human lives and cultural and environmental resources, also often is difficult.

With this context in mind, **risk** is defined in this Plan as the potential for the full or partial loss of something of societal value due to current or proposed courses of action under conditions of uncertainty regarding real-time and future adverse events. The probability-based perspective of risk remains one interpretation, but is not the only approach. Instead, risk is more broadly characterized as the confluence of a hazard with societal assets or systems exposed to that hazard (fig. 2). In this frame, the vulnerabilities of the assets or systems are determined by their unique characteristics (for example, load and structural elements of a utility) and the societal context and perceptions of potential consequences over different timescales. Expected losses and the extent of uncertainty in risk assessments can be described quantitatively or qualitatively, based on the purpose of the analyses, and are interpreted within unique societal contexts. Relevant terms for characterizing and communicating risk are in section, "Glossary."

External Users of USGS Risk Research and Applications

All individuals, businesses, organizations, and agencies regularly make risk-related decisions. In order to make effective decisions, they require objective information on potential adverse events, the likelihood of their occurrence, and for societal consequences of proposed actions, including the *status quo*. Users of risk information range from the individual deciding where to live or work to nations and international groups developing policies and competencies to efficiently manage system-level threats. The extent of use varies by user and product—some users may engage for event-only information, whereas other users may engage over long-lasting partnerships of sharing data and products. Therefore, a diverse audience for USGS risk research and applications exists, where each stakeholder would have different needs for information. An illustrative, but not exhaustive, list of users of USGS risk research and applications is shown in figure 3. In some cases, these decisions pertain to multiple and sometimes competing objectives.

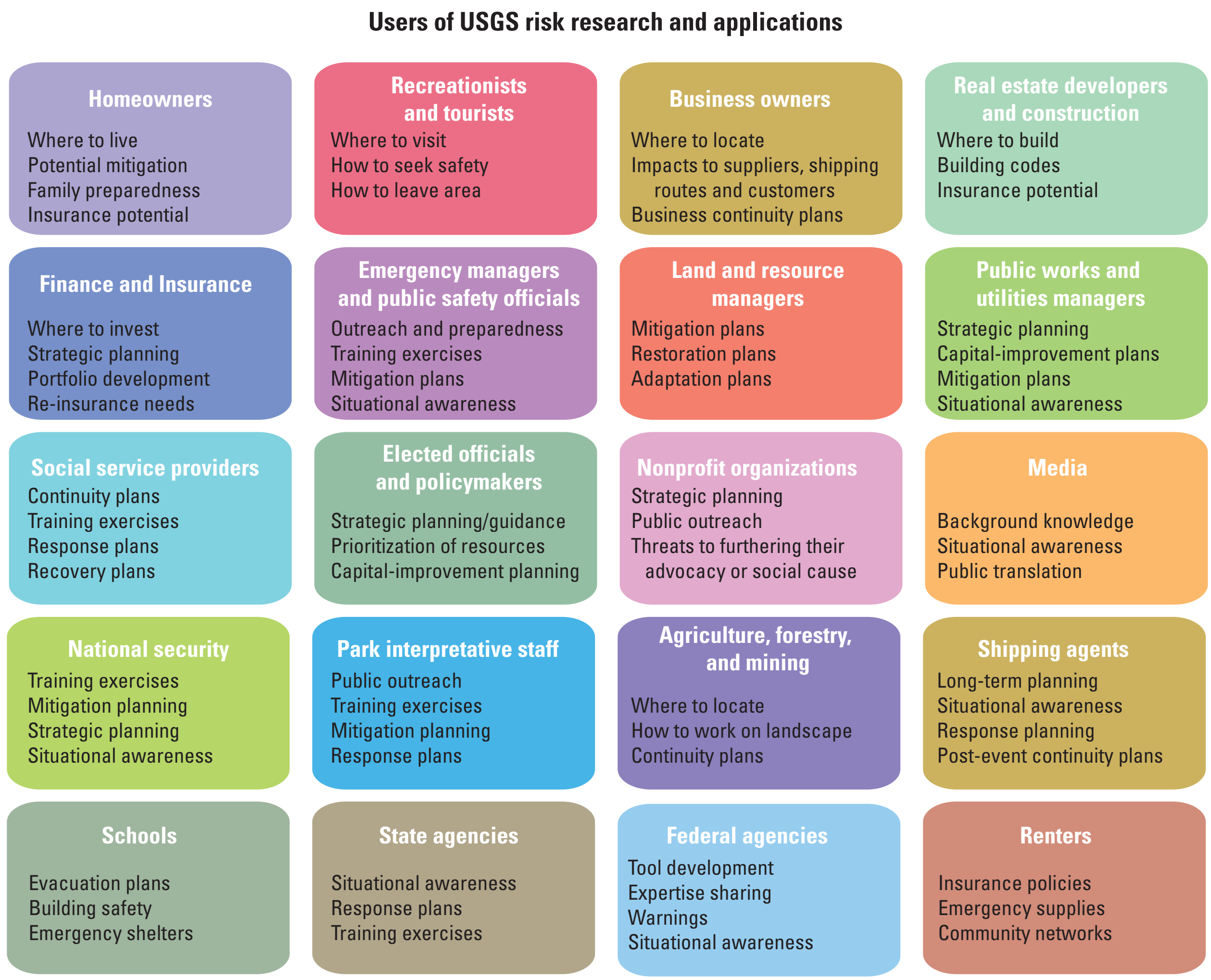


Figure 3. Typical users (including their needs) that potentially benefit from U.S. Geological Survey (USGS) risk research and applications. Uses and applications vary at different scales of home, community, county, State, and the Nation. Colors are used to differentiate user groups.

The USGS supports a wide range of stakeholders with science and applications that benefit risk-management and risk reduction efforts. Some USGS partners seek information to communicate risks to their constituents; others seek information to reduce unacceptable risks through structural and non-structural mitigation; and still others seek to manage risks through targeted education, preparedness planning, or disaster financing. **The objective of USGS risk research and applications is to serve as a vital analytical foundation upon which decision makers can integrate their information, assets, abilities, and priorities to make more informed, science-based decisions.** USGS scientists and staff working in risk research and applications do not make decisions for our partners, but instead serve as listeners, translators, facilitators, educators, and scientific guides that help frame societal decisions in a dynamic world.

Range of USGS Risk Research and Applications

The USGS delivers a range of risk research and applications, from peer-reviewed publications to actionable hazard assessments and decision-support systems (fig. 4). **These activities and products are connected by the need to directly support decision makers in their efforts to better understand societal risk from hazards and to have the necessary information to make science-based, risk reduction decisions.**

Providing this support is a transformative process of connecting USGS fundamental science to society and integrating multiple fields of knowledge and practice to create products that serve policy makers, emergency managers, and the public, as well as USGS scientific staff, managers, and leadership. This process manifests itself in the following ways within the USGS (fig. 4), with numerous examples of existing efforts from USGS and its partners (appendix 3):

Hazard assessments include efforts to characterize and delineate areas and (or) times where adverse physical events may occur and the specific characteristics of those events. Hazard assessments support risk reduction efforts because of their use for actionable outreach, preparedness efforts, planning, and other activities. Important hazard attributes for decision makers include spatial extent, speed of onset, duration, magnitude, the potential for pre-event warnings, and post-event recovery considerations.

Examples: A map of all possible lahar-hazard zones on a single volcano; maps showing potential groundshaking during earthquakes; a tsunami-hazard map that shows maximum inundation from several earthquake sources around an ocean basin; and estimated potential coastal inundation based on an observed hurricane storm track.

Forecasts and warnings are similar to hazard assessments, but are integrated with relevant initial or boundary conditions and operationally focused visualizations, numerical modeling, rapid data processing, and communications technology for prompt dissemination and use by external partners for situational awareness and short-term decision making.

Examples: USGS/National Weather Service-issued post-fire debris flow warnings; forecasts of storm-induced erosion, overwash, and inundation; and earthquake forecasts and fault afterslip forecasts.

Vulnerability assessments are efforts to characterize the **exposure, sensitivity,** and **adaptive capacity** of individuals or systems to adverse events, either to a broad range of events or a specific event. Vulnerability assessments focus not only on what is threatened by an adverse event, but also on why and how individuals or systems may be affected, and in some cases describe the societal forces that contribute to these vulnerabilities. Vulnerability assessments are useful for supporting general outreach and equity promotion; and planning and training for preparedness, prevention, mitigation, response, and recovery efforts.

Examples—Exposure: The presence of populations and societal assets in hazard zones related to earthquakes (for example, Wood and others, 2014; Jaiswal and others, 2015; Federal Emergency Management Agency, 2017); tsunamis (Jones and others, 2016); volcanic lahars (for example, Diefenbach and others, 2015); flooding related to sea level rise and storm surge (for example, USGS Hazard Exposure Reporting and Analytics [HERA]; Frazier and others, 2010; Abdollahian and others, 2016), and projected changes in population exposure to tsunami hazards (for example, Sleeter and others, 2017).

Examples—Sensitivity: Demographic differences of residents in tsunami hazard zones that may influence the degree to which individuals or groups are disproportionally affected by an extreme event (for example, Wood and others, 2010).

Examples—Adaptive Capacity: Pedestrian evacuation potential from Cascadia tsunami hazards (for example, Wood and others, 2015); Vehicular evacuations from distant tsunami hazards (for example, Henry and others, 2017); and Construction of vertical evacuation areas.

Risk assessments summarize estimated impacts and losses from a specific event or scenario, or from all potential events. Risk assessments synthesize existing knowledge of hazards and vulnerable systems and (or) communities for a given location or time to provide descriptive quantitative or qualitative loss estimates. Estimates can be based on deterministic or probabilistic assumptions of event occurrence, the specific hazards from that event, damage or failure of an asset, and loss of an asset, system, or individual.

Examples: Estimated annualized earthquake losses for the United States (Federal Emergency Management Agency, 2017); USGS Science Application for Risk Reduction (SAFRR) project scenarios including ShakeOut (Jones and others, 2008), ARkStorm (Porter and others, 2011), and the Tsunami Scenario (Ross and others, 2013); and rockfall hazard and risk assessment for Yosemite Valley in Yosemite National Park (Stock and others, 2014).

Risk communication includes efforts informed by the social sciences to communicate information with various audiences in a way that leads to improved knowledge, actions, and behavior change for effective protective actions in the general public, practitioners, and elected officials.

Examples: Regional coordination plans for volcanic unrest (for example, Washington Military Department, 2014); and Great ShakeOut Earthquake Drills worldwide earthquake preparedness exercise.

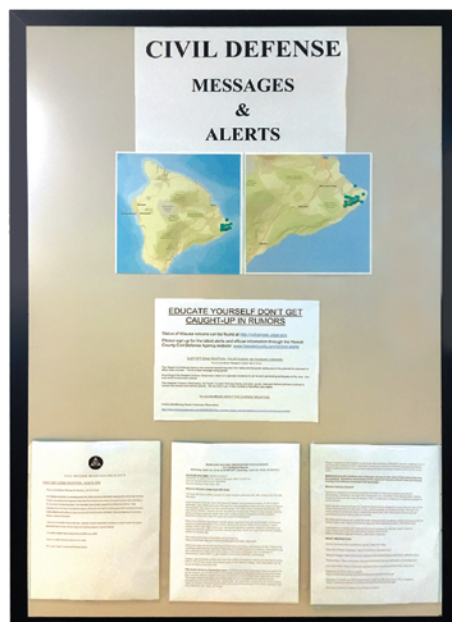
Decision-support systems structure information in ways that allow decision makers to test alternative courses of actions. These systems may include decision-tree diagrams to guide emergency managers, modeling and geographic information system (GIS) tools for overlaying determinants of multiple risks and challenges, and computer-based tools for comparing mitigation options. These systems are distributed by USGS and sometimes serve as the foundation for local entities to develop their own support systems or products.

Examples: Department of the Interior Strategic Sciences Group scenarios (for example, Department of the Department of the Interior Strategic Sciences Group, 2013); and USGS Pedestrian Evacuation Analyst ArcGIS™ extension.

Post-event assessments include estimates or quantification of actual hazard magnitude or loss after an event has occurred.

Examples: ShakeMap showing peak ground motions after an earthquake; PAGER (Prompt Assessment of Global Earthquakes for Response) alerts showing earthquake-induced fatality and economic loss impact estimates; ShakeCast supporting assessment of impacts to infrastructure; and Photographic or topographic observations of hurricane impacts.

The USGS Hawaiian Volcano Observatory provided forecasts and warnings of eruptive activity during the spring and summer of 2018 for fissures along Kīlauea's Lower East Rift Zone in lower Puna, Hawai'i. Photograph shows lava fountains and channelized flow erupting from Fissure 8 spatter cone in the Leilani Estates subdivision on June 11, 2018. Photograph by David Ramsey, USGS.



Hawai'i County Civil Defense messages and alerts bulletin board for Lower East Rift Zone eruption of Kīlauea as seen in the lobby of the Hilo Hawaiian Hotel on June 16, 2018. USGS forecasts and warnings of eruptive activity provided guidance for risk communication by emergency managers to a variety of audiences, including guests in local hotels. Photograph by David Ramsey, USGS.

Core Competencies for USGS Risk Research and Applications

Three core competencies form the foundation of USGS risk research and applications: (1) Partner engagement, (2) research, and (3) product development (fig. 4). For any product, there is interaction and iteration across these three competencies. Because of the importance of "early and often" interaction with partners to determine and meet their needs, partner engagement frequently is the starting point of these competencies (fig. 4). This interaction is underpinned by research, in which partner engagement is combined with research to develop products. USGS time, resources, and expertise are required in each core competency to support the risk reduction efforts of external partners.

Partner Engagement

Mechanisms to better understand partner needs are required to determine the kinds of USGS research and applications and the best delivery methods that would most help Bureau partners reduce risk. This requirement affects the need for collaboration across disciplinary, institutional, and jurisdictional boundaries. Collaboration can occur throughout the entire course of science investigation, from identifying societally relevant issues to delivering USGS results in a way that directly supports risk reduction efforts. This engagement improves USGS science because partner feedback helps identify priority areas to reduce uncertainty and gaps in understanding. Examples of structured partner engagement include local connections between researchers and external partners, listening sessions with key stakeholders, and participation in local-, State- and Federal-level interagency working groups.

USGS Geographer Nate Wood addresses 50 participants from Bureaus across the Department of the Interior (DOI) at a February 27–28, 2018, workshop for the Strategic Hazard Identification and Risk Assessment Project, a collaboration between the USGS and the DOI Office of Emergency Management to identify hazards and assess risks to DOI assets. Photograph by Alice Pennaz, USGS.

Figure 4. Portfolio of U.S. Geological Survey (USGS) risk research and applications supporting external partners in risk reduction efforts. Core competencies in partner engagement and outreach, research, and product development are integrated in every project and are critical to the success of all USGS risk research and applications.

Case Study—Partner Engagement and Outreach at the Cascades Volcano Observatory

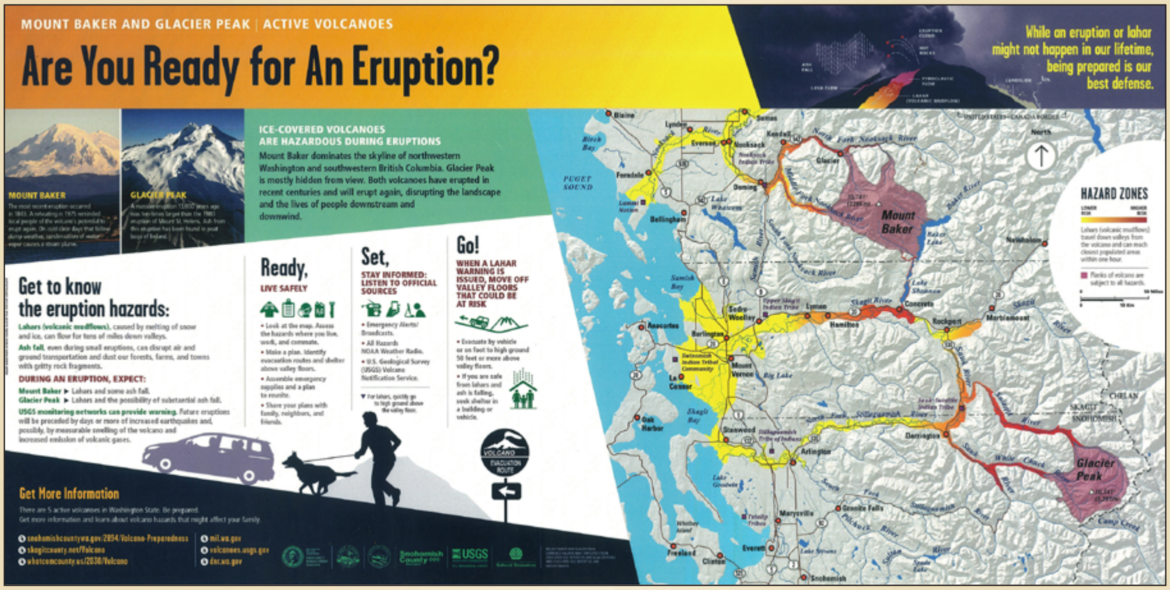


Figure 5. Interpretive sign for Mount Baker and Glacier Peak in Washington State developed through an interagency partnership between U.S. Geological Survey, State, and local authorities.

The USGS Cascades Volcano Observatory (CVO) helps people in the Pacific Northwest live knowledgeably with volcanoes. CVO scientists study and monitor volcanoes and communicate their findings to the public through a partner engagement and outreach program that was initiated in 1995. This program identifies and prioritizes stakeholders and partners; develops key complementary messages about hazards, risk, and preparedness; develops products in partnership with local stakeholders; and fosters mutually beneficial long-term, ongoing conversations between scientists and policy makers (as discussed in Mileti and Sorensen, 1990). Target audiences of CVO partner engagement and outreach include policy and decision makers; emergency managers; land-use managers; industry specialists; and professional information disseminators such as news media, educators, and park interpreters.

CVO scientists collaborate in interagency volcano hazards working groups with local-, State-, and Federal-level emergency managers at each volcano. Coordination plans for actions during potential volcanic crises are developed for each volcano by these working groups and are exercised and updated as needed. Volcano hazards messaging and many products are developed in partnerships, including interpretive signs (fig. 5), maps, web pages, teacher trainings, and a media guidebook. These products are designed to meet the specific needs of their intended audience, to provide clear images of what will happen when a volcanic event occurs, and to present steps for preparation and mitigation. Information about partner needs is commonly gathered through semi-structured interviews, focus group meetings, reviews by test audiences, and requests from teachers and park interpreters. As partner engagement and outreach is an ongoing conversation, CVO scientists often are engaged for highly valued consultation with partners.

Case Study—ShakeOut, USGS Science, and the City of Los Angeles

Figure 6. The ShakeOut scenario was published in 2008 and has since been used to raise public awareness about earthquake preparedness and to identify actions needed to reduce risk for the southern California water system, among other applications. Source: Perry and others, 2008.

Building upon the latest science, a USGS team developed a detailed scenario involving a magnitude 7.8 earthquake along the southern San Andreas Fault. Using input from scientific, engineering, economic and social science partners, the USGS "ShakeOut" scenario used a sophisticated simulation of shaking to analyze its plausible impacts on human populations and infrastructure (Jones and others, 2008). The consequences of fault rupture and other ground failure as well as fire following the earthquake also were considered.

This realistic, science-based multi-hazards scenario provided the State of California with the foundation for a statewide emergency management exercise (fig. 6). It also highlighted important societal and infrastructural vulnerabilities to be further explored and addressed. For example, the Los Angeles Department of Water and Power has formed a Resilience Expert Panel and, along with the California Department of Water Resources and the Metropolitan Water District of Southern California, has also formed a Seismic Resilient Water Supply Task Force that USGS advises on risk reduction issues. These organizations have used the ShakeOut scenario to construct a more accurate estimate of the duration of disruption to imported water for all southern California. The scenario also was used to identify and prioritize a series of recommended actions needed to assess alternatives for reducing risk to the water system.

Research

Research targeted to advance fundamental understanding has been and will continue to be a core competency and priority of the USGS. USGS hazard science can be applied to risk reduction by improving basic understanding of hazardous processes, as well as by using scientific observations and analyses to reduce or quantify uncertainties that stem from hazards. These uncertainties include the nature, magnitude, and frequency of future hazard events compounded by the uncertainty of how hazard events impact and alter built and natural environment systems. USGS science also may be used to distinguish between real and perceived risks and to underpin critical public communications during and after a hazard event. Additionally, much remains to be understood as to whether and how human activities may aggravate natural hazards (such as induced seismicity from wastewater injection as described in Petersen and others, 2016, 2017). USGS efforts to support risk reduction will require sustained research, baseline studies, and monitoring on the variability and change in human and biophysical systems, the natural or anthropogenic processes causing or driving these changes, and the potential consequences of these changes as a result of long-term stressors (for example, droughts, global change, and urbanization) and short-term events (for example, earthquakes, severe storms, hazardous material spills). The USGS is well situated to provide broad understanding of hazards and natural stressors given its multidisciplinary and distributed workforce, hazard monitoring networks, and ability to conduct longitudinal studies. However, the Bureau is only at the early stages of providing input on the origin, nature, and effects of societal stressors, and this remains a gap moving forward with multidisciplinary risk research and applications.

Case Study—Environmental Health Risks after 9/11

Figure 7. Photographs showing dust covering the interior of an apartment following the collapse of the World Trade Centers (top) and a U.S. Geological Survey researcher collecting dust samples for analysis at Ground Zero (bottom), in lower Manhattan, New York. Photographs by Mark Rushing (top) and Gregg Swayze (USGS, right), 2001. Used with permission.

Two days after the attacks of September 11, 2001, with the dust of the collapsed World Trade Centers (WTCs) still swirling in the air in the streets of Manhattan, USGS scientists were contacted by officials from the U.S. Environmental Protection Agency and the Public Health Service Commissioned Corps (Plumlee, 2009). These officials sought USGS expertise in mineralogical characterization of dust because they wanted to understand what risks to public health the WTC dust might pose. Using Airborne Visible/Infrared Imaging Spectrometer data and field samples of WTC dust, USGS scientists were able to allay fears of amphibole asbestos risk (generally viewed as the more dangerous asbestos variety) (fig. 7). However, USGS scientists found that the WTC dusts were a complex mix of bioreactive, bioaccessible, and biodurable particles (Plumlee and others, 2012). Incidental handling of dusts by hand-to-mouth contact or of dust particles cleared from the respiratory tract may have provided an exposure pathway for gastric-bioaccessible toxicants such as lead. Within two weeks of the initial attacks, USGS scientists were able to supply emergency managers with maps showing the distribution of other forms of asbestos, concrete, and other minerals producing dust around lower Manhattan to allow them to assess these risks and form mitigation strategies. Challenges that USGS scientists faced were being placed in a situation with an extremely high media profile; the media was pressuring scientists to make sensationalist statements. USGS scientists also described the challenges of having their work embroiled in numerous ongoing litigations concerning the WTC.

Product Development

USGS risk research and applications are of limited value if colleagues and external partners are not aware of them, do not understand them, or do not use them. To improve the use of USGS science by external partners, new investments will be needed in improving tool and product development. This would require social science expertise, flexible technology, amenable data policies, and staff to handle an ever-growing data input, analyze data, and deliver new and existing location-specific products in real time to a rapidly evolving, customizable, digital ecosystem. This work would benefit from additional technological expertise in visualization, data compilation and standardization, and application computer programming, as well from as an improved understanding of how users use USGS tools and products. A critical part of tool and product development also is the socialization of the use of the tools produced and the assurance that the correct user groups are aware of the existence of these tools.

Case Study—The USGS Coastal Change Hazards Portal

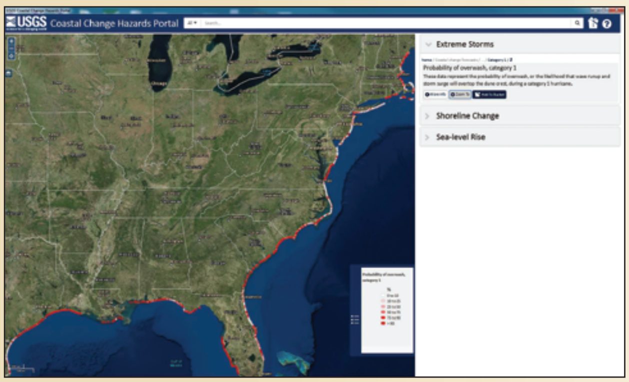


Figure 8. Screen capture showing home page of U.S. Geological Survey Coastal Change Hazards Portal.

The USGS Coastal Change Hazards Portal (hereinafter “the Portal,” U.S. Geological Survey, 2018) is a hazards assessment tool that integrates data, knowledge, and tools about storms, shoreline change, and sea level rise in an interactive online platform designed to support decision making for emergency managers, planners, and natural resource managers (fig. 8). Launched in 2014, the Portal was developed from a partnership between the USGS Coastal and Marine Geology Program and the Office of Water Integration.

The products presented through the Portal have their origins in research efforts that began in the late 1990s. This research was intended to develop methods and results that could quantify coastal change hazards consistently on a National scale. The research efforts were successful and the next step was to apply them to hazard and vulnerability assessments. The early development of the Portal was influenced by a need to increase user engagement and do so with limited resources to support such engagement. The shift toward prioritizing a tool such as the Portal came when Hurricane Katrina struck the Gulf Coast in 2005. The impact of Hurricane Sandy on the mid-Atlantic Coast in 2012 further increased interest in such a product and, finally, resulted in funding to support the Portal. The use of Portal assets during and after Hurricane Sandy also contributed to increasing public awareness and demand for coastal change forecasts, and the Portal has incorporated multiple variables of coastal change in response to user needs.

The Portal enables users to investigate nationwide coastal hazards at various scales by zooming in and out of the interactive map. During major storm events, such as hurricanes and nor’easters, users can overlay the projected storm track from the National Weather Service with predictions of the severity of coastal change hazards, such as dune overwash and inundation. This capability can support emergency managers, business owners, and residents in determining when and where they may be in danger of coastal erosion and flooding.

The Coastal Change Hazards Portal has been used to explain the occurrence and severity of coastal-change hazards along the Nation’s coastlines. Researchers and coastal resource and emergency managers depend on accurate, updated information that can be presented and delivered by the Portal. Challenges for the future are to maintain the Portal through investments in the information technology, data acquisition and analysis, and assessment models upon which it is based, as well as to integrate the Portal with flood event data to create a seamless understanding of storm events from the coast inland. The USGS is seeking new ways to ensure that this investment is made in a sustainable and nationally effective manner.

Case Study—USGS PAGER—Fast, Online, Earthquake Risk Information

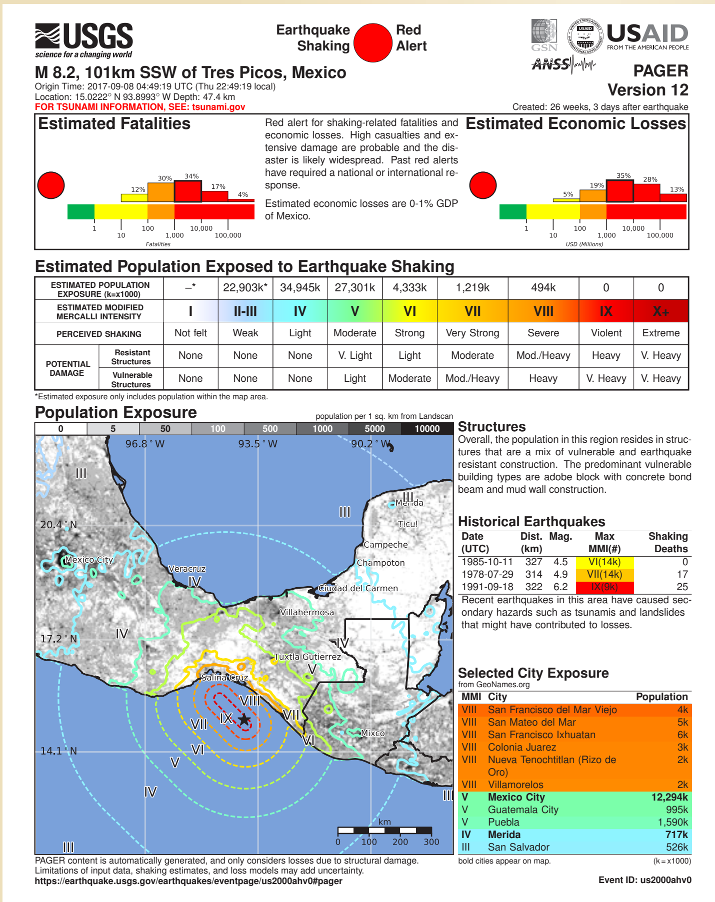


Figure 9. PAGER, the Prompt Assessment of Global Earthquakes for Response system, provides earthquake shaking and loss estimates following significant earthquakes worldwide. This example shows the estimated range of fatalities (left) and economic losses (right, in US dollars (USD), relative to the gross domestic product (GDP) for Mexico) for the magnitude (M) 8.2 earthquake occurring 101 kilometers (km) south-southwest (SSW) of Tres Picos, Mexico on September 8, 2017 at 4:49 Coordinated Universal Time (UTC). The histograms show the percent (%) likelihood that adjacent fatality/loss ranges occur.

PAGER, the Prompt Assessment of Global Earthquakes for Response system, was developed by USGS scientists to inform the general public, government and aid agencies, emergency managers, and responders at national and global scales of the potential outcomes of a significant earthquake within 20–30 minutes of the event (Wald and others, 2010). This system produces hundreds of alerts each year. Most often, these alerts emerge before eyewitness accounts are available. Accessible on the USGS web page and linked to the USGS Earthquake Notification Service that sends emails to subscribers, the automated PAGER system provides information on basic earthquake parameters, estimates economic losses and fatalities, exposed populations, and regionally specific commentary on the vulnerability of buildings in the region and potential secondary hazards (for example, tsunami) (fig. 9). The estimated losses trigger the appropriate color-coded alert (green, yellow, orange, red) to indicate suggested levels of response. As more information becomes available about the earthquake, these estimates are revised as needed. The ability of PAGER to make accurate assessments is based on rigorous USGS fundamental research on hazards, ground movement, and structures. PAGER alerts are used by emergency managers and responders to swiftly determine needed aid, by the media to share critical information with the public, by businesses to determine response activities, and by scientists and engineers to initiate post-earthquake investigations. On average, the PAGER site is viewed 12,514 times per month, but viewing can increase considerably when there is a significant earthquake in an urban area. PAGER also distributes earthquake information by alert notifications. About 600 alert recipients receive a onePAGER alert that is sent automatically to email and mobile devices. Many of these recipients redistribute PAGER content as a part of response-center and watch-officer briefings. PAGER originally was supported by the U.S. Agency for International Development (USAID) Office for U.S. Foreign Disaster Assistance (OFDA) after the 2004 tsunami earthquake in Indonesia under the President's Supplemental relief budget. PAGER primarily is supported by internal USGS Surveys, Investigations, and Research funding, and OFDA has continued to provide partial support for PAGER research, development, and operations.

Case Study—Post-Wildfire Debris-Flow Hazards

Wildland fires burned more than 80 million acres in the United States over the last decade, removing vegetation and changing hillside and stream channel hydrology. In mountainous areas, these changes can substantially increase the potential for flash floods and debris flows in the years immediately following the fire. Debris flows are slurries of water and loose soil and rock (debris) with the consistency of wet concrete. Because debris flows can grow in size, volume, speed, and momentum as they move downstream, they can be particularly destructive to nearby people, property, and infrastructure (fig. 10).

A decade-long effort by a team of Federal, State, and academic scientists to collect and analyze data from burned areas across the Western United States provided a basis for geospatial models to predict debris flow probability and volume given a rainfall amount (Cannon and others, 2009). The first emergency assessments of post-wildfire debris-flow potential were delivered in 2002 and were presented as USGS Open-File reports. These reports typically were made available about 1 month following requests from Burned Area Emergency Response (BAER) teams that are responsible for assessing and managing the impacts of wildfire and follow-on effects on Tribal and public lands. Between 2002 and 2013, USGS debris-flow hazard assessments provided key information for an average of about four major wildfires each year.

Figure 10. Photograph showing home and automobile buried by post-fire debris flow in Mullally Canyon, Los Angeles County, California. Photograph taken February 8, 2010, by Susan Cannon, U.S. Geological Survey retired.

To meet the growing number of requests from BAER teams and other partners for timely delivery of emergency hazard assessments, the USGS moved delivery to an automated web-based system in 2014. Building on the framework underlying other rapid-response information delivered by the USGS such as the PAGER product, post-fire debris-flow hazard assessments are routinely produced for fires across the Nation. This new framework has substantially decreased the time needed to meet requests and increased the ability to deliver critical, readily used geospatial data to existing emergency management systems. In 2016, more than 35 hazard assessments and their accompanying geospatial data were delivered for wildfires in eight States, typically within a few days following receipt of a request (fig. 11).

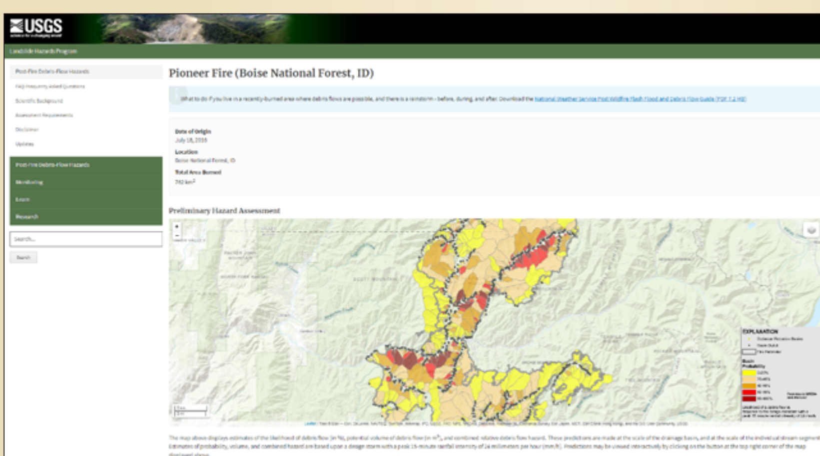


Figure 11. Web page from U.S. Geological Survey Landslide Hazards Program showing post-wildfire debris-flow hazard assessment for the 2016 Pioneer fire in the Boise National Forest, Idaho.

As shown by the preceding examples and the case studies provided throughout this Plan, the USGS is already deeply involved in risk research and applications across its mission areas (also see appendix 2). **Many of the products developed through this work have advanced fundamental research, leveraged monitoring and observation data, benefited partners, led to new collaborations, and garnered attention from many stakeholders ranging from decision makers to industry representatives.** Building on this success and the core competencies described in the section, "Core Competencies for USGS Risk Research and Applications," this Plan identifies several elements of building institutional capacity to further advance risk research and applications at the USGS.

Section 2. Building Institutional Capacity—Advancing and Creating Partnerships

Partner engagement and outreach is one of the three core competencies that form the foundation of USGS risk research and applications (fig. 4). Developing relationships and building trust with potential partners paves the way for further engagement. Effective engagement with external partners to understand their needs and to deliver the right research and products in a timely and appropriate format is essential to successful risk reduction. **Collaboration with partners *from the beginning* of scientific research and product development *through to* message delivery and continuing during use and evaluation is necessary to provide partners with information that can support actionable items for risk reduction.** The feedback from this engagement helps improve USGS risk research and applications.

USGS risk research and applications are complemented by the work of its partners in Federal, State, local, Tribal, and territorial agencies, as well as those in non-governmental and academic institutions. These partners include decision makers such as scientists, engineers, emergency managers, land-use managers, and industry specialists, as well as professional information disseminators such as the news media, educators, and park interpretive staff. Many of these partners also are the main users of USGS risk research and applications (fig. 3). It is therefore essential to understand partner needs so that the most useful research can be conducted and applications can be developed for risk reduction.

Recommendation 2.1—Support and encourage USGS scientists involved in risk research and applications to engage and collaborate with external partners on scientific research, product development, and complementary message delivery. *This engagement requires an investment of salary time and possibly travel that must be supported and funded in order to be successful.*

Effective engagement with external partners cannot be an add-on process that occurs only if there is extra time or funding at the conclusion of a risk research and applications project. Partner engagement needs to guide risk research and applications in order to be effective for risk reduction. This engagement often is long-term and ongoing, and involves a commitment of time and funding that needs to be considered and budgeted for in risk research and applications projects. The value of this type of engagement also should be socialized and emphasized across the Bureau.

Successful, ongoing partner engagement occurs through various avenues, including interagency hazards working groups and committees, focused face-to-face workshops and professional meetings, and less-formal communications and consultations (fig. 12). It is important for these activities to be supported and continued. All these avenues involve a commitment of time and may require funding for travel or event hosting in order to establish a relationship and to build trust.

Figure 12. A U.S. Geological Survey (USGS) volcanologist (left) and a Washington State Department of Transportation representative (right) discussing volcano hazards during a FEMA Volcano Crisis Awareness course in Mount Vernon, WA, March 2014. Photograph by Carolyn Driedger, USGS.

Active participation in interagency hazards working groups provides consistent opportunities for USGS representatives to gain new perspectives and to understand concerns from partners. One example of these groups is the National Tsunami Hazard Mitigation Program, where formal members include State geological and emergency-management agencies, as well as representatives from the Federal Emergency Management Agency (FEMA) and NOAA, and USGS scientists. Collaboration in interagency hazards working groups on risk product development leads to products and messaging that would be the most effective in conveying risk and eliciting action.

In order to engage and to collaborate with external partners outside existing interagency hazards working groups and across the government, academic, and private sectors, partners with a wide range of expertise can be brought together with USGS scientists for workshops focused on specific risk themes. These workshops can help broaden the use and understanding of USGS risk research and applications through brainstorming potential products, audiences, partnerships, and resources for risk reduction. Creative facilitation and human-centered design thinking, such as analyzing user experiences and product prototyping, can add beneficial structure to these valuable face-to-face interactions.

Although interactions among scientists, emergency managers, planners, and decision makers at events such as interagency hazards working group meetings and workshops are valuable, less formal communications and consultations also are a necessary part of successful partner engagement. These interactions include simple "day-to-day" communications such as emails, telephone calls, and visits to each other's offices to discuss needs and to work on complementary messaging and product development. Such communications help build strong relationships by continuing the cycle of dialogue between scientists and users (fig. 13). Engagement with partners at local community meetings, town halls, school activities, emergency management meetings, and scientific meetings also proves equally valuable for improving mutual trust and understanding of user needs. The 2015 "Translating USGS Science to Risk Products" workshop (appendix 1) identified one of the greatest strengths of USGS as its presence across the landscape, where USGS scientists are located and working in every state. USGS scientists should be encouraged to engage with partners in their local communities as a way to build and nurture relationships with local stakeholders. This engagement requires a commitment of time and possibly travel that must be supported and funded in order to be successful.

Recommendation 2.2—Establish and support a process to evaluate and improve the dissemination, usability, knowledge uptake, and impact of USGS risk research and applications with key partners, recognizing that partners will vary by hazard and region. *Work with external partners with expertise in program evaluation and adaptive management to help the USGS develop actionable metrics for gauging the societal use and impact of USGS risk research and applications.*

Gathering feedback and evaluating messaging and product success is a key component of partner engagement. Ultimately, most of the messaging and products developed through USGS risk research and applications partnerships would be presented to target audiences and acted upon by partners to reduce risk. Therefore, it is critical to know whether or not USGS risk research and applications are meeting partner needs in order to improve the usability, knowledge uptake, and impact of risk research and applications.

Evaluation of messaging and products should be conducted in a systematic manner, begun at the outset of project planning, and should integrate social science and communications expertise (for example, Perry and others, 2016; National Academies of Sciences, Engineering, and Medicine, 2018) as well as input from stakeholder focus groups and polling where appropriate. Actionable metrics to evaluate messaging and product effectiveness should be developed and applied. These metrics would address product use by diverse audiences (for example, people of different ages and genders, socio-economic, cultural, or ethnic backgrounds, urban compared to rural populations, and people with different technological capabilities). Feedback from partners then would be gathered consistently and evaluated. Findings from these evaluations should be documented and shared.

Tracking what messaging and products help USGS partners reach their goals would help improve the effectiveness of USGS risk research and applications. It also would help to prioritize and target partnerships that maximize combined effectiveness. An established USGS community of practice for risk research and applications (see Recommendation 4.1), in collaboration with partners in social science and communication, could help initiate effective messaging and product evaluation.

Figure 13. Scientists, designers, and community members work together during a "design storm" (a short, intensive burst of creative sessions with outside partners organized around a particular topic or challenge) as part of the development of the *Science Application for Risk Reduction Atmospheric River 1,000 year storm* (ARkStorm) scenario. This October 2010 meeting was a collaboration among U.S. Geological Survey scientists, potential users of the ARkStorm scenario, and the Art Center College of Design Designmatters program. Photograph by Dice Yamaguchi, courtesy of Designmatters at Art Center College of Design. Used with permission.

Case Study—Workshops with External Partners

Figure 14. Photograph showing a USGS hydrologist presenting information about the ARkStorm scenario to a group of emergency managers and natural resource managers at a workshop in Reno, Nevada, December 2013. Photograph by Dale Cox, USGS.

Facilitated, in-person workshops provide an effective means to connect USGS scientists and external partners for collective problem-solving in risk research and applications (fig. 14). Two such USGS-hosted workshops included the 2012 “Volcanism in the American Southwest” (VASW) workshop held in Flagstaff, Arizona, and the 2014 “New Audiences, New Products for the National Seismic Hazard Maps” (NSHM) workshop held in Denver, Colorado. The VASW workshop brought together USGS scientists, local geoscientists, social scientists with expertise in risk communication, and emergency managers to discuss the potential hazards and risks associated with low-probability, high-impact eruptive events in the American Southwest (Lowenstern and others, 2013). Discussions focused on bringing partners together to collaborate on risk messaging for people living in the Southwest and to discuss future product development and research directions. The VASW workshop served as a platform to identify and strengthen the community of practice for volcanic risk in the region.

The NSHM workshop brought together USGS scientists and SAFRR Cadre of Relevant Experts (CORE, see p. 21) partners with a wide range of expertise spanning 18 disciplines—anthropology, civil engineering, decision science, geography, geology, geophysics, hydrology, information design, journalism, marketing, medicine, political science, psychology, public health, seismology, sociolinguistics, sociology, and structural engineering. The workshop focused on broadening the use and understanding of the NSHM, with participants brainstorming potential products, audiences, partnerships, and resources for the NSHM. The NSHM team used the workshop outcomes to make maps for new users who need NSHM for planning, risk reduction, and education (Perry and others, 2016).

The USGS also co-sponsors workshops with other organizations. For example, the 2015 Dune Management Challenges on Developed Coasts Workshop was organized by the American Shore and Beach Preservation Association and designed to connect coastal dune research with the needs of coastal management practitioners (American Shore and Beach Preservation Association, 2015). Workshop discussions highlighted the benefits of using a community of practice to provide a forum for managers to express challenges to researchers and to facilitate communication and understanding between different sectors including government, non-profit, and academic organizations. These workshops were successful in bringing together USGS scientists and partners to work toward common goals for risk reduction.

Section 3. Building Institutional Capacity—Project Funding

USGS risk research and applications are supported using various funding streams, which include funds provided directly by the programs (appropriated funds); cooperative work funded across programs, centers, and regions (shared funds); and funding from other agencies or partners (reimbursable funds). In the aftermath of a disaster, project-specific funding sometimes is made available through awards from supplemental funding (supplemental funds).

Appropriated Funds

Many USGS programs allocate resources to support risk research and applications, and prominent, sustained efforts are occurring in the Natural Hazards and Land Resources Mission Areas. In particular, the Earthquake Hazards Program, SAFRR project, and the Land Change Science Program support the development and delivery of risk research and applications. These groups often cooperate or co-fund risk projects with other programs and regional management. Other strategies, such as interagency agreements or reimbursable funding, also are sometimes used to meet the need for expertise and product development across the Bureau.

The USGS periodically develops strategic plans, program plans, science plans, and new budget initiatives setting scientific priorities for the Bureau, and these plans and initiatives inform the direction of appropriated funds. The planning process presents unique opportunities to use risk reduction to frame stakeholder needs and to define scientific objectives and priorities.

Case Study—USGS Science Application for Risk Reduction (SAFRR) Project

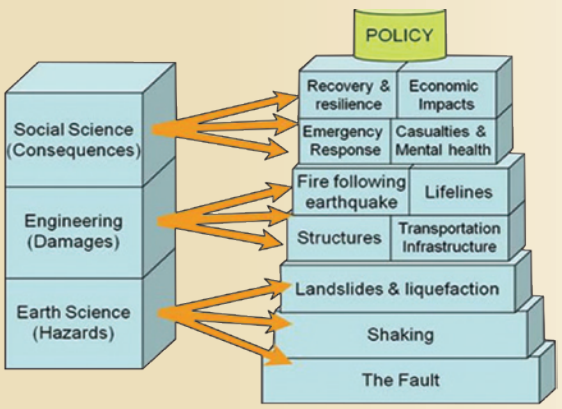


Figure 15. The U.S. Geological Survey Science Application for Risk Reduction (SAFRR) Project integrates earth science, engineering, and social science to develop hypothetical yet scientifically plausible scenarios to analyze the impacts of hazard events and their cascading consequences.

Improving risk research and applications was a key goal in establishing the USGS Science Application for Risk Reduction (SAFRR) project as part of the newly formed USGS Natural Hazards Mission Area (NHMA) in 2012. SAFRR evolved from the Multi-Hazards Demonstration Project (MHDP), which was created to improve resilience to natural hazards in southern California through the application of science to community decision making and emergency response.

Specifically, the MHDP was a 5-year effort to "assist the region's communities to reduce their risk from natural hazards by directing new and existing research towards the community's needs, improving monitoring technology, producing innovative products, and improving dissemination of the results" (Jones and others, 2007, p. 1). The MHDP obtained funding from several mission areas and focused on user engagement and developing science-based scenarios, culminating in the roll-out of the ShakeOut earthquake scenario in 2008, the ARkStorm winter storm scenario in 2011, the SAFRR Tsunami Scenario in 2013, and most recently the HayWired Scenario in 2018. These scenarios were developed in collaboration with USGS scientists and multiple external partners and stakeholders to examine the cascading consequences of hypothetical yet scientifically plausible hazard events. Products included scientific papers and public service announcements. Results have led to lasting partnerships, changes in policy, and emergency response drills.

SAFRR has innovated the application of multi-hazard, multidisciplinary science for the safety, security, and economic well-being of the Nation (fig. 15). SAFRR has done this by connecting users with experts, promoting community engagement, and using collaborations with artists and social scientists to strengthen scenario products. SAFRR has supported product evaluation, including assessment of potential new uses of the Natural Hazard Seismic Maps. SAFRR is supported by the USGS Core Science Systems, Ecosystems, Land Resources, Natural Hazards, and Water Mission Areas.

Shared Funds

To address unique or immediate needs, USGS projects and programs may provide funding to partners in the public and academic sectors to conduct risk research and applications based on (and in support of) USGS science priorities. This typically is done cooperatively through contracts or cooperative agreements of many kinds.

Interagency agreements and Participating Agency Program Agreements between government agencies provide effective partnering methods for sharing hazards science and risk research and applications. These agreements can be tailored for short-term projects or long-term programmatic needs.

Case Study—SAFRR Cadre of Relevant Experts (CORE)

Figure 16. Science Application for Risk Reduction Cadre of Relevant Experts workshop attendees sharing ideas for novel communication products. This workshop brought together social science researchers from the University of California Los Angeles, Art Center College of Design, and City College of New York with U.S. Geological Survey (USGS) staff from the Land Resources, Hazards, Water, Core Science Systems Mission Areas and the Office of Communications and Publishing. Photograph by Erin Burkett, USGS, June 2015.

The USGS Science Application for Risk Reduction (SAFRR) project collaborates with many experts whose knowledge and experience could benefit USGS communication and training efforts. To leverage this expertise, SAFRR established a style of partnership called the SAFRR Cadre of Relevant Experts (SAFRR CORE). SAFRR CORE was designed to convene a rotating group of experts together with USGS scientists to address common problems (fig. 16). CORE meetings typically included social scientists, marketers, and social impact designers, as well as potential users of USGS science. The CORE provided a way to share and gain expertise that may not be present in the USGS in order to improve the understanding and use of USGS science.

SAFRR CORE was launched in 2014 and its first project focused on the USGS National Seismic Hazard Maps (NSHM). The NSHM provide a broad view of earthquake ground shaking hazard across the Nation. The main user group of NSHM traditionally has been engineers working with earthquake building codes. SAFRR CORE worked with the NSHM team to make maps for new users who need NSHM for planning, risk reduction, and education. Additionally, the SAFRR CORE has been engaged in a usability study of the Kīlauea daily updates issued to emergency managers and the public by the Hawaiian Volcano Observatory. Findings of this study will help ensure that the updates are clearly understood and are used correctly by their intended audiences. The updates are a primary source for information on the status of eruptive activity at Kīlauea and were utilized extensively by emergency managers and the public during the Lower East Rift Zone eruption of Kīlauea in the spring and summer of 2018.

The successes and lessons learned from the NSHM effort resulted in the publication of USGS Circular 1419, “Get Your Science Used—Six Guidelines to Improve Your Products” (Perry and others, 2016). The circular will be complemented by a forthcoming publication on “Communicating Hazards—A Social Science Review to Meet U.S. Geological Survey Needs.”

Case Study—Rockfall Hazard and Risk Assessment for Yosemite Valley

In 2010, the National Park Service (NPS) partially funded USGS researchers to collaborate on a quantitative rockfall hazard and risk assessment for Yosemite Valley in Yosemite National Park, California. Rockfalls from steep cliffs are a common natural hazard in Yosemite Valley, posing substantial risk to the approximately 4 million people who visit each year. For example, in October 2008, a rockfall damaged or destroyed 25 wooden and tent cabins in the valley. Three people sustained minor injuries, and many more narrowly avoided injury or death. To inform preventative decisions to close, relocate, or repurpose buildings and campgrounds in Yosemite Valley, USGS and NPS research geologists and engineers developed probabilistic assessments of rockfall runout into the valley—the hazard—and consequent casualties—the risk. In doing so, the collaborators also developed a new rockfall hazard assessment methodology that is analogous to probabilistic earthquake hazard assessment and can be applied in other rockfall-prone areas. The results were used by the NPS to reduce the projected number of casualties in Yosemite Valley by 95 percent, partly by removing, relocating, or repurposing more than 200 structures in 2013. In February 2014, a rockfall boulder impacted the footprints of two wooden cabins that had been removed, as shown in figure 17*C*. Had the cabins not been removed, "they would have been extensively damaged, and had they been occupied, there almost certainly would have been injuries and perhaps even fatalities" (Stock and Collins, 2014, p. 261). The hazard and risk assessments also are being used to guide future park-planning efforts. The collaboration ultimately was published by Stock and others (2014) and posted to the NPS website.

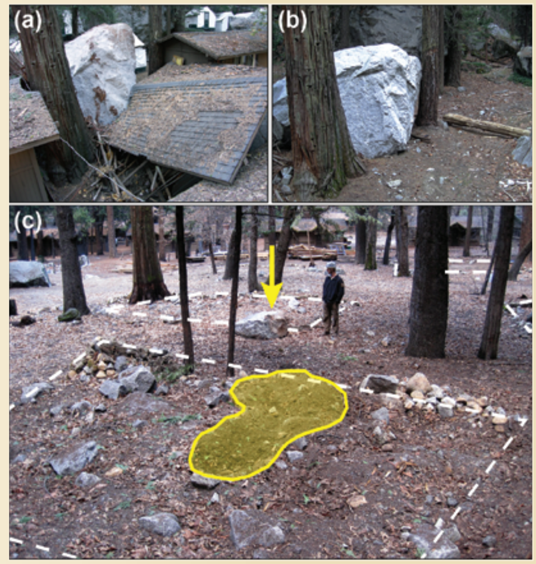


Figure 17. Photographs showing rockfall hazard and risk in Curry Village, Yosemite Valley, California. *A*, Cabin damage resulting from an October 2008 rockfall. *B*, Same area following removal of more than 200 cabins in 2013. *C*, Successful mitigation of rockfall risk. Dashed white lines indicate footprints of removed cabins. The yellow arrow identifies an approximately 1-cubic-meter boulder that fell in February 2014, and the yellow shaded area shows the impact crater from this boulder within the footprint of a former cabin. (Source: Stock and Collins, 2014).

Case Study—The Volcano Disaster Assistance Program (VDAP)

Figure 18. Volcano Disaster Assistance Program (VDAP) scientists and counterparts from the Indonesia Center of Volcanology and Geological Hazard Mitigation installing a volcanic gas monitoring system at erupting Sinabung volcano, Indonesia. Photograph by Christoph Kern, U.S. Geological Survey/ VDAP, September 2016.

There are about 1,500 potentially active volcanoes around the world and only one international volcano response team that can deploy to help prevent eruptions from becoming disasters—the Volcano Disaster Assistance Program (VDAP). Established in 1986 by the USGS and USAID/OFDA, VDAP has been providing technical assistance worldwide for more than 30 years.

VDAP formed in response to the devastating volcanic mudflow that buried the city of Armero, Colombia, on the night of November 13, 1985, killing more than 23,000 unsuspecting people. This tragedy was avoidable. Better education of the local population and protocols for communication would have allowed transmission of the important message that an eruption was underway at nearby Nevado del Ruiz volcano that would induce deadly lahars down the Río Lagunillas. VDAP strives to ensure that such a tragedy will never happen again.

VDAP scientific teams have deployed in response to 30 major crises worldwide, assisted counterparts with hundreds of additional volcanic events, and strengthened response capacity in 12 countries since the program began (fig. 18). At the request of affected governments, VDAP works with host-country national scientists to monitor volcanic activity, to assess hazards, to generate eruption forecasts, and to develop early warning capabilities to get people out of harm's way. VDAP also sponsors international exchanges where U.S. land managers and first responders visit the sites of foreign volcano disasters and learn from the survivors. Foreign officials, in turn, visit the United States to learn about U.S. emergency management systems, multi-agency response plans, and new monitoring tools as implemented in U.S. volcano observatory operations. The VDAP guiding philosophy is to assist international partners and to empower them to take the lead in mitigating hazards and risk from their threatening volcanoes in their respective countries.

Reimbursable Funds

Partners that fund USGS projects have direct input into the products and (or) assessments that are needed and are well positioned to implement risk reduction measures. Cooperator or reimbursable funding commitments ensure partner engagement and articulation of science needs to support decisions. Key examples of reimbursable work by USGS are available in the Water Mission Area, which relies heavily on cooperator funding for day-to-day operations of assets such as the streamgage network and for event-response activities. The Water Mission Area also has established pre-scripted mission assignments with FEMA to secure funding before, during, and immediately after significant hydrologic events.

Case Study—Tracking Rising Waters with the Flood Inundation Mapper

Figure 19. Photograph showing flooded house near the confluence of the Comite and Amite Rivers near Denham Springs, Louisiana, in August, 2016. Photograph by James Fountain, U.S. Geological Survey.

The USGS Flood Inundation Mapper is an online mapping application that combines flood inundation maps with real-time river-level data from USGS streamgages and National Weather Service flood forecasts in a powerful tool that helps communicate when and where floods may occur (U.S. Geological Survey, 2017d) (fig. 19). The Flood Inundation Mapper is part of the USGS Flood Inundation Mapping (FIM) Program, which focuses its efforts at State and local levels to help communities understand flood risks and make cost-effective mitigation decisions.

Flood inundation maps effectively translate historical and contemporary hydrographic data into operational maps that communicate risk and consequences. These maps are used to protect lives and property; to improve community preparedness, mitigation, response, and recovery; and to inform environmental assessments.

The Flood Inundation Mapper helps communities visualize potential flooding scenarios, identify areas and resources that may be at risk, and enhance their local response effort during a flooding event. Users also can use the application to access historical flood information and potential loss estimates based on the severity of the flood.

The USGS partners with communities to assist in the development and validation of flood inundation map libraries—sets of maps that show where flooding may occur over a range of water levels in the local stream or river of a community. The USGS also works with the National Weather Service, the U.S. Army Corps of Engineers, and FEMA to connect communities with all available Federal flood data resources, thereby ensuring the quality and consistency of flood inundation maps across the country.

Supplemental Funds

Following a Presidentially declared disaster, the USGS sometimes receives supplemental funding, either directly or made available through the Department of the Interior (DOI). With thoughtful planning, such funds can be used to advance ongoing research in the affected area, and in particular, can boost building new assessments, products, and tools that address and communicate risk. These products often are in high demand during and after an event, when situational awareness regarding assets at risk is needed to inform response and recovery efforts.

Case Study—Hurricane Sandy Supplemental Funding

Figure 20. Oblique aerial photographs of Pelican and Fire Islands, New York, taken before (May 21, 2009; top) and after (November 5, 2012; bottom) Hurricane Sandy. View is looking northwest across Fire Island towards Great South Bay. Location is within Fire Island National Seashore near Old Inlet—a very narrow part of the island that has breached in previous large storms. The island breached during Hurricane Sandy, creating a new inlet. Despite the breach, the fishing shack (yellow arrow) remained standing (U.S. Geological Survey, 2017e).

Hurricane Sandy struck the U.S. East Coast on October 29, 2012, as one of the largest and costliest storms to make landfall in the United States since Hurricane Katrina in 2005 (fig. 20). Sandy affected 17 States, inundating coastal towns, knocking out power to more than 8 million people including residents and businesses in lower Manhattan, and transforming coastal habitats. In the immediate response to the storm, more than 160 USGS personnel from offices across the Nation were deployed to predict impacts and deploy instrumentation to collect essential environmental data (Buxton and others, 2013).

In addition to the “boots on the ground” response in the immediate aftermath of the storm, the USGS developed the Hurricane Sandy Science Plan, “Meeting the Science Needs of the Nation in the Wake of Hurricane Sandy—A U.S. Geological Survey Science Plan for Support of Restoration and Recovery” (Buxton and others, 2013). The plan (Buxton and others, 2013) defined five science themes to delineate USGS priorities and to coordinate continuing USGS activities with other agencies. In October 2013, the USGS received $44.5 million in supplemental funds to support the Sandy Science Plan and to help with the Nation’s efforts to recover from the disaster and to improve the ability to respond and recover to future storms. Projects included observational assessment of substantial coastal and inland topographic and bathymetric changes, determining potential environmental health threats caused by the release of contaminants, evaluating coastal ecosystem impacts, and developing improved predictive and observational capabilities to better respond to future events. These funds have been used to substantially advance the development of numerous new products and tools for USGS science delivery, including the USGS Coastal Change Hazards Portal.

Recommendation 3.1—Explicitly identify risk research and applications when setting funding priorities and setting the course for new projects. *Language to fund risk research and application projects should be included in annual mission area guidance, program plans, science plans, budget initiatives, and the annual USGS Budget Justification ("Greenbook").*

Risk reduction is one of the four foundational mandates of the USGS ("reduce loss of life and property from natural disasters"). Thus, risk research and applications should identify needs and affect priorities as program plans, science plans, and budget initiatives are developed within and across all mission areas of the USGS. Stakeholder engagement and the determination of project needs early on is essential to developing comprehensive budget plans. These plans and initiatives provide important opportunities to advance the goals and objectives outlined in this Plan. Importantly, they should emphasize that risk research and applications be considered at project inception and throughout project life spans.

Recommendation 3.2—Use existing Bureau-level funding opportunities, communities of practice, and collaboration mechanisms such as venture capital funds, the USGS Innovation Center, the Community for Data Integration (CDI), and the Powell Center to support risk research and applications initiatives. Encourage scientists from across USGS working in risk research and applications to submit proposals and to join or form working groups for research-to-operation transitions, communications approaches, and analytical methods related to risk research and applications. *In turn, collaborate with leaders of these capital fund efforts to identify incentives for soliciting risk research and application-specific proposals.*

The Bureau has invested capital funds in programs such as the Innovation Center, CDI, and the Powell Center to explore new means for product development, cross-program collaboration, and data integration. Specifically, the Innovation Center was created with the mission to "identify national scientific problems where USGS core interests are aligned with those of our external partners, and to pursue innovative technological solutions together, using scarce dollars to best serve the public" (U.S. Geological Survey, 2017a) The CDI "leads the development of data management tools and practices, cyber infrastructure, collaboration tools, and training in support of scientists as well as technology specialists throughout the project and data lifecycles" (U.S. Geological Survey, 2017b). The CDI is a venue for initiating short term pilot projects that advance Bureau priorities such as building Integrated Predictive Science Capacity. The Powell Center "serves as a catalyst for innovative thinking in Earth system science research by providing the time, creative space, and computational, data manipulation and data management resources to promote synthesis of existing information and emergent knowledge" (U.S. Geological Survey, 2017c) Together, these resources offer unique opportunities to advance the development of risk products and to share and exchange expertise across programs and with external partners.

Recommendation 3.3—Capitalize on opportunities to advance the recommendations of this Plan by including risk research and applications in proposals for supplemental funding when available. *Project leads should be encouraged to consult the risk research and applications community of practice (see* Recommendation 4.1*) at the outset of project planning to identify opportunities and resources.*

The preparation of a proposal for possible supplemental funding that includes risk research and applications before a disaster strikes could improve the chances of successful funding and help capitalize on opportunities to advance the recommendations of this Plan. Consultation between project leads and the risk research and applications community of practice (see Recommendation 4.1) to help draft effective proposals also could help projects get started immediately if and when they are funded.

Logs and other debris jammed up against house along the South Fork Toutle River in Washington State resulting from the May 18, 1980, lahars. Supplemental funding and long-term investments following the devastating eruption of Mount St. Helens allowed scientists to research, study, and better understand the mechanics and depositional processes of previously unrecognized volcanic phenomena and events. Communities far distant from volcanoes were vulnerable to long-traveled lahars and associated erosion, sedimentation, and flooding. Photograph by Lyn Topinka, USGS.

Section 4. Building Institutional Capacity—Professional Staff and Capabilities

If the USGS is to succeed in meeting demands from external partners and its commitment to addressing risk as part of its hazard mission, then additional professional capacity must be added and capabilities must be built. A key strength of USGS risk research and applications is that the people and projects involved are distributed throughout the Bureau, spanning mission areas, programs, and science centers (fig 21). Collaborating to build risk research and applications across this distributed workforce also is a challenge, as the people involved may not communicate on a regular basis, nor have the common demands for risk research among mission areas, programs, and centers been defined. Improved internal communication and collaboration are required across the organization to connect those involved in risk research and applications with specific areas of expertise and to share the methods, impacts, and potentially wider applicability of ongoing and completed risk research and application projects.

The development of the US West Coast ShakeAlert—Earthquake Early Warning (EEW, see Burkett and others, 2014) system is an example of the critical roles of the individuals involved in risk research and applications, and how these roles are interconnected:

- Science—advance research and monitoring of seismic properties and activity in EEW region, and understand how individuals and communities take action for EEW.

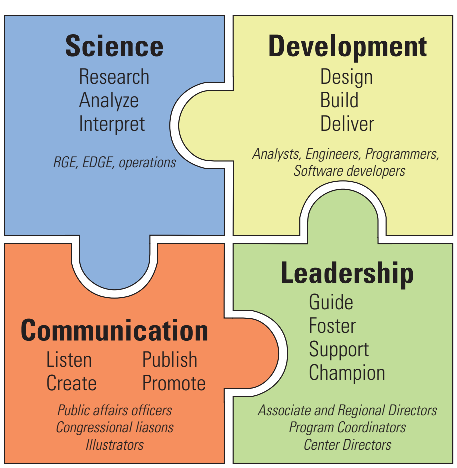


Figure 21. How risk research and applications require input from many individuals across many levels of the U.S. Geological Survey. EDGE, Equipment Development Grade Evaluation; RGE, Research Grade Evaluation.

- Development—determine ShakeAlert seismic parameters within seconds from monitoring and develop cellphone push technology for messaging.
- Communication—foster partnerships with beta test users to iteratively test the system and collect user feedback, and to disseminate information on what EEW is and how it would benefit users.
- Leadership—share information on EEW progress, secure funding, enable internal resources and expertise, and manage relationships with multiple levels of stakeholders and supporters.

Recommendation 4.1—Create a community of practice for risk research and applications to create a central, Bureau-wide point of contact for risk research and applications and to identify, connect, and coordinate relevant expertise across the Bureau. *The CDI could be used as a model, where elements of the CDI could be emulated for a risk-related community of practice, including holding regular meetings of users, providing funds for supporting working groups, and issuing an annual request for proposals process to award seed funds for projects that focus on innovative risk research and applications.*

By definition, a **community of practice** is a group of people who share a passion, expertise, or goal for something they do and who learn how to do it better as they interact and share information regularly. The USGS has multiple communities of practice and working groups, including the CDI, which can be used as a model for creating a USGS risk research and applications analog. This community would serve as a nexus for connecting scientists and staff within the USGS, sharing best practices, and for connecting and coordinating with partners at other agencies and organizations.

Recommendation 4.2—Develop an internal community of practice for risk research and applications web page or wiki to establish an online "home" for a USGS community of practice on risk research and applications. *Like the* CDI web page*, this web page would facilitate the exchange of information on projects, in-house expertise, useful resources, and opportunities for collaboration in risk research and applications across the Bureau. This web page should have an external facing component to provide partners with information on the community of practice (for example, contacts, activities, opportunities for collaboration) (see* Recommendation 5.1*).*

Creating an online collaborative workspace for people and projects in risk research and applications from across the Bureau would be a valuable tool for socializing the importance of this type of work, for improving communication and collaboration across organizational boundaries, and for helping individuals to advance and improve their own projects. The workspace would help to identify those involved in risk research and applications and their specific areas of expertise. It would briefly describe the characteristics of risk research and application projects, including methodologies and impact. The workspace also would provide contact information and (or) an interactive forum for community discussions and collaborative problem solving. Other projects and personnel that are not explicitly identified with risk research but that are recognized as having information and expertise that could complement or benefit risk researchers also would be included in the wiki. Pending interest, the community of practice could use the workspace to organize and advertise regular webinars, to disseminate information on ongoing projects through a blog or electronic newsletter, and (or) to facilitate group critiques of projects in development.

Recommendation 4.3—Convene an annual meeting of the USGS risk research and applications community of practice. *This meeting would create a standing opportunity for scientists and staff to meet in person to exchange ideas, to network, and to report on new research and products, and challenges. This meeting potentially could be held in conjunction with another risk research and applications-related event, such as a conference or workshop, to leverage resources.*

Transferring valuable knowledge and skills among people involved in risk research and applications across the Bureau also can be bolstered by convening a face-to-face meeting of the risk research and applications community of practice. This meeting could be structured similarly to the annual USGS Innovation Center Workshops or the annual CDI workshop and would include presentations, posters, panel discussions, and working groups. These meetings would allow for sharing innovative methods, project results, and project needs across disciplines with other USGS researchers as well as with partners and contacts from collaborating agencies. It would be a venue for identifying priority audiences and customers for USGS risk research and applications, including needed products and preferences in how they receive information. This meeting would be held annually, possibly in conjunction with another risk research and applications event such as the Natural Hazards Center Research and Applications Workshop.

Recommendation 4.4—Address needs for social science expertise by funding experts inside and outside USGS and by identifying Bureau needs for increasing staffing to advance risk research and applications. *Continue to fund and promote opportunities for USGS scientists and staff to consult with internal and external social and hazard scientists. Additionally, Bureau hiring needs should be identified for long-term investments in building professional capacity in this area.*

One of the main goals of building institutional capacity in USGS risk research and applications is to gain skills and knowledge for the creation of risk products that meet the needs of partners and external agencies. However, this may require expertise not currently available within a specific science center or the entire USGS workforce in some cases. For example, the expertise of a geographer or demographer may be needed to characterize the population potentially at risk from a specific hazard. A sociologist may be needed to help identify the reasons certain groups are more vulnerable to hazards than others. A behavioral psychologist may be needed to understand how individuals react to information about risk. Social impact designers may be needed to help create products and messaging specifically tuned to reaching these vulnerable groups. Adding this expertise can be accomplished through short-term collaborations and contracts or through long-term investments in Bureau hiring.

SAFRR CORE is an existing mechanism for addressing needs for expertise in social sciences and product design through collaborations and contracts with outside experts (see "Case Study—USGS Science Application for Risk Reduction (SAFRR) Project" and "Case Study—SAFRR Cadre of Relevant Experts (CORE)"). Although collaborations and contracts can provide short-term support, long-term investments in Bureau hires could integrate additional social and behavioral science expertise in the USGS workforce and in USGS risk research and applications. The 2015 "Translating USGS Science to Risk Products" workshop identified social scientists and visualization expertise as potential staffing gaps (appendix 1). Because workforce planning is science-center-directed, science centers would need to decide in conjunction with programs and mission areas what expertise is needed to accomplish major goals in risk research and applications and to achieve Bureau workforce goals.

Recommendation 4.5—Provide mentoring resources for scientists and staff pursuing risk research and applications. *Encourage early career scientists and staff interested in risk research and applications to enter the USGS Mentoring Program as protégés and to select mentors with experience in risk research and applications. Encourage those with experience in risk research and applications to apply to be mentors.*

The USGS Mentoring Program focuses on intentional mentoring, the deliberate transfer of skills and knowledge from more experienced employees to those who are less experienced. This partnership between mentor and protégé often involves coaching, networking, sponsoring, and career training. Mentors and protégés who have taken part in this program note that it has contributed to valuable personal and professional growth opportunities. Mentoring is available to all USGS employees and is a cost-effective tool for employee growth and development. The USGS Mentoring Program, therefore, would be an established Bureau-level means through which early career scientists and staff protégés could gain valuable skills and knowledge from mentors experienced in risk research and applications. Acknowledgment of risk research and applications at the USGS Mentoring Program “rollout” and quarterly “check in” meetings (which are attended by mentors and protégés nationwide) would help to heighten the awareness of people involved in and projects focused on risk research and applications across the Bureau.

Recommendation 4.6—Provide scientists and staff with opportunities for informal and formal training related to risk research and applications. *Develop in-person and (or) online training courses on topics related to risk research and applications and (or) identify opportunities available at other agencies or organizations. Topics could include effective partnering, human-centered design thinking, risk analysis, risk communication, web application development, project management, and others.*

Everyone involved in risk research and applications, from early career scientists to experts, benefits from acquiring new skills and knowledge that can be directly applied to their work. One way to gain new skills and knowledge is through in-person and (or) online training that can be done through informal mechanisms, such as webinars and project critiques, or formal mechanisms such as short courses.

Development of training opportunities on topics such as successful partner engagement, risk communication to stakeholders, GIS application building, web tool programming, collaborative project management, and design thinking strategies for risk products would benefit all involved in risk research and applications. These training resources could be developed by internal and external subject matter experts and presented in-person or online. At present (2018), there are no formal USGS or DOI training courses specifically geared toward the skills and knowledge needed for successful risk research and applications. Implementing this recommendation would require a determination of what types of training are needed and what training resources are available (for example, the Data Management Training Clearinghouse (Federation of Earth Science Information Partners, 2017) may be used as a model), and then creating a prioritized list of training resources to be developed or acquired to suit these needs. The USGS may be able to co-develop training with or leverage resources available at other organizations, such as the FEMA Emergency Management Institute.

Recommendation 4.7—Share expertise in risk research and applications through short-term personnel assignments. *Identify funding and administrative support for short-term assignments where individuals with risk expertise work with internal USGS projects and (or) partner agencies.*

Another method for building professional capacity in risk research and applications is through short-term assignments (for example, detail opportunities or collaborations on specific projects), where those with risk expertise would work with projects in need from across the Bureau. Crossover collaboration helps transfer knowledge and skills between projects and people. Short-term assignments could be extended to include partner agencies that collaborate in risk research and applications with the USGS. These interagency collaborations would help transfer knowledge and skills while increasing the understanding of partner agency needs and their goals in risk research and applications.

Recommendation 4.8—Ensure risk research and application experts are selected to serve on internal peer evaluation panels of scientists working in risk research and applications. *The risk research and applications community of practice (from* Recommendation 4.1*) may be a useful resource for finding research scientists to serve on Research Grade Evaluation (RGE) and Equipment Development Grade Evaluation (EDGE) panels that will be reviewing research scientists and staff making contributions to risk research and applications. A new RGE peer review group focused on societal risk could be an option for risk researchers whose work transcends a single hazard or environmental stressor.*

Many USGS employees currently involved in risk research and applications are in positions officially classified as research scientists under RGE or as research engineers and scientists under EDGE. The performance of individuals in these positions is evaluated by a peer panel review process based on guidelines from the Office of Personnel Management. Because current USGS efforts in risk are distributed across the Bureau, an ongoing challenge is building review panels with sufficient background and understanding to review risk RGE and EDGE scientists. RGE and EDGE researchers with expertise in risk research and applications would be the most knowledgeable evaluators of their peers, as they would have a better understanding of the scientific journals where risk research is published, the types of USGS risk products commonly developed, and the impacts of risk research and applications. These researchers may be different from research scientists and technicians, with expertise in other fields.

An RGE peer group devoted specifically to societal risk research may be warranted to provide a more representative review process for interested researchers. The number of individuals self-identified in the community of practice of USGS risk research may be large enough now for such a group and likely will grow in the future. Like current panel review groups, a societal risk panel review group could become an option for interested researchers who work across multiple hazards or environmental stressors. It would not impact researchers who would prefer to be evaluated through one of the existing discipline-specific groups.

Recommendation 4.9—Recognize excellence in risk research and applications with a USGS Shoemaker Communications Award. *A new award for Best Risk Product, created in the External Communications category, would be judged on how effectively a product addresses the needs of external partners by communicating risk and the significance of the product to external partners in reducing risk.*

Recognition of the importance of risk research and applications to the mission of the USGS helps to legitimize and encourage work in risk research and applications. One way to recognize this importance is by granting prestigious Bureau-level awards (such as the Shoemaker Communications Award) for excellence in risk research and applications.

The criteria upon which these awards are given are the same as many of the elements of successful risk communication. Several risk-related products and scientists communicating risk concepts have won awards, although they may not have been explicitly recognized as being awarded for risk. In order to explicitly recognize USGS risk research and applications, a Shoemaker Communications Award could be established in the External Communications category for the Best Risk Product. This new award would heighten the visibility of USGS risk research and applications across the Bureau.

Recommendation 4.10—Develop regularly scheduled communications and events to broadly share information about USGS activities in risk research and applications both internally and externally. *Create an annual "Hazards Risk Reduction Month" campaign to highlight risk research and applications and why they matter. This campaign would help to identify the people, projects, and partners involved in risk research and applications and the impact of their work in risk reduction.*

In order to highlight risk research and applications across the Bureau, an annual "Hazards Risk Reduction Month" campaign could be created, where USGS web page feature stories, leader blogs, public lectures, congressional briefings, and social media posts would focus on risk research and applications. This campaign would be coordinated with the community of practice and would help to identify the people, projects, and partners involved in USGS risk research and applications and the broader impacts of their work in contributing to risk reduction, Bureau prestige, and product innovation. Highlighting the breadth of the USGS community of practice and the significance of risk research and applications to the risk reduction efforts of external partners could encourage more scientists and managers to become involved, thereby building professional capacity and enthusiasm within the Bureau. This annual event would be an excellent opportunity to introduce new products and other items recommended in this Plan, should they be adopted. To improve external visibility, the annual "Hazards Risk Reduction Month" could be organized in conjunction with the annual September National Preparedness Month or the October ShakeOut exercise. It would be strengthened by partnering with a professional society or other organization (for example, the American Geophysical Union, American Meteorological Society, American Society of Civil Engineers, Geological Society of America, the Natural Hazards Center, or the USGS Coalition) to broaden its reach and the scope of campaign-related communications. Additional communications, such as a regular blog or newsletter, may be considered to maintain interest throughout the year.

During a National Water Quality Network (NWQN) sampling trip in May to the St. Lawrence River, Hydrologic Technician Dave Knauer finds a batch of Zebra mussels, an invasive species, attached to the boat anchor. Risk is posed by a variety of hazards, ranging from the geophysical and meteorological to the ecological and climatological. The risk community of practice is intended to draw on USGS experts from across the Bureau. Photograph by John Byrnes, May 30, 2018.

Case Study—Award-Winning Risk Communication

Figure 22. U.S. Geological Survey (USGS) presenting the John Wesley Powell Award to Dr. Mary Skopec of the Iowa Department of Natural Resources (IDNR), center, for her research and development in estimating streamflow and water-quality values. Photograph courtesy Advisory Committee on Water Integration, U.S. Geological Survey, 2009.

Risk research and applications have been rewarded and applauded by the USGS community through formal mechanisms such as the Shoemaker and John Wesley Powell Awards. The Shoemaker Award was established in 1997 to recognize “extraordinary examples of communicating and translating complex scientific concepts and discoveries into words and pictures that capture the interest and imagination of the American Public” (U.S. Geological Survey, 2017f, p. 21). Although the Shoemaker Award does not exclusively award risk communication, numerous scientists who work in risk research and applications have been honored with this award. For example, Brian Atwater, USGS research geologist, received a 2014 award for his ability to communicate the risks of megathrust earthquakes and tsunamis to both scientific and lay audiences. The John Wesley Powell Award honors non-Federal government employees or groups for contributions to the objectives of the mission of the USGS (fig. 22). Like the Shoemaker Award, the John Wesley Powell Award does not exclusively award risk-related work, but risk-related activities have been recognized by these awards in the past. Walter Arabasz of the University of Utah received a 2007 award for his efforts in helping the public and elected officials understand the risks posed by earthquakes and how to reduce these risks. Such awards, along with Meritorious, Dallas Peck Outstanding Scientist Emeritus, and Special Thanks for Achieving Results (STAR) Awards, could be used to continue to encourage risk-related efforts within and in partnership with the USGS. Risk-related work such as the research of USGS geochemist Michael Meyer examining the exposure risk of ecosystems to various contaminants, the studies of wildlife ecologist Diann Prosser on avian influenza risk, or the advancements of the Volcano Disaster Assistance Program’s (VDAP) in reducing volcanic risks abroad also have been recognized by awards external to USGS. Highly prestigious departmental and national awards such as the Distinguished Service Award, the Presidential Early Career Award for Scientists and Engineers and the Service to America Medal have acknowledged the importance of USGS risk work at a national level.

Section 5. Building Institutional Capacity—Product Delivery and Expansion of Information Technology Capabilities

Disseminating risk products and communicating hazards and risks to multiple users requires a modern digital approach to reach a diversity of audiences in a timely fashion on widely used, increasingly mobile platforms. In a progressively digital world, USGS risk products are increasingly delivered to computers and (or) mobile devices through web applications. The results are flexible, easily updated interactive products that are more accessible to multiple audiences (for example, USGS Coastal Change Hazards Portal, USGS Earthquake Notification Service, and USGS WaterAlert). These products are developed at different scales, where some allow increasingly more personalized delivery of information according to geographic location.

USGS risk products are grounded in fundamental research and long-term monitoring; the Bureau has published numerous reports, maps, and journal articles on risk research and applications over many years. A recent keyword search of the online USGS publications warehouse resulted in about 4,000 entries related to impact, disaster, emergency, exposure, hazard, risk, vulnerability, or warning. These and future reports would continue to be important for establishing the scientific integrity of risk-related research in the USGS as well as serving as the scientific foundation upon which future reports are written and new digital risk applications are constructed.

The recommendations in this section build on several core principles of information technology (IT) infrastructure:

- Facilitating the ability for developers to find new applications, code, and projects that are in progress, or have already been done;
- Promoting the re-use of capabilities;
- Ensuring that the development process, from start to finish, includes multiple feedback loops to enable iterative improvements informed by communications between stakeholders and scientists, and scientists and developers; and
- Leveraging cloud services while ensuring secure platforms.

Digital Tools and Applications for Risk Reduction

The development of digital tools is a strength of the USGS and examples include PAGER alerts, the Coastal Change Hazards Portal, the Hazard Exposure Reporting and Analytics (HERA) mapping application, the Flood Event Viewer (FEV), and the Flood Inundation Mapper (FIM). Many tools also are developed in collaboration with other agencies and institutions such as the Famine Early Warning System that was developed in partnership with the USAID. Digital dissemination of risk products often includes descriptive web pages that draw the attention of the viewer to USGS research and how USGS science can be applied to critical decisions. Online, real-time products such as model visualizations (for example, Ash3D models of volcanic ash plume transport) or educational videos (for example, the SAFRR "Preparedness Now" public service announcement, U.S. Geological Survey, 2017g) capture the attention of an audience and educate viewers about hazards in their environment that may become future threats. Some of the most common vehicles for delivering hazard assessments and risk products include interactive mapping applications, social media and crowdsourcing, and robust data-aggregation tools.

Interactive Mapping Applications

Interactive mapping applications that place multiple datasets in a geographic context in near-real time allow users to quickly visualize the extent and severity of persistent and evolving threats, ranging from floods and droughts to contaminants and debris flows. For community planning, this fusion of data and geographic information can help local and state decision makers analyze and mitigate risks. For emergency response, geo-located information can be integrated in the USGS Hazards Data Distribution System and, therefore, would be accessible through the Department of Homeland Security Geospatial Information Infrastructure, enabling emergency managers to make decisions and to allocate resources with the best information available. The USGS has developed multiple interactive mapping applications to support hazards preparedness response and recovery, including the following:

- FIM, which allows users to explore inundation maps that show where flooding would occur given a selected stream condition;
- The Disaster Coordination Preparedness & Response web map, which provides USGS geospatial data integration with partner data for situational awareness and resource management; and,
- The Emergency Assessment of Post-Fire Debris Flow Hazards, which show the likelihood of debris flows in drainage basins burned by recent wildfires.

Case Study—HERA—A Web Application for Visualizing Community Exposure to Natural Hazards

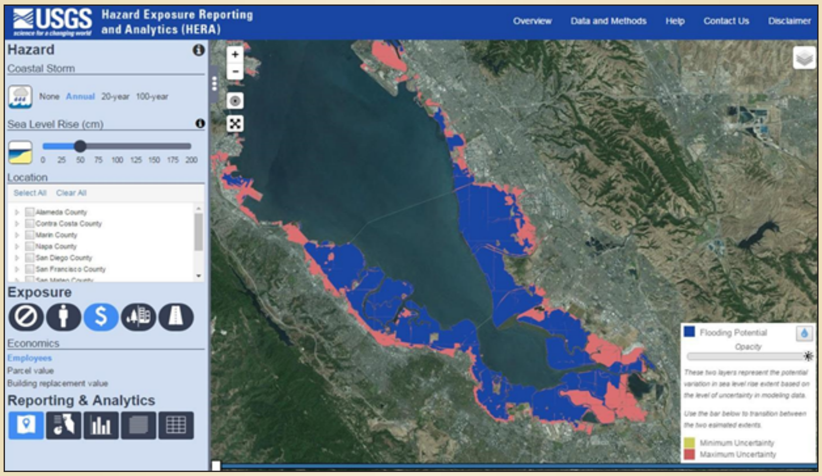


Figure 23. Screen capture showing home page of the U.S. Geological Survey Hazard Exposure Reporting and Analytics (HERA) web application. The panel on the left allows the user to choose coastal storm and sea level rise scenarios; community or communities to display; exposure category; and whether to look at maps, figures, or tabular data. Image shows flood-hazard zones ("=Flooding Potential", in blue) associated with an annual storm and 50 centimeters of sea level rise in lower San Francisco Bay, California. "Maximum Uncertainty" areas (in pink) denote additional flood hazard zones if one takes into account the maximum uncertainty in the modeling. "Minimum Uncertainty" areas can be shown by toggling the slider bar at the bottom of the screen.

Understanding how certain communities may be specifically vulnerable to natural hazards enables elected officials, emergency and public works managers, business owners, non-profit organizations, and the public to make better risk-management decisions. The USGS Hazard Exposure Reporting and Analytics (HERA) (U.S. Geological Survey, 2017h) web application provides interactive maps, charts, and graphics to visualize hazard exposure at the community level in terms of populations, businesses, economic assets, land cover, and infrastructure (fig. 23). Currently (2018), HERA focuses on California community exposure to coastal flooding hazards based on storm and sea level rise scenarios. Users can examine flood-hazard exposure for an individual community, explore changes in community exposure given multiple scenarios, and compare multiple communities. To promote science literacy of the general public, HERA provides guidance on the range of sea level rise predictions for a given year based on the scientific literature and dynamic maps allow users to see how modeling uncertainty impacts the size of flood-hazard zones. To support targeted interventions at the local level, the web application provides detailed information on the demographics of exposed populations and the types of exposed businesses. HERA is a collaboration of the USGS Western Geographic Science Center, which developed the web application and the exposure analysis, and the USGS Pacific Coastal and Marine Science Center, which funded the effort and produced the hazard zones under the Coastal Storm Modeling System (CoSMoS) project. Partners at multiple levels of government and at non-profit organizations have leveraged USGS efforts to add community exposure to descriptions of hazard zones and are using results in climate adaptation plans. Challenges in creating HERA were largely related to management of large and disparate geospatial datasets from multiple sources and to compliance with new security protocols for USGS cloud-based applications.

Case Study—Hurricane Matthew Response

Figure 24. U.S. Geological Survey (USGS) response to Hurricane Matthew, as characterized by hydrographer standing on flooded West 5th Street in Lumberton, North Carolina, preparing to measure discharge at the Lumber River (USGS streamgage 02134170). Photograph by Jeffrey Moss, USGS, October 13, 2016.

When Hurricane Matthew reached the Caribbean Sea in October 2016, it caused significant loss of life and economic damage and the United States braced for its impact along the coastline of the Southeast (fig. 24). As emergency responders at national and local levels prepared for the storm, they needed information about where the storm was most likely to breach the protective coastal dunes.

In near real-time, the USGS Coastal Change Hazards Portal and the USGS Flood Event Viewer (FEV) communicated these risks and allowed emergency managers to understand the probabilities of dune erosion, overwash, and inundation for sandy beaches and inland rivers along the Gulf and Atlantic Coasts during a category 4 or 5 hurricane. As the storm progressed and brought heavy rains, high waves, and storm surges to Florida, Georgia, and the Carolinas, responders on the coast and inland waterways needed to know which areas were most likely to flood or were actively flooding, and by how much. The USGS Coastal Change Hazards Portal and FEV, used in conjunction with data from many of the 8,000 USGS real-time streamgages and partner-agency forecast information, allowed responders to understand these risks and respond accordingly (Hamilton, 2017). Although stream gages and coastal event viewers are directly paid for by the USGS (or through cooperative agreements with States, counties, Tribes and other local entities), USGS deployment during a storm event like Hurricane Matthew is often paid for using a FEMA mission assignment that allows the USGS to respond rapidly and effectively to provide risk-related information to the Nation.

The information provided by USGS monitoring or prediction of high water marks, inundation, storm surges, and dune erosion is used as a basis for the design of future dams and other water-related infrastructure such as water or wastewater treatment plants, highway bridges, and contaminant containment sites. This information also is critical to the successful delineation of floodplain maps by FEMA.

Social Media, Citizen Science, and Crowdsourcing

The USGS has leveraged social media, citizen science, and crowdsourced observations to share real-time information during a crisis and to enhance scientific observations of unfolding events. For example, the Texas Water Dashboard is a web mapping application that presents USGS real-time stream, lake, reservoir, precipitation, and well data in Texas in context with current weather and hazard conditions by combining data from the National Water Information System (NWIS) with a real-time Twitter feed to notify users of flood hazards. Current digital delivery methods are having an increasing ability to direct information to particular groups geographically using wireless emergency alerts. Likewise, long-standing crowdsourcing projects can gather information from groups of citizens. For example, the USGS "Did You Feel It?" web page collects information from people who felt an earthquake and produces maps that show what people experienced and the extent of damage. The USGS "Is Ash Falling?" web page uses observations from individuals who observe volcanic ash to develop a better understanding of ash distribution. As mobile devices become more ubiquitous, there likely would be many more opportunities in the future to harness citizen science and crowdsourced information for risk research and applications.

Data Aggregation Tools

Data-driven applications are able to aggregate multiple data types and models to support various stakeholders—including emergency managers, businesses, and community leaders—in risk analysis. Analytical tools have been developed to create evacuation scenarios for tsunami-prone areas or model hazard scenarios such as extent of groundwater contamination by a chemical spill. Decision-support tools help to quantify risk in ways that focus on emergency management or response needs (for example, PAGER, Pedestrian Evacuation Analyst). In turn, partners integrate USGS data into their own applications (for example, FEMA Hazus).

Challenges of Creating and Delivering Digital Risk Products and Assessments

Expanded capabilities in information technology have arisen repeatedly as a topic in discussions about advancing risk research and applications. Digital tools for risk reduction offer continuously evolving opportunities to share, to integrate, to visualize, and to communicate data and information for addressing increasingly complex problems. However, the process of creating and delivering these products faces multiple challenges and needs. The ever-increasing scale and size of data available requires computing capacity beyond that which is traditionally available. Curating and sharing these products internally and externally is challenging in that they all have a different look and feel, and typically are "housed" on the web page of a specific program such that there is no unified online portfolio of these products. As digital risk products are developed, the demand for them likely would increase. As a result, new products would need to be developed and delivered effectively, potentially taxing USGS capacity in this area. The delivery of these products also is complicated by the need to regularly update or maintain applications as data and technology change. In response to these challenges, following are several recommendations to address specific needs in improving digital product delivery and expanding IT capacity.

Recommendation 5.1—Create a web page dedicated to USGS risk research and applications. *This may be housed on the National Hazards Mission Area (NHMA) web page, but should link to this Plan and to USGS risk tools and applications across programs and other mission areas.*

Creating a central web page for USGS risk research and application products would facilitate the internal and external sharing of current and planned USGS capabilities in this area. This web page would provide links to existing products that are hosted in different locations across the USGS web page. For future risk products, visual identity standards should be considered for creating a consistent "look and feel" for USGS risk products. This web page would link to the online collaborative workspace for the community of practice on risk research and applications (see Recommendation 4.2).

Recommendation 5.2—Develop a Bureau-level capability to host and to maintain operational USGS products in a secure and powerful online environment for digital delivery to computers and mobile devices. *Risk products should be included in this effort.*

Web pages and applications increasingly require skilled developers and visualization experts to create and maintain them. These experts often must have access to high-performance computing capabilities able to handle, model, and visualize large, complex hazards data. At the same time, the security requirements for online products are constantly changing. To keep up with these changes, the USGS should improve its capability for hosting and maintaining operational products as well as using and improving existing investments in advanced computing for model calculation and visualization. This issue extends beyond risk products, and may require additional staff or equipment.

Case Study—USGS Evacuation Modeling to Help Save Lives from Future Tsunamis

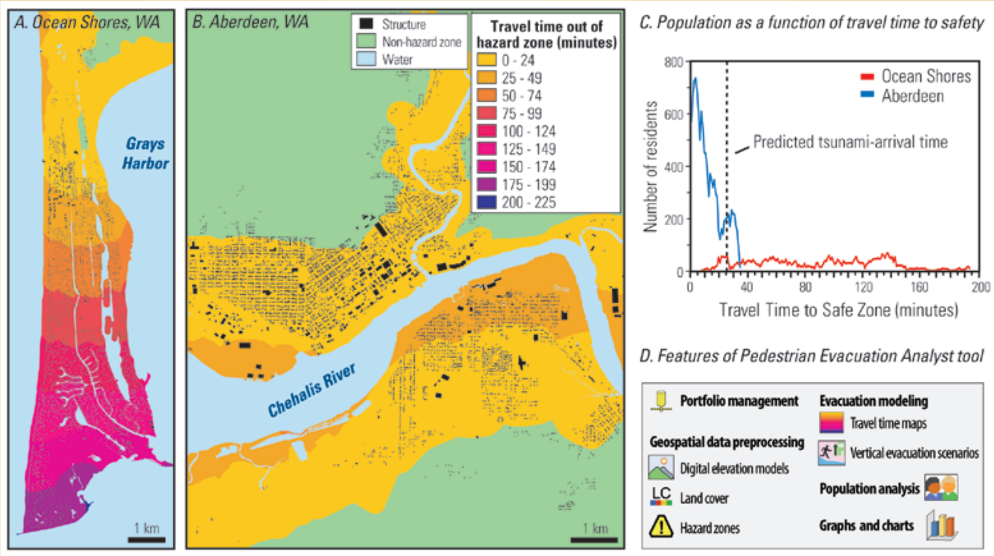


Figure 25. U.S. Geological Survey (USGS) pedestrian-evacuation modeling of future tsunamis including travel time schematics for (*A*) Ocean Shores and (*B*) Aberdeen, Washington (WA), (*C*) graph comparing population exposure as a function of travel time to safety for both communities, and (*D*) features of the USGS Pedestrian Evacuation Analyst tool. Tsunami-hazard zones for the travel time schematics are based on a moment magnitude scale (M_w) 9.0 Cascadia subduction zone earthquake and assume a pedestrian travel speed of 1.1 meters per second.

In the past two decades, tsunamis have killed hundreds of thousands of people and destroyed coastal communities throughout the world. Many U.S. coastal communities are threatened by tsunamis from an array of local and distant sources and include threats that could impact shorelines within minutes of offshore generation. Geographers at the USGS Western Geographic Science Center recognized that there had been little research devoted to determining whether or not at-risk individuals in these communities would have enough time to evacuate before wave arrival. Funding by the USGS Land Change Science Program allows these researchers to develop geospatial modeling techniques for estimating and mapping pedestrian travel times out of tsunami hazard zones (fig. 25). To date, USGS efforts have included efforts in the Pacific Northwest, San Francisco Bay, Alaska, American Samoa, and New Zealand. Modeling of pedestrian travel times takes into consideration not only how far people have to travel in order to be safe, but also the landscape and elevation changes over which they need to travel. Modeling results are integrated with demographic data to estimate the number and type of people in hazard zones as a function of travel times to safety. Recent research also helps emergency managers identify major evacuation corridors, estimate population demand at assembly areas, understand regional trends in community vulnerability, minimize over-evacuations, and compare the benefits of vertical evacuation refuge locations. USGS evacuation-modeling research in the Pacific Northwest contributed to the decision to build a vertical-evacuation structure at a local elementary school in Ocosta, Washington, which could save more than 1,000 students and community members from future tsunamis. A free geospatial tool (Pedestrian Evacuation Analyst) has been developed by the USGS and it is now being used by partners to map tsunami-evacuation travel times in Alaska, Oregon, Puerto Rico, New Zealand, and India, and has been incorporated in a new tsunami module of the FEMA Hazus loss-estimation software.

Recommendation 5.3—Develop life-cycle plans for risk products. *Proposed new risk products should include a well-articulated life-cycle plan that allows for the development and operationalization of the product to be funded in-place and (or) transferred to another USGS group, government agency, or non-government entity that is better equipped to maintain the product to meet user needs. The life-cycle plan should include a realistic cost-benefit analysis to ensure funding or to justify the use of existing funds, and should include architectural solutions to ensure that the final product is flexible. A clearly communicated sunset date, in the absence of long-term funding, is recommended as part of the life-cycle plan.*

One of the key challenges that arises in the development and dissemination of USGS risk products is the transformation from development to operations—in many cases, products are developed and become widely adopted. As more people access digital USGS risk products, more server space and speed are required to meet demands, which can quickly escalate during a hazard event (for example, fig. 26).

All of this can add substantially to the cost of maintaining risk products, something that the groups who developed the products may not be prepared to fund or are capable of funding, especially as they continue the innovative research that made their products popular. This increasing strain on resources often results in delayed maintenance or in some products being discontinued in order to continue development of other products. Business models that proactively plan for the application life cycle are needed for the USGS to be able to continue innovating with new risk-related products. If successful, these models could be used in other USGS communities.

Recommendation 5.4—Assess and document current and pending digital risk products and developers. *Develop and maintain an online catalog of current and pending USGS risk products, including web pages, publications, and applications. Host and maintain this catalog on a central web page that includes points-of-contact and case studies in their use for risk research and applications.*

An assessment of current and pending digital risk products, developed to inform stakeholders and to assist development of future products, would catalog USGS web pages, publications, and applications in risk research and applications. This catalog should be made available on a central web page along with other key risk science information, such as points-of-contact, case studies, and awards. Additionally, a risk product catalog would serve as a starting point for future development, collaboration, and integration efforts within the USGS and with USGS partners. The ScienceBase Catalog may be a useful tool for this documentation.

Recommendation 5.5—Identify opportunities to collaborate with other agencies and outside partners to leverage resources for product development. *Develop partnerships with other Federal, State, and local agencies that will provide cost efficiencies for sharing data and developing products for the benefit of all, including determining demand for new or updated products. Collaboration will require support for time and travel for USGS scientists and staff to participate in working groups or meetings with partners.*

In an increasingly collaborative scientific environment, interagency (and even crowdsourced) data collection is gaining momentum and outside support. Relationships with external partners often are necessary to build collaborative datasets for risk reduction. Iterative approaches to application development must include partner evaluation and input to ensure their usefulness to an intended audience (Perry and others, 2016). Applications are in development and intended for collaborative risk-related data collection. For example, the USGS Short Term Network for high-water mark and storm surge data collection is being used as a post-disaster data collection point by the USGS, FEMA, State partners, and others. Similarly, USGS ShakeMap provides FEMA and State emergency management offices with the necessary shaking input for post-earthquake loss assessments using the FEMA Hazus loss estimation software. Another example is the Washington State Earthquake Scenario Catalog, which was developed using USGS data and technical assistance and then hosted by the Washington State Geological Survey.

Other loss and risk systems and products that have heavily leveraged partner resources in their development include PAGER, which received initial and continued partial support from the USAID/OFDA, and the USGS ShakeCast system, which was initially primarily funded by the California Department of Transportation and subsequently funded by the U.S. Nuclear Regulatory Agency, the U.S. Department of Veterans Affairs, and the International Atomic Energy Agency.

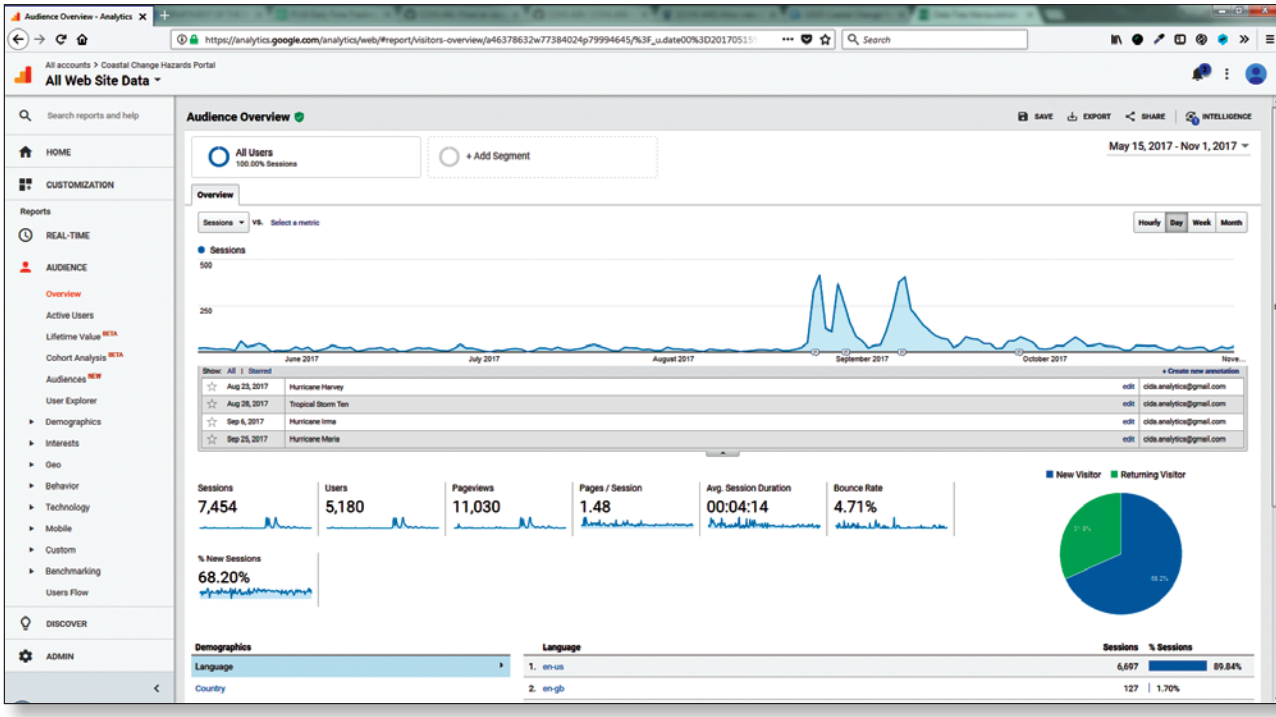


Figure 26. Screen capture of web page analytics for the U.S. Geological Survey (USGS) Coastal Change Hazards Portal showing increased page hits for Hurricanes Harvey, Irma, and Maria in 2017. Image courtesy of M. Hines, USGS.

Recommendation 5.6—For each risk product, include language guiding users to effective use and product limitations, including information on data provenance and uncertainty.

Current digital trends and government policies encourage aggregation of data into novel products (for example, https://www.data.gov or https://data.usgs.gov). A potential consequence from the aggregation process is that data shared through web services and other modes may be stripped of its source information before it reaches its audience. Sometimes ensuring that data are widely used runs counter to ensuring that proper credit and quality attributions for the data are received. Potential confusion can be mitigated by thorough product documentation. Using Digital Object Identifiers for risk data and products and Open Researcher and Contributor ID (ORCID) identifiers for USGS researchers can support documentation, understanding, discoverability, and reuse of USGS risk resources.

Many ocean-front homes on Fire Island, New York, were damaged or destroyed during Hurricane Sandy. The USGS Coastal Change Hazards Portal allows users to overlay the projected track of major storms from the National Weather Service on an interactive map with predictions of the severity of coastal change hazards, such as dune overwash and inundation. Photograph by U.S. Geological Survey.

Case Study—Mitigating Risk Using the U.S. Seismic Design Maps Web Application

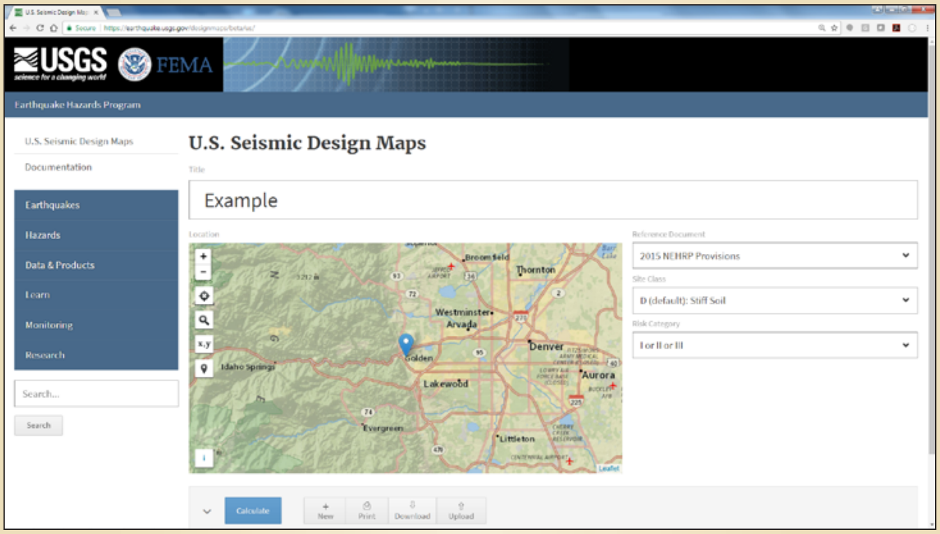


Figure 27. Screen capture showing example page of U.S. Geological Survey U.S. Seismic Design Maps web application, which is used in designing earthquake-safe buildings and other structures throughout most of the United States.

Since the mid-1990s, the USGS National Seismic Hazard Modeling Project (NSHMP) has collaborated closely with building code committees funded by FEMA to develop maps of earthquake ground shaking used in designing trillions of dollars of construction. The maps are printed in building code documents such as the NEHRP (National Earthquake Hazard Reduction Program) Recommended Seismic Provisions for New Buildings and Other Structures (Building Seismic Safety Council, 2015). To enable users to obtain accurate values from the printed maps and to correctly implement them in building code provisions, structural engineers in the NSHMP have worked with USGS software engineers to develop tools. This group developed the U.S. Seismic Design Maps web application shown in figure 27. These tools have facilitated application of hazards science from the NSHMP and USGS-FEMA research on risk mitigation through design of safe structures. However, maintenance of the tools—including replying to inquiries, updating the software, and incorporating new editions of various building code documents—has consumed significant USGS resources, eventually beyond the capacity of the USGS developers assigned to the project. The roughly 1,800 uses per day of the tools have attracted private-sector developers who can monetize similar web applications. This outside interest allows USGS developers to focus on the underlying services that compute the earthquake ground shaking, as well as other hazard and risk research and applications, while industry developers provide graphical user interfaces that facilitate the design of earthquake-safe structures.

Section 6. Measurable Milestones—the Path to Implementation

The Important and Growing Role of USGS

The USGS serves an important role in the characterization and communication of risk from an array of hazards. This role is well-supported by congressional authorizations, program and mission area directives, years of scientific experience, and extensive collaborations with partners and stakeholders at the Federal, State, and local levels. This role would become increasingly vital and would need to grow as hazards continue to disrupt built and natural environment systems and as human populations expand into hazard-prone areas.

Because of the complex socioeconomic context within which USGS risk research and applications may be used, the success of USGS work in this area cannot solely be measured on the basis of whether or not a decision maker ultimately uses USGS risk research and applications to decide to change land use, strengthen building codes, develop new regulations, change insurance premiums, or take other societal actions. Attaching the success of USGS risk research and applications to specific risk reduction efforts by external partners may foster the perception of the USGS becoming an advocate for certain courses of action and thereby reduce our objectivity in helping the Nation understand the threats posed by natural hazards. Instead, the goal of USGS engagement in risk research and applications is to provide decision makers and the public with the best possible science, information, and products to inform their decisions about actual or perceived risks before, during, and after a hazard event.

Plan Recommendations

This Plan presents a suite of recommendations aimed at advancing existing capabilities in risk research and applications and leading future investigations toward risk reduction (table 1). The success of this Plan depends on the implementation of these recommendations.

Some recommendations are intended to be implemented in the short term (for example, in less than 1 year), such as building a community of practice and associated internal web page of USGS scientists and staff engaged in risk research and applications (in accordance with Recommendations 4.1 and 4.2). Building this community and creating a first version of its web page could be accomplished within 1 year.

Other recommendations more realistically would be accomplished over several years. The following are all goals that would take time and buy-in to achieve:

- Developing mechanisms and formal opportunities for USGS scientists to share lessons learned in doing risk research and applications,
- Creating training courses to share best practices, and
- Including language advocating for USGS work in risk research and applications in program plans, science plans, and budget initiatives.

Accomplishing short-term recommendations as quickly as possible would take advantage of the momentum gained by the publication of this Plan. Implementing the collection of Plan recommendations would cement the USGS position in risk research and applications and would ensure that Bureau capacity and capability in risk research and applications grows with demand.

Recommendation 6.1—Develop a Bureau-level request for proposal (RFP) process to enable USGS science centers to contribute to various products recommended in this Plan (for example, databases, guidelines, courses, workshops, detail opportunities, mentoring).

Within the Bureau, no one science center will have all the capabilities and capacity to ensure the success of this Plan. Involvement of science centers across mission areas and regions will help increase communication and collaborations.

Recommendation 6.2—Routinely assess the progress of implementing this Plan.

To ensure that this Plan is implemented and remains topical, the authors of this Plan or some form of an advisory working group should convene annually to assess and report on progress towards implementation.

Table 1. Summary of recommendations.

[**Abbreviations and symbol:** This Plan, this report (Science for a Risky World—A U.S. Geological Survey Plan for Risk Research and Applications); USGS, U.S. Geological Survey; <, less than]

	Recommendation	Recommended timeline for implementation
	Building Institutional Capacity—Advancing and Creating Partnerships	
2.1	**Support and encourage USGS scientists involved in risk research and applications to engage and collaborate with external partners on scientific research, product development, and complementary message delivery**. This engagement requires an investment of salary time and possibly travel that must be supported and funded in order to be successful.	<1 year
2.2	**Establish and support a process to evaluate and improve the dissemination, usability, knowledge uptake, and impact of USGS risk research and applications with key partners, recognizing that partners will vary by hazard and region.** Work with external partners with expertise in program evaluation and adaptive management to help the USGS develop actionable metrics for gauging the societal use and impact of USGS risk research and applications.	1 year
	Building Institutional Capacity—Project Funding	
3.1	**Explicitly identify risk research and applications when setting funding priorities and setting the course for new projects.** Language to fund risk research and application projects should be included in annual mission area guidance, program plans, science plans, budget initiatives, and the annual USGS Budget Justification ("Greenbook").	1–3 years
3.2	**Use existing Bureau-level funding opportunities, communities of practice, and collaboration mechanisms such as venture capital funds, the USGS Innovation Center, the Community for Data Integration (CDI), and the Powell Center to support risk research and applications initiatives. Encourage scientists from across USGS working in risk research and applications to submit proposals and to join or form working groups for research-to-operation transitions, communications approaches, and analytical methods related to risk research and applications.** In turn, collaborate with leaders of these capital fund efforts to identify incentives for soliciting risk research and application-specific proposals.	1 year
3.3	**Capitalize on opportunities to advance the recommendations of this Plan by including risk research and applications in proposals for supplemental funding when available.** Project leads should be encouraged to consult the risk research and applications community of practice (see Recommendation 4.1) at the outset of project planning to identify opportunities and resources.	As opportunities arise
	Building Institutional Capacity—Professional Staff and Capabilities	
4.1	**Create a community of practice for risk research and applications to create a central, Bureau-wide point of contact for risk research and applications and to identify, connect, and coordinate relevant expertise across the Bureau.** The CDI could be used as a model, where elements of the CDI could be emulated for a risk-related community of practice, including holding regular meetings of users, providing funds for supporting working groups, and issuing an annual request for proposals process to award seed funds for projects that focus on innovative risk research and applications.	<1 year

Table 1. Summary of recommendations.—Continued

	Recommendation	Recommended timeline for implementation
	Building Institutional Capacity—Professional Staff and Capabilities—Continued	
4.2	**Develop an internal community of practice for risk research and applications web page or wiki to establish an online "home" for a USGS community of practice on risk research and applications.** Like the CDI web page, this web page would facilitate the exchange of information on projects, in-house expertise, useful resources, and opportunities for collaboration in risk research and applications across the Bureau. This web page should have an external facing component to provide partners with information on the community of practice (for example, contacts, activities, opportunities for collaboration) (see Recommendation 5.1).	<1 year
4.3	**Convene an annual meeting of the USGS risk research and applications community of practice.** This meeting would create a standing opportunity for scientists and staff to meet in person to exchange ideas, to network, and to report on new research and products, and challenges. This meeting potentially could be held in conjunction with another risk research and applications-related event, such as a conference or workshop, to leverage resources.	1 year
4.4	**Address needs for social science expertise by funding experts inside and outside USGS and by identifying Bureau needs for increasing staffing to advance risk research and applications.** Continue to fund and promote opportunities for USGS scientists and staff to consult with internal and external social and hazard scientists. Additionally, Bureau hiring needs should be identified for long-term investments in building professional capacity in this area.	1 year
4.5	**Provide mentoring resources for scientists and staff pursuing risk research and applications.** Encourage early career scientists and staff interested in risk research and applications to enter the USGS Mentoring Program as protégés and to select mentors with experience in risk research and applications. Encourage those with experience in risk research and applications to apply to be mentors.	1–2 years
4.6	**Provide scientists and staff with opportunities for informal and formal training related to risk research and applications.** Develop in-person and (or) online training courses on topics related to risk research and applications and (or) identify opportunities available at other agencies or organizations. Topics could include effective partnering, human-centered design thinking, risk analysis, risk communication, web application development, project management, and others.	2–3 years
4.7	**Share expertise in risk research and applications through short-term personnel assignments.** Identify funding and administrative support for short-term assignments where individuals with risk expertise work with internal USGS projects and (or) partner agencies.	1–2 years
4.8	**Ensure risk research and application experts are selected to serve on internal peer evaluation panels of scientists working in risk research and applications.** The risk research and applications community of practice (from Recommendation 4.1) may be a useful resource for finding research scientists to serve on Research Grade Evaluation (RGE) and Equipment Development Grade Evaluation (EDGE) panels that will be reviewing research scientists and staff making contributions to risk research and applications. A new RGE peer review group focused on societal risk could be an option for risk researchers whose work transcends a single hazard or environmental stressor.	1–2 years

Table 1. Summary of recommendations.—Continued

	Recommendation	Recommended timeline for implementation
	Building Institutional Capacity—Professional Staff and Capabilities—Continued	
4.9	**Recognize excellence in risk research and applications with a USGS Shoemaker Communications Award.** A new award for Best Risk Product, created in the External Communications category, would be judged on how effectively a product addresses the needs of external partners by communicating risk and the significance of the product to external partners in reducing risk.	1 year
4.10	**Develop regularly-scheduled communications and events to broadly share information about USGS activities in risk research and applications both internally and externally.** Create an annual "Hazards Risk Reduction Month" campaign to highlight risk research and applications and why they matter. This campaign would help to identify the people, projects, and partners involved in risk research and applications and the impact of their work in risk reduction.	<1 year
	Building Institutional Capacity—Product Delivery and Expansion of Information Technology Capabilities	
5.1	**Create a web page dedicated to USGS risk research and applications.** This may be housed on the Natural Hazards Mission Area (NHMA) web page, but should link to this Plan and to USGS risk tools and applications across programs and other mission areas.	1 year
5.2	**Develop a Bureau-level capability to host and to maintain operational USGS products in a secure and powerful online environment for digital delivery to computers and mobile devices.** Risk products should be included in this effort.	2–3 years
5.3	**Develop life-cycle plans for risk products.** Proposed new risk products should include a well-articulated life-cycle plan that allows for the development and operationalization of the product to be funded in-place and (or) transferred to another USGS group, government agency, or nongovernment entity that is better equipped to maintain the product to meet user needs. The life-cycle plan should include a realistic cost-benefit analysis to ensure funding or justify the use of existing funds, and should include architectural solutions to ensure that the final product is flexible. A clearly-communicated sunset date, in the absence of long-term funding, is recommended as part of the life-cycle plan.	1 year, as new products are proposed
5.4	**Assess and document current and pending digital risk products and developers.** Develop and maintain an online catalog of current and pending USGS risk products, including web pages, publications, and applications. Host and maintain this catalog on a central web page that includes points-of-contact and case studies in their use for risk research and applications.	1–2 years
5.5	**Identify opportunities to collaborate with other agencies and outside partners to leverage resources for product development.** Develop partnerships with other Federal, State, and local agencies that will provide cost efficiencies for sharing data and developing products for the benefit of all, including determining demand for new or updated products. Collaboration will require support for time and travel for USGS scientists and staff to participate in working groups or meetings with partners.	<1-2 years, as opportunities arise
5.6	**For each risk product, include language guiding users to effective use and product limitations, including information on data provenance and uncertainty.**	1 year
	Measurable Milestones—The Path to Implementation	
6.1	**Develop a Bureau-level request for proposal (RFP) process to enable USGS science centers to contribute to various products recommended in this Plan (for example, databases, guidelines, courses, workshops, detail opportunities, mentoring).**	1 year
6.2	**Routinely assess the progress of implementing this Plan.**	Annually

Section 7. Potential Projects for Advancing Risk Research and Applications

Developing new projects centered on risk would provide an opportunity to implement the recommendations of this Plan. Following are several envisioned projects that would build on existing USGS expertise while advancing specific elements identified in this Plan and meeting stakeholder needs. This list is not ranked, nor is it intended to be prescriptive—instead, it is meant to provide inspiration for some new projects as well as some long-standing visions held by the USGS and its colleagues for supporting the Nation with science-based decisions regarding risk in the future.

Hazards in My Backyard

Stakeholders ranging from State and local decision makers to urban planners are becoming increasingly interested in obtaining regional-to-neighborhood-scale information on hazards to better tailor mitigation projects and to better tailor individual/household preparedness recommendations. This presents an opportunity for the USGS to develop an interactive map to enable users to examine and understand hazards "in their backyard." Hazards information would be geocoded such that anyone can input an address to see all the hazards that could affect them. This hazards information could be visualized using enhanced-reality applications or visualizations to show the potential real-world impacts of these events. One of the challenges of this project is overcoming differences in scale, coverage, units, and availability of data to accomplish this level of scalability. This project would require significant collaboration with Federal, State, and local agencies to overcome these challenges, and may require the acquisition of new data to close the gaps.

Landslide Risk Assessment for the Nation's Transportation Infrastructure

In cooperation with the U.S. Department of Transportation (DOT), State departments of transportation, State geological surveys, USGS 3-D Elevation Program (3DEP), National Cooperative Geologic Mapping Program, and Landslide Hazards Program, this project would develop a risk assessment for landslide impacts along the major transportation routes across the United States to support improvements to the Nation's aging infrastructure. Such an assessment would require new high-resolution topographic, geologic, and geophysical information, which combined with State department of transportation information on traffic volume and value, would be used to develop a consistent and comparable landslide risk assessment. The development of these products should include State and local agencies to determine implications for liability with the release of a new, comprehensive assessment. Results would be used to identify the highest-priority route sections for structural mitigation, near-real-time monitoring, and repeat topographic survey.

Multi-Hazard PAGER-Type Alerts

PAGER has been a widely used tool for rapidly estimating the fatalities and economic losses of seismic events and determining the level of needed response. The development of a PAGER-equivalent for other hazards (for example, contaminant spills, volcanic eruptions, severe coastal inundation, post-wildfire debris flows and (or) multi-hazards and cascading consequences) would benefit a similar group of users by communicating risk (including social, economic, health, environmental impacts), and would be delivered in near real-time. Results could be used to inform and communicate evacuation plans, water and recreation use limitations, changes to accessible roadways and transportation corridors, and anticipated property damage or loss in affected areas. Such a tool would be modeled on PAGER but would be focused on domestic events, ideally using a similar "stoplight" color pattern for alert levels to inform response. Like the Hazards in My Backyard project, this effort would require significant collaboration with Federal, State, and local agencies to overcome challenges in collecting available data and may require the acquisition of new data to close the gaps.

Risk Assessments in Public Lands

Hundreds of millions of visitors frequent U.S. national parks, Bureau of Land Management lands, U.S. Fish and Wildlife National Refuges, and other public lands every year, generating revenues to nearby communities and supporting jobs in the DOI and local communities. More than 4 million people live and work on Tribal lands in the United States. Bureau of Reclamation lands are home to billions of dollars' worth of critical infrastructure upon which millions of Americans depend. Thousands of cultural sites, artifacts, national icons, and important areas for ecosystem services and economic production also are located on public lands. Public safety and the preservation of valuable national treasures could be improved through the evaluation and understanding of hazards and associated risks posed to assets in these areas and the use of tools to help mitigate those risks. Using quantified relative risks to human populations and to cultural, economic, and environmental resources, the USGS would: train local land and emergency managers in the use of USGS-developed evacuation modeling; develop GIS maps and decision tools depicting areas of high risk to human health and safety, as well as to various environmentally and societally important resources; monitor and prioritize relative risks from different types of exposures; and, collaborate with outreach programs on public lands to use citizen science to engage visitors, employees, and residents to report observed hazards. Challenges with this project include the availability of some hazards and asset data at a nationwide scale, as well as the interoperability of these data. Probabilistic risk products may not be possible for all hazards given the high level of uncertainty inherent in the occurrence of some hazards.

National Hazard Exposure Assessment

This project would entail the development of a national exposure assessment available at the community level to all hazards of USGS interest and their likely cascading consequences (for example, earthquakes, volcanoes, tsunamis, landslides, flooding, coastal change, invasive species, and contaminants). The assessment would be based on geospatial data characterizing hazards and their intersection with populations, hydrology, habitats, land cover, infrastructure, and critical facilities. Geospatial analysis could be used to quantify community-level exposure, statistical cluster analysis could be used to develop "sister cities" of common vulnerability issues, and visualizations using a web-based platform would be used to allow users to compare and contrast communities of interest or focus on specific hazards. The assessment could be updated on a consistent timescale and could be scalable at community, county, congressional-district, and national levels. Because the national assessments would show relevance to everyday lives and livelihoods, the work would raise public awareness of USGS hazards science. The HERA platform (U.S. Geological Survey, 2017h) could be expanded to handle such a national assessment.

Conclusion

This Plan presents a set of recommendations for enhancing U.S. Geological Survey (USGS) development and delivery of actionable information to improve risk reduction. By introducing a Bureau-wide focus on risk research and applications, the USGS is well-positioned to meet the challenge of reducing risk in the face of increasing disaster-related losses combined with rapid environmental change, shifts in urbanization, and evolving resource management needs. This Plan describes specific actions that the USGS may take to advance partnerships, to adjust project planning, to develop internal professional capacity and capabilities, and to improve product delivery. These activities are underpinned by fundamental needs, including bolstered information technology capacity, adding expertise to the USGS and access to expertise outside the USGS, and developing new opportunities for fostering a community of practice focused on risk research and applications. The process of implementing the recommendations of this Plan can be incorporated in new projects. This Plan presents several projects that would build on existing USGS expertise while advancing specific elements identified in this Plan and meeting long-standing stakeholder needs.

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Glossary

Key terms in risk reduction have a range of definitions and consensus on each term is difficult given the spectrum of disciplines and practitioners using them. This section provides working definitions for terms used in this report taken from the literature (for example, Dow, 1992; Cutter, 1996; Hewitt, 1997; Weichselgartner, 2001; Turner and others, 2003; Holmes and others, 2013; Intergovernmental Panel on Climate Change, 2014).

Adaptive capacity The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to imminent threats.

Community of Practice A group of people who share a passion, expertise, or goal for something they do and learn how to do it better as they interact and share information regularly. This definition is modified from Wenger (1998). According to Lave (2014), "communities develop their practice through a variety of methods, including: problem solving, requests for information, seeking the experiences of others, reusing assets, coordination and synergy, discussing developments, visiting other members, mapping knowledge and identifying gaps."

Exposure The presence of people, livelihoods, species or ecosystems, environmental functions, services, infrastructure, or other assets (for example, economic, social, or cultural resources) in places that could be adversely affected. Exposure is related to hazard proximity and the environmental characteristics of the hazard, such as speed of onset, duration, and pre-onset cues.

Hazard A dangerous process, phenomenon, substance, activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. Acute or sudden-onset hazards are those events that occur on timescales of minutes to days (for example, earthquake, flood, tsunami, wildfire, hurricane), whereas chronic hazards occur on longer timescales (for example, seasonal coastal erosion, drought, sea level rise).

Loss Death, injury, and health impacts to human populations; damage to or destruction of homes, businesses, livestock, critical infrastructure, and other property; disruption or cessation of livelihoods, cultural or social structures, activities, and customs, economic exchange, and critical services; and environmental degradation.

Mitigation Action, including education, that eliminates or reduces the potential effects of a hazard.

Resilience The ability to prepare for and adapt to changing conditions and to withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents.

Risk The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk sometimes is represented quantitatively as probability of occurrence of hazardous events multiplied by the impacts if these events occur. Risk results from the interaction of hazards and a vulnerable asset or system. Risk can be further broken down into various sub-categories, including the following three entries.

Risk assessment The qualitative and (or) quantitative scientific estimation of risks.

Risk management Plans, actions, or policies to reduce the likelihood and (or) consequences of risks or to respond to consequences.

Risk perception The subjective judgment that people make about the characteristics and severity of a risk.

Sensitivity The personal or situational conditions that influence the degree to which an individual, group, system, or species may be affected by a hazard. For example, demography and socioeconomic status have been found to influence the sensitivity of an individual to hazards, whereas construction type and practices influence the sensitivity of buildings to certain hazards (for example, earthquakes and floods).

Vulnerability The combination of physical, social, cultural, economic, historical, and political components that influence the degree to which an individual, community, or system is susceptible to damaging effects of a hazard. Although definitions and applications of the term, vulnerability, vary, common elements within the hazards literature include concepts of exposure, sensitivity, and adaptive capacity.

Appendix 1. Executive Summary from the 2015 "Translating USGS Science to Risk Products" Workshop

During November 3–4, 2015, the "Translating USGS Science to Risk Products Workshop" convened 38 scientists from across several USGS mission areas and science centers to advance the element of "risk translation" in the Hazards Science Strategy (Holmes and others, 2013). This element aims to ensure that hazards information gets the broadest and most effective use by communities at risk. The workshop aimed to identify priorities for translating USGS science to risk products and to develop a draft framework for an implementation plan.

Over the course of 2 days, participants explored definitions; analyzed case studies; identified strengths, weaknesses, opportunities, and threats; and brainstormed ways to develop capacity for risk translation. Discussions showed that risk translation has different interpretations and is more than risk communication. It can involve a broad spectrum of activities, including risk analysis research, stakeholder engagement, product evaluation, and collaboration across traditional disciplinary, institutional, and jurisdictional boundaries. Successful outcomes can advance risk reduction, increase stakeholder engagement and expectations, and lead to additional support for underpinning research and monitoring networks.

Analyzing case studies proved to be a valuable way to learn from one another about the process of translating science to risk products. Despite seemingly diverse situations, examples from different centers and hazards revealed commonalities and values, including strong partnerships, local connections, agile development, and unanticipated spinoff projects. In some cases, changes in technology revolutionized product development; in others, products were spurred by specific hazard events. Some centers and programs have had more experience than others in the area of risk translation; documenting best practices, sharing resources, and finding more regular means to interact across centers and hazards would enable future growth and innovation.

To address future needs and opportunities, the following are included in a list of priorities: clarifying the USGS role in risk relative to other federal agencies, forging stronger ties to the social science community, and elevating the importance of risk translation internally. Exploring the role of technology and visualization as well as establishing a better understanding of USGS product audiences hold promise for future work. Institutional barriers, such as contracting external expertise, ensuring research scientists are rewarded for work in risk translation, and keeping up with stakeholder expectations, are challenges that should be addressed in the implementation plan.

Participants agreed that USGS accomplishments in risk translation should be shared and celebrated; these stories can provide useful examples for others to use while messaging the importance and value of this work within and outside the Bureau. Creating mechanisms to enable USGS scientists and stakeholders to cross institutional and disciplinary boundaries would support future efforts in developing risk assessments. Participants identified a need for an institutional structure that addresses issues such as funding, workforce planning, and contracting related to risk translation. Organization options may include a central "matchmaker," hub, or a decentralized-but-connected network of risk translation specialists to coordinate resources. Additionally, fellowships or detail opportunities would facilitate cross-fertilization and new connections. Pilot activities that convene experts and stakeholders from multiple areas may be a useful way to highlight flagship products and break down silos of expertise.

At the end of the workshop, participants generated a list of implementation plan key elements and next steps. These ideas, combined with results from the workshop discussions documented in this report, will be the foundation for the implementation plan. The critical next step will be for these ideas to be incorporated in an actionable plan that serves the goal of infusing risk translation in USGS culture to advance its natural hazards mission.

Appendix 2. Risk Science in USGS Science Strategies and Planning Documents

Many USGS science strategies and planning documents have identified different components of risk research and applications as a critical component of USGS work and professional outputs, as exemplified by the following strategy documents:

- **The U.S. Geological Survey Climate and Land Use Change Science Strategy—A Framework for Understanding and Responding to Global Change (Burkett and others, 2013).** The authors note that the USGS plays an important role in helping partners and stakeholders understand the consequences of a changing climate. The science strategy proposes various products to "help society anticipate and adapt to global change" (p. 3). These products include predictive models (for example, models of coastal retreat), decision-support products (for example, water planning and management under land-use, water-use, and climate change), validated maps (for example, rates of regional, national, and global land-use and land-cover change), regional and national scenarios (for example, sea level rise scenarios for U.S. coastlines), summarized data (for example, observed and projected climate change and land-use impacts on water supply quantities), and the "translation of research results for application in a management context" (p. 7).

- **The U.S. Geological Survey Core Science Systems Strategy—Characterizing, Synthesizing, and Understanding the Critical Zone through a Modular Science Framework (Bristol and others, 2013).** This strategy emphasizes the use of USGS data to help partners manage and assess hazards. For example, "New techniques of merging hydrologic information with Hazus social and economic data from Federal Emergency Management Agency (FEMA) allows for unique scenarios of impacts based upon each incremental reading of the USGS streamgage—allowing emergency managers to know what the potential impacts could be before the first raindrop falls" (p. 26). The science strategy also suggests developing research and methods for a "comprehensive virtual observatory containing relevant observations of physical and biological phenomena important to USGS research, including plant and animal species occurrence and human structures of importance to hazards characterization and risk assessment" (p. 30). The strategy highlights how USGS science can identify and potentially map risk, using Valley Fever as an example.

- **The U.S. Geological Survey Ecosystems Science Strategy—Advancing Discovery and Application through Collaboration (Williams and others, 2013).** The authors note how USGS science can be used in risk assessment. For example, the USGS assesses habitats that may be at risk of invasion by exotic species such as Asian carp, and develops information on control strategies to share with partners (p. 13). Furthermore, stressing the importance of modelling and forecasting in the risk space, the science strategy states, "Observations and research, together with models and forecasts, help scientists and managers understand environmental variability, explain vulnerabilities and risk, and evaluate management options" (p. 29). Actions proposed in this report also highlight USGS science in providing information on risk. For example, the report highlights the capacity of the USGS to provide information on vegetation and fuels across a landscape, thereby forming a better understanding of wildfire risk to people and property (p. 33). Another proposed action focuses on developing new tools and methods to manage "at-risk" species using environmental toxicology, epidemiology, genetic, and genomic techniques.

- **The U.S. Geological Survey Energy and Minerals Science Strategy—A Resource Lifecycle Approach (Ferrero and others, 2013).** The authors cite the National Resource Council (2007), remarking that a "comprehensive understanding of the interactions among energy and mineral resources and environmental and biological receptors can help... citizens to be informed about risks and benefits associated with resource extraction" (p. 15). The science strategy notes that creating geologically based environmental models can assist in identifying the potential environmental risks and data gaps of conventional and emerging critical energy and mineral commodities. The strategy also stresses the importance of USGS understanding of the availability of energy and mineral materials at global and national scales to "inform decisions about risks associated with import dependence and possible actions to mitigate supply risk (p. 28; National Research Council, 2012).

- **The U.S. Geological Survey Environmental Health Science Strategy—Providing Environmental Health Science for a Changing World (Bright and others, 2013).** The authors state that although it does not have a directly mandated public health mission, the USGS Environmental Health Mission does contribute directly to the work of partner agencies that are responsible for human and domesticated animal health. The science strategy describes their science as “useful for defining human exposure to zoonotic and vector-borne diseases, parasites, harmful earth materials, synthetic chemicals and substances, and biogenic contaminants” (p. 10) and provides the products of their research to decision makers at all levels of government (p. 11). The science strategy does not highlight as many “risk products” as some of the other strategies reviewed here, but emphasizes the importance of developing baseline data, and characterizing the aspects of different environmental health hazards (for example, characterization of transmission pathways) as informing decision making on these topics. The strategy emphasizes the importance of “[p]romptly gather[ing] and releas[ing] preliminary data and interpretations to emergency responders, disaster planners, and other decision makers in a timely and useful context” (p. 32). The science strategy identifies the following as important means to communicate, manage for, and mitigate risks associated with environmental health: development and implementation of real-time monitoring and surveillance techniques that can use early-warning of rapid-onset threats (for example, threats to drinking water biosecurity; p. 18); risk analysis and statistical/epidemiological techniques to target surveillance systems/mitigation activities to geographic areas and populations with the highest likelihood of disease emergence; development of models and approaches to forecast emerging environmental health threats (for example, infectious disease), contaminant occurrence and distribution, and identification of vulnerable settings, ecosystems, and species; development of messaging about health threats in consultation with risk communication specialists; and, use of social media and local media to deliver time-sensitive, or high-visibility findings (p. 35).

- **The U.S. Geological Survey Water Science Strategy—Observing, Understanding, Predicting, and Delivering Water Science to the Nation (Evenson and others, 2013).** The authors note that the USGS Water Mission Area plays a critical role in helping stakeholders understand and act upon information pertaining to water-related hazards. The science strategy identifies the following as important means to communicate, manage for, and mitigate risks associated with these hazards: software and computer programs developed to assist in predictions of flood inundation, hydrology, and water chemistry; validated maps (for example, flood-inundation mapping); geospatial products developed to identify potential hydrological hazards to a community; web-based tools (for example, WaterWatch and StreamSTATS); alert/warning systems (for example, WaterAlert); observation systems for detecting and tracking conditions leading to both water-related emergencies and long-term hazards such as droughts; and USGS rapid deployment teams that interface with local responders. The strategy also emphasizes the importance of basic data products that can be used in emergency management or planning efforts such as analyzing vulnerabilities in water supply systems, ensuring that streamgage data meet flood forecasting and warning requirements (NOAA and State), and producing information and analyses that help communities understand their exposure to extreme hydrologic events (for example, debris flows, coastal erosion, drought, and flooding). The strategy recommends using communication methods such as social media and local news networks to inform citizens during water-hazard events. The science strategy stresses the importance of producing information and tools that are “usable for planning, response, recovery, and mitigation in regards to hydrologic hazards” (p. 34).

- **The Geography for a Changing World – A Science Strategy for the Geographic Research of the U.S. Geological Survey, 2005–2015 (McMahon and others, 2005).** The authors emphasize the importance of the risk science space. The circular recognizes that discipline-specific research that, for example, assesses flood frequency or volcanic activity is “often not blended to develop an integrated perspective on important societal concerns” (p. 7). Thus, the circular stresses, it should be a fundamental goal of land-change science to help the public, resource managers, and decision makers understand the social and economic consequences of land change at multiple spatial and temporal scales (p. 15–16). Two of the nine goals in the circular specifically touch on risk research and applications. Strategic Action 3.3 suggests that USGS scientists should “conduct research leading to improved capabilities to assess wildfire conditions, predict wildfire potential, prioritize treatment areas, and monitor effectiveness of fire treatments to support risk reduction efforts in the urban-natural landscape interface" (p. 16). Goal 4 suggests that USGS seek to "improve the scientific basis for vulnerability and risk assessment, mitigation, response, and recovery related to the human and environmental dynamics of land change" (p. 18). In this part of the circular, the authors note that, although USGS has a long and distinguished history in hazard assessment research, it has conducted far less research "to describe and understand the potential for loss or damage" in terms of vulnerability—exposure to hazards combined with the sensitivity/resilience of the human-environment system (p. 18–19). The circular emphasizes that the success of "vulnerability and resilience science" is dependent on linking science and decision making (p. 19) and calls for a national set of vulnerability assessment tools for researchers and practitioners (p. 20). This vulnerability research would incorporate new methods for communicating uncertainty in communications about hazards to decision makers and the public. The circular envisions that such research would consider exposure, sensitivity, and adaptive capacity to hazards at multiple scales to help protect public safety, societal assets, and environmental resources. The circular also suggests the development of a national monitoring program to identify at-risk areas to prioritize additional USGS hazard and vulnerability assessment research and the risk reduction efforts of local and national partners. The report also suggests the development and application of methods to assess the efficacy of proposed scenarios for hazard mitigation strategies and risk assessment. Additionally, the circular directs USGS scientists to "focus on techniques for distinguishing high-probability/low-consequence events from low-probability/high-consequence events for public policy decision making (Cutter and others, 2003)" (p. 21). The development of a "national toolbox of metrics, indicators, models, and decision-support systems that characterizes the environmental, social, and economic consequences of land change" also is suggested (p. 24).

- **Grand challenges for integrated USGS science—A workshop report (Jenni and others, 2017).** The authors of this workshop report identified "social risk from existing and emerging threats" as one of four overarching "grand challenges" for integrated USGS science. The authors summarize the vision for this grand challenge as, "the USGS will prepare the Nation to cope with and reduce the risks of existing and emerging threats associated with the Earth system. We will provide directly relevant integrated science that management entities can use in planning and response. This science will leverage existing technologies, data, and models; new science and technology; and community participation and co-creation of knowledge." (p. 8). The authors explore obstacles that need to be overcome to pursue this challenge, including insufficient social science and information science expertise and the need for updated product delivery mechanisms. The report includes specific ideas for projects to implement this grand challenge at a bureau-wide scale.

Appendix 3. Examples of USGS Efforts in Risk Research and Applications

Table 3-1 shows a wide range of efforts and should not be considered an exhaustive inventory. Some of these products are applicable to multiple efforts in risk research and applications. We recommend the development and maintenance of such an online inventory of U.S. Geological Survey (USGS) efforts to further USGS risk research and applications by leveraging best practices, identifying new opportunities and applications, and connecting USGS researchers and external partners.

Table 3-1. Examples of USGS Work in Risk Research and Applications.

Risk research and applications type	Example products
Hazard Assessments: Unconditional (*that is, independent of any single scenario or observation*)	The Coastal Change Hazards Portal provides assessments of long- and short-term rates and probabilities of shoreline change due to the effects of long-term sea level rise.
	Volcano hazard assessments summarize the types and likelihood of future hazardous phenomena expected to occur at a specific volcano or volcanic region.
	The National Seismic Hazard Modeling Project develops short- and long-term forecasts of potentially damaging earthquake ground shaking.
Hazard Assessments: Conditional (*that is, takes into account current observations, forecasts, or scenario assumptions*)	Debris-flow hazard assessments related to the aftermath of recent fires.
	Flood-inundation maps are based on a selected stream condition or historical information.
	The Flood Event Viewer shows streamgage levels and flood zones during flooding events.
	Earthquake hazard scenarios based on a particular magnitude, location, and fault-rupture geometries.
	The Sediment-bound Contaminant Resiliency and Response (SCoRR) strategy defines baseline and post-event sediment-bound environmental health stressors resulting from sea level rise and storm-derived disturbances.
Forecasts and warnings	Alert notification for volcano activity.
	Earthquake early warning.
	ShakeCast automates the delivery of ShakeMap estimated shaking levels at user-specific facilities.
	WaterAlert provides streamflow and flood-stage messages when certain parameters exceed user-definable thresholds.
	SPARROW (SPAtially Referenced Regressions On Watershed attributes) is a tool for the regional interpretation of water-quality monitoring data, including contaminant sources and factors influencing terrestrial and aquatic transport.
	Hydrodynamic and sediment modeling supported response efforts related to the Deepwater Horizon Oil Spill.
Vulnerability assessments	Community clusters of vulnerability to tsunami hazards associated with Cascadia subduction zone earthquakes based on population exposure, demography, and evacuation potential.
	The Hazard Exposure Reporting and Analytics (HERA) application provides community-level estimates of coastal- hazard exposure based on sea level and storm scenarios.
	Earthquake shaking hazard estimates and population-exposure changes in the conterminous United States
	Community-level exposure reports for tsunami, volcano, and coastal-hazard scenarios

Table 3-1. Examples of USGS Work in Risk Research and Applications.—Continued

Risk research and applications type	Example products
Risk assessments	Science Application for Risk Reduction (SAFRR) reports summarize a wide range of societal impacts related to plausible earthquake, atmospheric storm, and tsunami scenarios.
	Building-related earthquake loss estimates, as determined by estimated annualized earthquake losses for the United States
	The Seismic Risk Web Application calculates the risk of earthquake damage to one or many structures based on fragility curves.
	A probabilistic assessment of rockfall runout and consequent casualties in Yosemite Valley.
Risk communication	Guidelines for developing successful science products for risk communication, based on the social science literature.
	Laymen flood poster to explain 100-year flood concepts.
	Overview of risk reduction alternatives for volcanic lahar hazards.
Decision support systems	U.S. Seismic Design maps allow users to retrieve seismic design parameter values for the design of buildings and bridges at sites in the U.S. and its Territories.
	Pedestrian Evacuation Analyst is a geographic information system (GIS) tool that provides users with the ability to model pedestrian evacuation potential out of hazard zones, as well as test the impact of vertical-evacuation alternatives.
Post-event assessments	The Prompt Assessment of Global Earthquakes for Response (PAGER) system provides users with a quick assessment of earthquake intensity and population exposure.
	Fault afterslip forecast for use by residents impacted by fault rupture from the 2014 South Napa earthquake.

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