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National Strategy for Landslide Loss Reduction

Open-File Report 2022–1075

U.S. Department of the Interior
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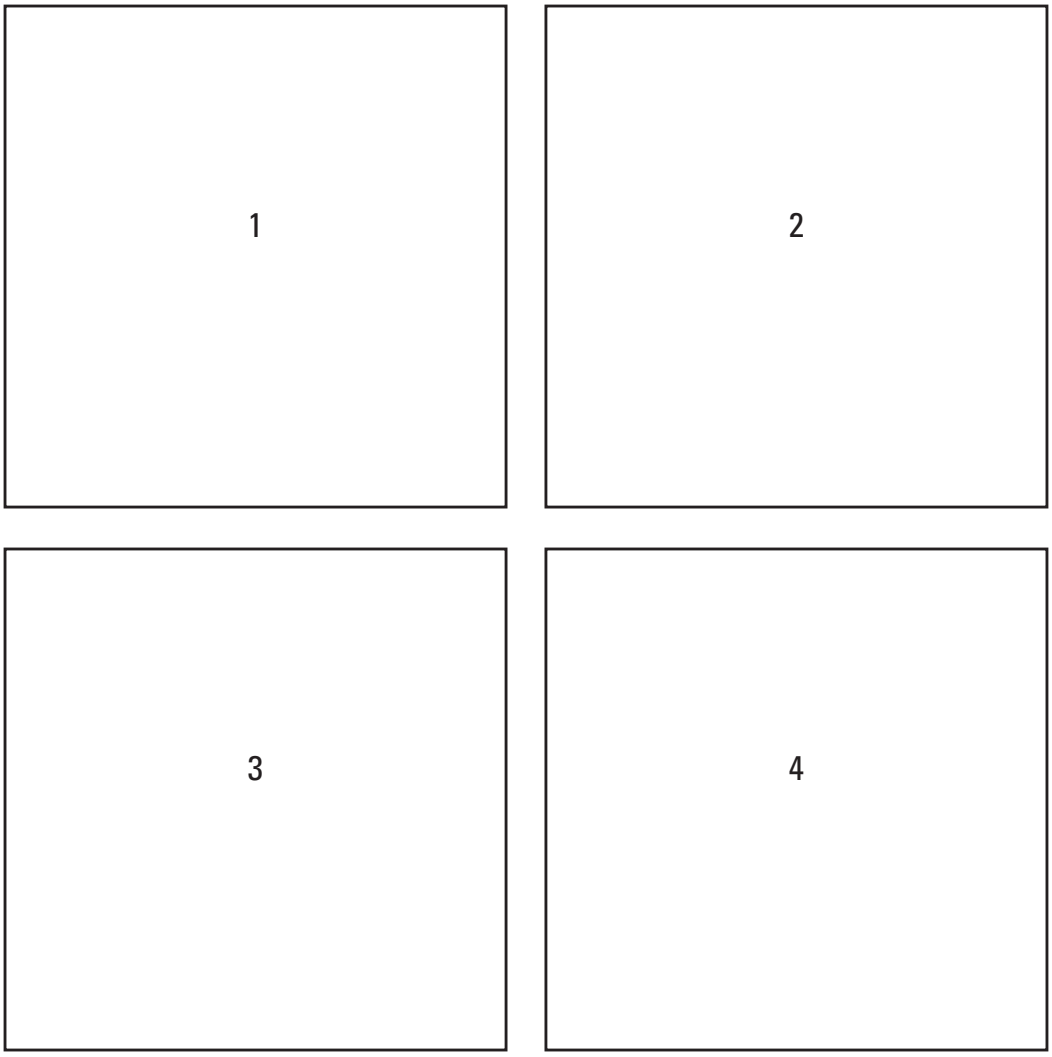

Cover. Compilation of photographs related to landslides, including (1) landslide damage after Hurricane Maria in the Utuado municipality, Puerto Rico; (2) a 2005 debris flow in La Concita, California; (3) a 2021 debris flow that damaged Highway 1 near Big Sur, California, and (4) a landslide surveillance site near San Rafael, California. Photograph 1 by Erin Bessette-Kirton, U.S. Geological Survey (USGS); photograph 2 by Mark Reid, USGS; photographs 3 and 4 by the USGS.

National Strategy for Landslide Loss Reduction

By Jonathan W. Godt, Nathan J. Wood, Alice B. Pennaz, Connor M. Dacey, Benjamin B. Mirus, Lauren N. Schaefer, and Stephen L. Slaughter

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Preface

This strategy document fulfills the requirements of the National Landslide Preparedness Act (Public Law 116–323) for the publication of a national strategy for landslide hazards, risk reduction, and response. The document was prepared in coordination with a Federal interagency working group and incorporates input and feedback from a 3-day workshop held virtually on June 22–24, 2021.

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
centimeter (cm)	0.3937	inch (in.)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)

Abbreviations

3DEP	3D Elevation Program
BAER	Burned Area Emergency Response
DOI	U.S. Department of the Interior
FAIR	findable, accessible, interoperable, and reusable
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
ICCLH	interagency coordinating committee on landslide hazards
ICS	Incident Command System
IMT	Incident Management Team
InSAR	interferometric synthetic aperture radar

IROC	Interagency Resource Ordering Capability
NASA	National Aeronautics and Space Administration
NIMS	National Incident Management System
NLHRR	national landslide hazard risk reduction
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NSF	National Science Foundation
NWS	National Weather Service
Risk MAP	Risk Mapping, Assessment and Planning
SAR	synthetic aperture radar
SLE	significant landslide events
THIRA	Threat and Hazard Identification and Risk Assessment
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

National Strategy for Landslide Loss Reduction

By Jonathan W. Godt, Nathan J. Wood, Alice B. Pennaz, Connor M. Dacey, Benjamin B. Mirus, Lauren N. Schaefer, and Stephen L. Slaughter

Executive Summary

Landslide hazards are present in all 50 States and most U.S. territories, and they affect lives, property, infrastructure, and the environment. Landslides are the downslope movement of earth materials under the force of gravity. They can occur without any obvious trigger. Widespread or severe landslide events are often driven by such hazards as hurricanes, earthquakes, volcanic eruptions, heavy rain events, flooding, and wildfires. Landslides can also cause their own cascading consequences, such as the spread of hazardous materials or the creation of devastating local tsunamis.

This strategy document describes goals and strategic actions of a comprehensive strategy to meet key challenges to reducing the Nation's risk from landslide hazards equitably and effectively. The document follows the direction of the National Landslide Preparedness Act (Public Law 116–323) by presenting a strategy for addressing landslide hazards, including risk reduction and response. The act directs the Department of the Interior to establish a program that will work with State, Tribal, and local governments as well as with academia, the private sector, community-based groups, and nonprofit organizations to identify landslide hazards and risk and improve communication, coordination, and emergency preparedness, with the objective of reducing landslide losses. As the only Federal program dedicated to landslide hazard science, the U.S. Geological Survey's Landslide Hazards Program will lead and coordinate many of the efforts described in this strategy document. Landslide hazard risk reduction must be undertaken collectively and collaboratively across the Federal Government. This strategy document will provide a framework for the creation of an interagency management plan that describes the programs, projects, workforce, and budgets required to carry out the national strategy.

The strategy outlined in this document presents a vision of how to equitably produce, communicate, and apply landslide data and science to support a broad range of land management, infrastructure, planning, and emergency response decisions. These decisions are made by a variety of actors, including private and nonprofit landholders; State, Tribal, territorial, city, and county planners; emergency managers; engineers; infrastructure managers; Federal agencies and their partners; and community leaders and individuals. Supporting those decisions and reducing the Nation's vulnerability to landslides requires overcoming three main challenges: (1) gaps in basic information needed to describe and understand landslide occurrence and societal risk, (2) difficulty in accurately mapping and forecasting landslide hazards, and (3) communication and coordination among the many jurisdictions and sectors that have responsibility for and interest in reducing landslide losses. To address those challenges, this strategy document puts forward a series of strategic actions to achieve four goals:

Assess: Decision makers have access to detailed, nationwide, and contextually relevant information on landslide hazard and risk.

Coordinate: Landslide hazard mitigation, preparedness, response, and recovery efforts are coordinated across Federal, State, Tribal, territorial, and local levels.

Plan: Communities and land managers are prepared and able to plan for landslide hazards.

Respond: Landslide surveillance, warnings, and responses to events are effective, efficient, equitable, cooperative, and data-driven to protect lives, property, infrastructure, and the environment.

Table ES1 describes the set of strategic actions needed to achieve these four goals. They focus on expanding the knowledge of societal risk posed by landslides as well as better understanding of where, when, and why they occur. These strategic actions focus on applying that knowledge to support landslide risk reduction efforts and decisions, including the establishment of new advisory, coordination, and working groups focused on landslide hazard and risk. They take into account that supporting landslide loss reduction decisions also requires new guidance, tools, and training codeveloped with the entities, organizations, and individuals faced with making those decisions. Finally, they address actions needed to support and expand landslide warning information and improve the technical response to landslide emergencies.

The response, science, technology, outreach, and coordination efforts outlined in this strategy document will help the Nation become better prepared for, and more resilient to, landslide hazards. It is important to remember that although future landslide events are inevitable, future landslide disasters are not.

Table ES1. Strategic actions needed to achieve the four goals of a national strategy to reduce the Nation's risk from landslide hazards.

Goals and Strategic Actions	
	Assess
1.1	Characterize the societal risks posed by landslide hazards
1.2	Expand research and development to assess the where, when, and why of landslide hazards
1.3	Develop a publicly accessible national landslide hazard and risk database
1.4	Provide publicly available reports of significant landslide events
	Coordinate
2.1	Establish an interagency coordinating committee on landslide hazards
2.2	Establish a formal Federal advisory committee on landslide hazards
2.3	Develop and maintain cooperative landslide hazards and risk grants
2.4	Establish and support a national landslide hazard risk reduction working group
	Plan
3.1	Provide guidance, tools, and training to include landslide information in hazard planning
3.2	Develop landslide outreach initiatives to improve public knowledge and preparedness planning
	Respond
4.1	Support existing warning systems to include landslides
4.2	Improve response actions by having technical experts on site

Introduction

What Are Landslides and Why Should We Care About Them?

Landslides occur in all 50 States and most territories in the United States, and they affect lives, property, infrastructure, and the environment (for example, Jibson and others, 2004; Bessette-Kirton and others, 2019; Mirus and others, 2020). Landslides are the downslope movement of earth materials (rock, debris, and soil) at rates that range from inches per year to tens of miles per hour (Varnes, 1978; Cruden and Varnes, 1996) (Highlight 1). They can happen with no notice or can take place over a period of days, weeks, or longer. Landslides can occur as the result of local topographic, geologic, or anthropogenic conditions, or they can be created by hazard events, such as hurricanes, earthquakes, volcanoes, heavy rainfall, and wildfires. They can also have cascading consequences; for example, landslides can form natural dams that block stream channels that can fail rapidly, causing downstream flooding (Costa and Schuster, 1988). Landslides can pick up or bury homes, destroy critical infrastructure, shut down transportation corridors, and disrupt vital utilities and communication lines (for example, Jibson, 1992; Lancaster and others, 2021). The frequency and size of landslides are expected to increase in certain areas owing to rising temperatures, increasingly intense rainfall, and more frequent and severe wildfires as a result of climate change (for example, Gariano and Guzzetti, 2016; Coe, 2020; Kean and Staley, 2021).

In the United States, exact loss estimates for landslides are largely unknown; however, landslides are estimated to cause billions of dollars in damage and multiple deaths each year (Schuster, 1996). Reducing these losses requires new information and better understanding to inform strategies for improving preparedness and mitigation, and for increasing the Nation's capacity to respond to and recover effectively from landslides when they affect communities. Addressing landslide hazards requires collaboration and coordination across Federal agencies; State, Tribal, territorial, and local governments; academia; private industry; and nongovernmental and community organizations. The response, science, technology, outreach, and coordination efforts outlined in this strategy document will help the Nation become better prepared for, and more resilient to, landslide hazards. It is important to remember that although future landslide events are inevitable, future landslide disasters are not.

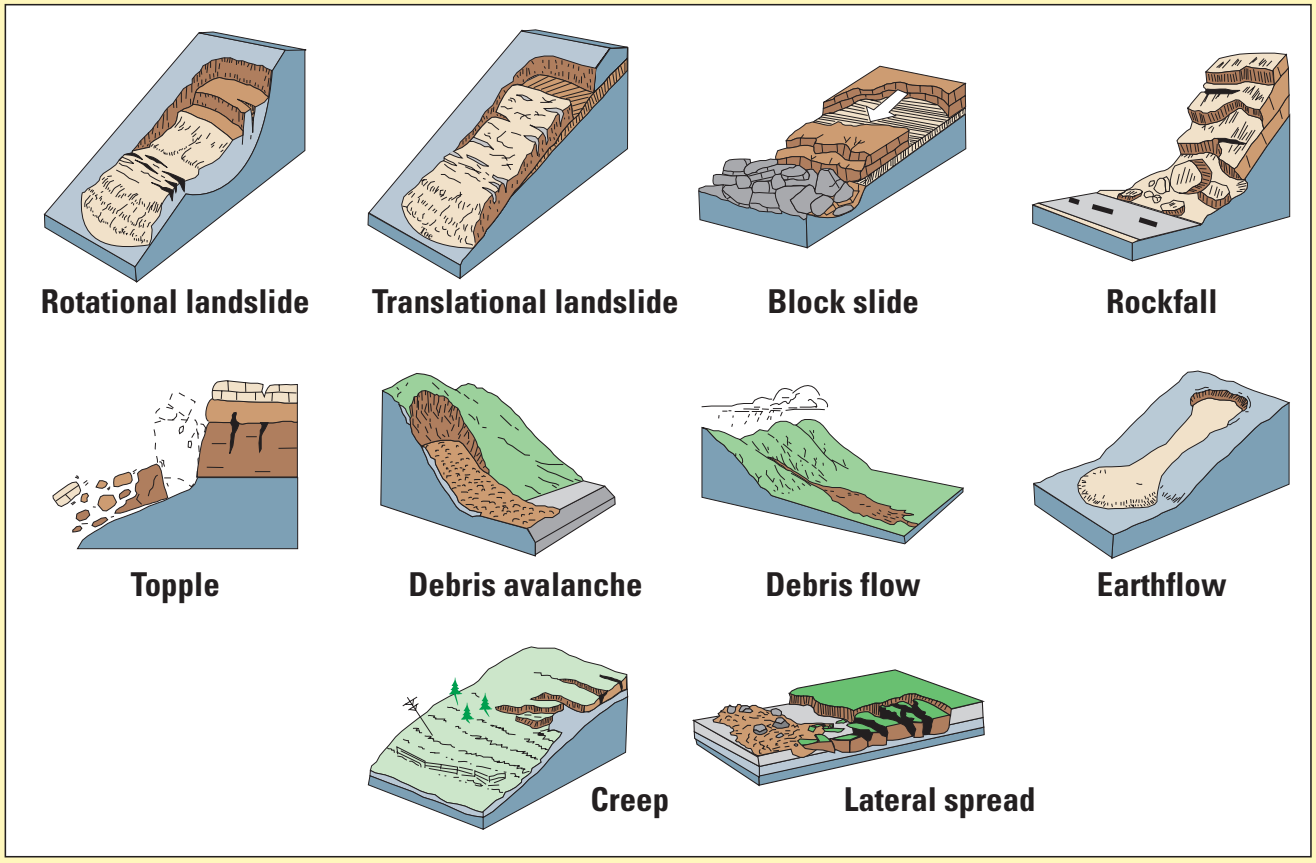
Challenges to Reducing the Nation's Vulnerability to Landslides

Reducing the Nation's vulnerability to landslides requires overcoming three main challenges, which are (1) the major gaps in basic information related to landslide occurrence and societal risk, (2) the difficulties of accurately mapping and forecasting of landslide hazards because of the geographically and contextually specific nature of the hazard, and (3) that landslide mitigation, preparedness, response, and recovery fall under numerous jurisdictions, which can impede consistent management to reduce losses.

Challenge 1. Gaps in Basic Information Needed to Describe and Understand Landslide Occurrence and Societal Risk

Currently, gaps in the basic understanding of landslides inhibit many mitigation and preparedness activities. For example, scientists do not have a precise estimate of how many landslides occur in the United States each year or what effects these events have had on people's lives and on local economies, infrastructure, housing, and ecosystem services. In addition, a consistent and actionable mapping of landslide-prone areas is unavailable at a national scale. As the adage goes, you can't manage what you can't measure.

1. What is a landslide?



These schematics illustrate the major types of landslide movement. Modified from Highland (2004, fig. 3).

The pull of gravity can move rocks, mud, or dirt downhill through processes of toppling, sliding, and (or) flowing. The word "landslide" is used to describe all these movements. Other terms can be used for certain types of landslides, such as "rockfall" and "debris flow." Distinguishing among the style and speed at which materials move downhill, as well as the materials involved, helps describe the hazard the landslide poses to people and the natural and built environment.

Slow-moving landslides composed of rock or soil can damage buildings and infrastructure. They generally do not present a threat to people because they move slowly, but they can cause continuous damage to infrastructure over years or decades.

Rockfall is common from natural cliffs, road cuts, and excavations. Rocks falling from even modest heights are hazardous to people and things.

Debris flows are slurries of rock, soil, water, and objects in their path as they flow downhill. Because debris flows can travel rapidly for long distances along stream channels, they can be particularly deadly and destructive.

Rock or debris avalanches occur in mountainous areas and often result from the rapid acceleration of very large rockslides.

Challenge 2. Landslides Are Difficult to Map and Forecast Accurately

Because precise and accurate prediction of landslide occurrence is challenging even with intensive monitoring, alerts are not available before most landslides take place. Contributing to this unpredictability is a lack of robust information on the physical nature of landslide occurrence, hindering the implementation of protective actions. The factors that drive landslide occurrence vary with landslide type and are often hidden beneath our feet. Landslide forecasting with sufficient lead time to save lives and protect property will remain out of reach without (1) a comprehensive accounting of landslide events across the United States, (2) improved understanding and monitoring of the factors that lead to landslide occurrence, and (3) an operational system to integrate and interpret observations in near-real time.

Challenge 3. Landslide Hazards Span Jurisdictions and Sectors, Making Coordination and Communication Difficult

The U.S. Geological Survey (USGS) is home to the only Federal program dedicated to landslide hazard science (U.S. Geological Survey, 1982; Spiker and Gori, 2003), yet more than 10 different Federal agencies and offices have some stake in landslide hazard mitigation, response, and recovery. Beyond the Federal interest, each State, Tribal, and territorial government has responsibilities for landslide assessment, mitigation, and response. Research on and knowledge of landslide processes, hazards, risk, and mitigation practices are spread across the Federal, State, academic, and private sectors. Without a forum for information and data exchange, development of common messaging and guidance, and sharing of best practices, this constellation of interested parties will remain less effective than they could otherwise be.

Strategic Goals

On January 5, 2021, the National Landslide Preparedness Act (Public Law 116–323) became law. The new law directs the Department of the Interior (DOI) to create a program to—

- Identify and understand landslide hazards and risks;
- Reduce losses from landslides;
- Protect communities at risk of landslide hazards; and
- Help improve communication and emergency preparedness, including by coordinating with communities and entities responsible for infrastructure that are at risk of landslide hazards.

To meet these four primary aims of the National Landslide Preparedness Act, which include addressing the three challenges laid out above, this national strategy document for landslide loss reduction puts forward a series of strategic actions to achieve the following four main goals (fig. 1):

Assess: Decision makers have access to detailed, nationwide, and contextually relevant information on landslide hazards and risk.

Coordinate: Landslide hazard mitigation, preparedness, response, and recovery efforts are coordinated across Federal, State, Tribal, territorial, and local levels.

Plan: Communities and land managers are prepared and able to plan for landslide hazards.

Respond: Landslide surveillance and warnings and responses to landslide events are effective, efficient, equitable, cooperative, and data-driven to protect lives, property, infrastructure, and the environment.

Achieving these four main goals would mean that lives, livelihoods, and natural and cultural resources will be better protected from landslide hazards than ever before and that the Nation will be more resilient, even as these hazard events intensify and increase with changes in climate and land-use patterns.

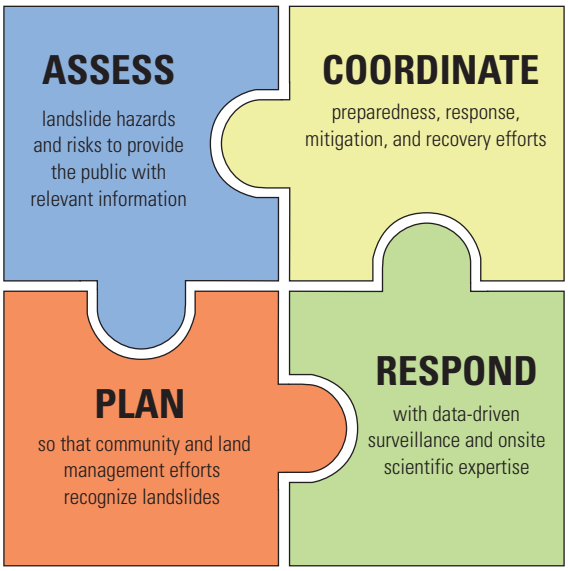


Figure 1. The four goals of the national strategy for landslide loss reduction.

Scope of This Strategy Document

This strategy document outlines the DOI's role in leading the Nation's efforts to reduce landslide hazard risks. As the science bureau of the DOI, the USGS will lead in the implementation of the strategy laid out in this document. The USGS Landslide Hazards Program is the only Federal program dedicated to landslide hazards science. This program is informed and supported by a broad range of USGS scientific capabilities in the geological, hydrological, and geographical sciences, as well as by research and monitoring done by other DOI bureaus and offices (Spiker and Gori, 2003; National Research Council, 2004). Although the execution of the

actions laid out in this strategy document is a DOI-led effort, landslide hazard risk reduction must include collaboration across Federal agencies, as well as with State, Tribal, academic, and private industry partners. This document highlights areas where collaboration has been and would be most relevant, as well as mechanisms that would enable these critical exchanges to continue and expand, and it defines the specific goals and strategic actions needed to meet the strategic goals in general terms for the Nation. An associated management plan that outlines the programs and costs associated with these strategic actions will be written separately and approved by the interagency coordinating committee on landslide hazards (ICCLH) once the committee is established (Strategic Action 2.1).

Goal 1. Decision Makers Have Access to Detailed, Nationwide, and Contextually Relevant Information on Landslide Hazards and Risk

The first step in reducing societal losses from landslides is understanding where and under what conditions landslides occur, what could be lost when they do occur, and what actions can be taken to reduce these losses. The difficulty in identifying the location, timing, and type of potential landslide activity presents substantial challenges to the development of cost-effective landslide risk reduction. The effect of gravity on the landscape can generate landslides in a wide variety of shapes and sizes. The landslides can be muddy or rocky; fast or slow; triggered by earthquakes, glacial retreat, volcanic activity, prolonged or intense rainfall, rapid snowmelt, changing temperatures, extreme storm-driven wave events, river-bank erosion, or human activity; and they can even occur without a discernable initiating event (Wieczorek, 1996). Each of these landslide scenarios has unique risk components for society, and unique assessments and tools are needed to forecast and mitigate the landslides. The inability of current science to predict precisely where and when a landslide may occur, how big it will be, and how far a landslide will travel makes it difficult for decision makers to know which of their limited resources to devote to landslide risk reduction.

Planners, managers, and policymakers could make more informed decisions to reduce potential landslide losses in their communities, on their lands, and to their infrastructure if they had better insight into the following questions:

- What type of landslide hazards are present in the community, locale, or region?
- Which areas are most prone to which type of landslide?
- When are landslides likely to occur and will there be warning signs?
- What climatic and other conditions increase the potential for landslides?
- Who is most likely to be affected by landslide hazards, and how?
- What steps can communities and land mangers take to reduce future losses?
- What are the short- and long-term effects of a landslide to the built environment, economy, and natural and cultural resources in the affected zone and surrounding areas?

Initiating a national, coordinated effort to provide insight into these questions will help decision makers working at a range of scales reduce landslide losses. Part of this effort will include monitoring and collecting data on current landslide activity to understand what is moving, and where and why. Another part of this effort will be collecting data on past events to identify where and why landslides occurred; how they behaved; how events and related cascading hazards affected communities, infrastructure, and the environment; and how that knowledge can inform future landslide hazard and risk assessments. The past is not the only key to understanding the future of landslides, however. Understanding the potential for future landslides will also require recognition of the role that projected increases in wildfire, extreme weather and rainfall, glacial retreat, sea-level rise, Great Lakes level rises, and other physical processes related to climate change may have, in addition to the effects of human activities on the landscape. Incorporating these dynamic processes into a holistic understanding of landslide hazards and risk will require better use of existing landslide data as well as the creation of new data, greater access to high-resolution imaging, and application of advanced data analysis techniques.

Currently, there is no coordinated U.S. effort to characterize and communicate the exposures and sensitivities to or the adaptive capacities of communities, managed lands, the built environment, and natural, cultural, and economic resources to landslide hazards. Strategic actions in Goal 1 will focus on comprehensive assessment of the Nation's landslide hazards and the societal risks associated with these hazards while recognizing the proprietary or sensitive nature of some landslide information. Publicly available deliverables related to this goal will include the following:

- Hazard maps that show which locations are susceptible to landslides, given past events and projected changes in the landscape;
- New technologies for landslide monitoring and alerts that enable protective measures and actions to be taken before landslides occur;
- A national database of landslide hazards and associated societal risks;
- Information products that describe the warning signs and potential for societal consequences of landslides in different regions of the United States and its territories; and

- Reports of significant landslide events (Strategic Action 1.4) that have had considerable adverse consequences for human health and safety, infrastructure, economic activity, or natural or cultural resources.

Goal 1 Vision Statement

The vision for this goal is that planners; land, infrastructure, and emergency managers; and policymakers at multiple levels understand what types of landslides are possible where and under what conditions, and what could be affected when landslide events occur. Armed with this information, these individuals will be able to develop and implement risk-reduction and mitigation strategies to minimize unacceptable losses and prepare communities so that they can respond to and recover from events quickly and effectively. Over time, these methods will become standardized practices. As a result, new development and infrastructure will accommodate, rather than ignore, landslide hazards, and loss of life from landsides will become rare because forecasting tools, warning systems, and informed plans for the evacuation of at-risk individuals will be in place. Ultimately, the social and economic costs of landslides will decrease as communities become more resilient to nature's challenges (Highlight 2).

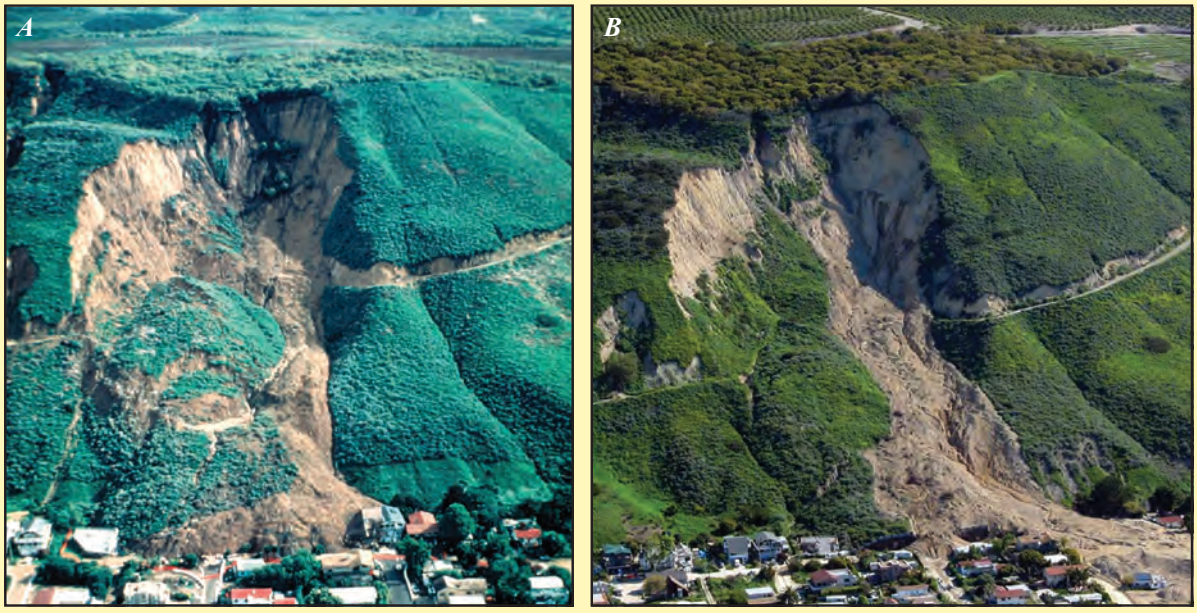
2. Why is planning for landslides so challenging?

Educating people on what they could expect from landslide hazards at a specific location is challenging because landslides come in all shapes and sizes. Where the hazards are in relation to communities, infrastructure, and resources also varies across the country. These differences result in different types of effects and may require different approaches for planning, response, and recovery.

Slow or fast: Landslides can unfold slowly or take place very quickly, and sites of previous landslides can reactivate differently than the original event.

Local or regional: Landslides can affect a single structure or can create cascading hazards that affect communities hundreds of miles away by causing downslope flooding or by damaging or blocking such things as pipelines, waterways, or transportation corridors. Hurricanes or earthquakes can trigger widespread landslides, the effects of which can require regional management.

Multiple triggers: Forecasting tools or warning systems are difficult to create when landslides can be triggered by different activities or events, such as earthquakes, volcanic activity, development undercutting the base of a hill, underwater slope failures, prolonged rainfall, intense storms, or rapid snowmelt.



These photographs show landslides that occurred in 1995 and in 2005 in the town of La Conchita, California. The 1995 earthflow, *A*, moved slowly enough that people could evacuate. Although 10 houses were destroyed, no lives were lost (Highland, 2004, p. 1). In 2005, following weeks of prolonged rainfall, a part of this landslide, *B*, failed catastrophically, triggering a rapidly moving debris flow that killed 10 people. In 2018, a storm triggered multiple debris flows just a few miles away above the town of Montecito, killing 23 people, destroying more than 400 homes, and blocking U.S. Highway 101 for months. La Conchita remained unscathed in the 2018 storm, however (Kean and others, 2019). Photograph *A*, by R.L. Schuster, USGS; photograph *B*, by Mark Reid, USGS.

Strategic Action 1.1—Characterize the Societal Risks Posed by Landslide Hazards

Overview

The risks posed by future landslides are a function of the potential hazards of a place, what may be directly in harm's way, how socioeconomic and natural systems may be indirectly affected, and the choices that people make before, during, and after a landslide (fig. 2). An improved understanding of the exposures, sensitivities, and adaptive capacities of communities, managed lands, the built environment, and ecosystems to landslide hazards will provide decision makers with insight into how vulnerabilities can be reduced or managed. Interdisciplinary data-driven approaches to focus research, monitoring, and outreach efforts can help ensure a more equitable approach to landslide hazards work. For example, examining where susceptibility overlaps with communities known to be disproportionately affected by landslides and other disasters can help prioritize research interventions. Improving understanding of how people have experienced and perceive landslide risk will help Federal agencies better communicate these risks and improve the use of landslide hazard information in risk-reduction and mitigation efforts. This work will also support the DOI's responsibility in the National Response Plan to provide technical assistance in community planning and expertise in natural and cultural resources and natural hazard vulnerability analysis (Emergency Support Function #14—Long-Term Community Recovery and Mitigation). Important questions to address for this strategic action include the following:

- Who and what are vulnerable to landslides (Highlight 3)?
- How do different land uses, land-management practices, and development in landslide-prone areas amplify the potential impacts of landslides (Highlight 4)?
- How have historical and current processes and policies created inequities that make certain groups of people more vulnerable to landslide hazards?
- What can be done to equitably reduce societal vulnerability to landslides?

Figure 2. Landslides have the potential to cause damage and disruption to people, businesses, economic systems, critical facilities, infrastructure, and cultural and natural resources.

3. Landslides create humanitarian crises

Landslides can disrupt basic community services that result in damage that goes well beyond the initial fatalities and direct damages from the initial landslide. For example, torrential rains associated with Hurricane Maria in 2017 triggered more than 70,000 landslides across Puerto Rico (Hughes and others, 2019), and these slides caused significant disruptions to roads, power lines, and water and wastewater infrastructure.

A humanitarian crisis emerged when many communities went without power and water for 9 months or more in certain areas. Access to schooling, health care, and transportation was also heavily compromised and contributed to the crisis. The long-term effects of school closures, lack of access to health care, the trauma of lost housing, and an inability to meet basic needs are hard to measure but are likely to echo for years into Puerto Rico's future.

An aerial view of landslide damage after Hurricane Maria in Utuado municipality, Puerto Rico. Photograph by Erin Bessette-Kirton, USGS.

4. Landslides cause persistent infrastructure damage

A storm that hit California's coast between January 26 and January 28, 2021, destroyed a portion of Highway 1 near Big Sur. A U.S. Geological Survey reconnaissance flight captured this photograph above the Rat Creek drainage showing the debris flow that damaged the highway. Photograph by the U.S. Geological Survey.

Slow-moving landslides can have equally damaging effects on infrastructure as those that happen quickly. In August 2021, National Park Service officials in Denali National Park, Alaska, were forced to close the only major road in and out of the park for the remainder of the summer season because of downslope movement of the roadbed. In the two weeks following the closure, the road dropped approximately 14 vertical feet (National Park Service, 2021). Photograph by the National Park Service.

Involved Parties

Characterizing societal risk from landslides is an interdisciplinary endeavor that will require the data, collaboration, and coordination of many State and Federal agencies and organizations as well as representatives from at-risk communities, nongovernmental organizations, and the private sector. Key to this work is the development of better national-scale landslide hazard maps. These maps can then be used to target vulnerability and risk-assessment activities and help identify where more-detailed hazard assessments and improved monitoring are needed to reduce the uncertainty of where, when, and why landslides could occur (Strategic Action 1.2). These maps, combined with place-based sociological research, can also help focus outreach and communications about landslide risk reduction and preparedness (Strategic Action 3.2). To undertake this interdisciplinary effort—

- The USGS would take the lead on integrating data and products from partners to provide nationwide hazard-exposure monitoring of societal risks associated with landslide hazards. The USGS would also coordinate across stakeholder groups to develop case studies and scenarios to enhance planning, communication, and collaboration.
- Representatives from affected communities, historically marginalized populations, the private sector, academia, and interested nongovernmental organizations could also collaborate on or lead case studies and scenario-driven approaches to understand local landslide-risk and environmental justice issues.

Examples of relevant data to characterize societal risks from landslides would come from many agencies and organizations that could include, but are not limited to, those listed in table 1.

Table 1. Examples of landslide risk data and their providers.

Provider	Data
U.S. Geological Survey	Regional and national perspectives on landslide hazard assessments, related foundational geospatial data (for example, elevation, land cover, hydrology), and descriptions of landslide impacts
National Weather Service	Storm event data and damage assessments
U.S. Census Bureau	Demographic data that are critical to understanding the population exposure and aspects of social vulnerability to landslides
Bureau of Land Management; Bureau of Reclamation; Bureau of Indian Affairs; U.S Fish and Wildlife Service; National Park Service; U.S. Department of Agriculture, Forest Service	Records of past landslides and the effects on people, property, and infrastructure on lands that these agencies administer or manage, recognizing the need for protection of proprietary or sensitive information
U.S. Department of Homeland Security	Critical facilities and infrastructure that could be disrupted by landslides
U.S. Department of Transportation and State departments of transportation	Transportation corridors and lifeline assets
U.S Fish and Wildlife Service	Maps of critical habitats in landslide-prone terrain
National Park Service	Sites recognized in the National Register of Historic Places
State, Tribal, and territorial geological agencies	Local landslide hazard assessments, geologic mapping, records of past landslides and the effects on people, property, and infrastructure in their jurisdictions, and specific critical facilities, such as schools and hospitals
Private sector and nongovernmental partners	Economic data and building footprint data

Ongoing Efforts

A national-scale landslide hazard map has been created for the conterminous United States using coarse, 1-kilometer data (Mirus and others, 2020). USGS research is underway to make more precise maps with higher-resolution elevation data and an improved understanding of which landscapes and environmental factors are most relevant in landslide-hazard mapping. The isolated effect of individual landslides leads to a limited understanding of the aggregate effects of these hazards to individuals and communities. Although the number of fatalities attributed directly to landslides is approximately known (Froude and Petley, 2018), there is no research on the short- or long-term effects of landslides on the health and well-being of affected people. Economic losses attributable to landslides across the United States are largely unknown, and limited data on direct losses are available in only a handful of areas that have persistent landslide damage. Indirect costs, such as those incurred when transportation routes are closed, are unknown but are assumed to exceed direct costs by a factor of two or more (for example, Schuster, 1996). Existing efforts to characterize societal risk from landslides are recorded mainly in individual journal articles or reports from public agencies or academic institutions (for example, Highland, 2006; Pollock and Wartman, 2020). Often these studies investigate only a specific threat, scale, or societal concern. There is no agreement on a consistent set of national societal data to communicate variations in societal risk from landslides from place to place. Insights into how at-risk individuals or risk managers may use or interpret landslide information or how choices in land use and development may affect landslide risk must be gleaned from studies focused on other sudden-onset hazards.

Specific Actions and Initiatives

- Improve the national-scale, landslide hazard map by incorporating into it current landscape conditions, improved three-dimensional geologic mapping, historical events, and projected landscape changes (Strategic Action 1.2). This includes—
  - Using higher-resolution digital elevation data acquired through the 3D Elevation Program (3DEP) and high-performance computing to integrate these data with other geospatial data;
  - Leveraging relevant climate change research and new landslide process understanding to advance future mapping efforts; and
  - Identifying landslide-prone areas that could create direct cascading hazards, such as seiches, tsunamis, critical infrastructure failure, or hazardous material releases.
- Use landslide hazard maps to develop case studies or scenarios for potentially imminent or substantial events, as well as for national hazard-exposure monitoring, that provide indices at multiple spatial and temporal scales of societal risks associated with landslides, including—
  - Demographic exposure and vulnerability that take into account—
    - Environmental justice considerations, such as discriminatory land-use practices;
    - The daily movement of people;
    - Seasonal movement of people, such as an influx of tourists to a landslide-prone area during the summer months; and
    - Long-term population trends in landslide hazard zones.
  - Economic loss estimation (both direct and potentially indirect costs);
  - Land use and land cover in landslide-prone areas;
  - Exposure of and potential impacts to critical facility and infrastructure, such as transportation corridors and pipelines;
  - Exposure of and potential impacts to ecological, natural, cultural, and economic resources; and
  - Evacuation potential for areas with high landslide hazard risk and substantial downslope development.
- Conduct research to improve understanding of—
  - The impacts of landslides to structures, infrastructure, the environment, and natural resources;
  - The short- and long-term effects of landslides to local and regional economies, especially for Tribal and underserved communities;
  - The influences of land-use policies and practices on creating or amplifying societal vulnerability to landslides;
  - The perception and behavioral aspects of landslide preparedness and warnings;
  - The long-term effects of landslides on mental health and community recovery; and
  - Projected changes in landslide hazard and risk as a result of climate change.
- Document and disseminate information on the societal consequences and recovery process of landslide disasters (Strategic Actions 1.3, 1.4, and 3.2).
- Standardize approaches and estimates for assessing direct and indirect costs and other effects associated with landslides.

Strategic Action 1.2—Expand Research and Development to Assess the Where, When, and Why of Landslide Hazards

Overview

To better reduce and manage landslide risk as a society, we must improve our ability to understand and communicate where, when, how, and why landslides are possible. Without this information, communities, land managers, businesses, and critical facility and infrastructure operators will continue to be surprised by catastrophic landslides. Improving the Nation's ability to assess landslide hazards will require advances in research, monitoring technology, data analysis and computing resources, and coordination among data providers. More detailed forensic investigations of consequential past landslide events are needed to better explain the timing, triggering mechanisms, direct and indirect effects, and possible cascading hazards of landslides in different settings (Highlight 5). Cutting-edge technologies, such as remotely sensed and ground-based data, machine learning, three-dimensional geologic mapping, and high-performance computing, need to be applied and developed in select areas to better inventory past landslides, characterize and map areas with landslide potential, detect where landslides just occurred, and forecast where they may be imminent. Development or modification of data management systems are needed to treat landslides as an integral part of tracking the location, condition, and mitigation of infrastructure. Data collection, technology development, and research efforts described in this strategic action will be prioritized according to the types and distribution of societal risks posed by landslides as outlined in Strategic Action 1.1. These efforts in turn will improve the national-scale landslide hazard maps used to characterize societal risks, thereby refining the Nation's ability to characterize risks posed by landslides.

An improved understanding of landslide behavior combined with technological advances will be leveraged to develop multiple types of national-scale products (fig. 3), such as—

- Inventories of past landslides based on field investigations, remote sensing, and other observations;
- Long-term (years or longer) landslide hazard assessments based on historic events, current landscape and environmental conditions, and climate change projections (Strategic Action 1.1);
- Medium-term (months to years) landslide outlooks based on seasonal meteorological trends, such as El Niño forecasts; the potential effects of other recent extreme events, such as wildfires, earthquakes, and hurricanes; or landscape changes owing to shifts in land use or sea-level and (or) Great Lakes level rises; and
- Short-term (days to months) landslide surveillance based on real-time environmental data (Strategic Action 4.1).

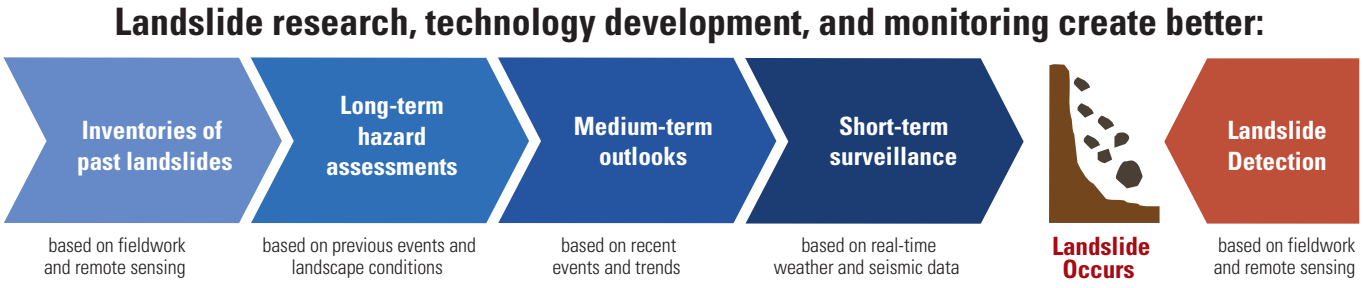


Figure 3. Landslide research, technology development, and monitoring described in Strategic Action 1.2 will help with landslide detection through the creation of better inventories of past events, long-term hazard assessments, medium-term outlooks after major events, and short-term surveillance based on weather forecasts and landslide monitoring observations.

5. Landslides cause cascading hazards

Landslides are often the result of other extreme events, such as wildfires, hurricanes, and earthquakes. Landslides can create cascading hazards of their own, however, and these secondary hazards can be more damaging than the original landslide. These follow-on hazards include—

- Train Derailments
- Dammed Waterways
- Water Pollution
- Tsunamis and Seiches
- Long-term Flooding
- Dam and Reservoir Stresses

In 1949, a landslide in the Tacoma Narrows of Puget Sound created a local 6- to 8-foot tsunami that reflected off of the opposite shore and hit the shoreline where the slide occurred (Photograph from Gonzalez and others, 2003, back of front cover).

In 1953, a large mud flow was created in New Zealand when a volcano lake held back by a tephra dam collapsed. This mud flow destroyed a railway bridge, causing a passenger train to derail into the river and killing 151 people on board. Photograph courtesy of Archives New Zealand Te Rua Mahara o te Kāwanatanga and licensed under the Creative Commons Attribution 2.0 Generic (CC BY 2.0; https://creativecommons.org/licenses/by/2.0/).

Description of Involved Parties

Landslide research, mapping, and monitoring are inherently interdisciplinary activities. Each of these efforts requires collaboration and coordination among Federal, State, Tribal, and territorial agencies and organizations, as well as academic partners, to accelerate data collection and advance emerging technologies. Although not exhaustive, expanded landslides research and development would include actions by the following agencies:

- National Weather Service (NWS) for coordination with the USGS to enhance the scope, accuracy, and effectiveness of post-fire debris-flow and landslide-generated tsunami alerts.
- State geological surveys; U.S. Department of Agriculture, Forest Service (USDA Forest Service), USDA, National Resources Conservation Service; U.S. Army Corps of Engineers (USACE); National Park Service (NPS); Bureau of Indian Affairs; and others for continued coordination with the USGS to develop best practices and tools for landslide identification and mapping.
- Federal Highway Administration (FHWA) and NPS for continuing work on the Unstable Slope Management Projects and coordination with the USGS to maintain and share data on active landslides.
- Academic institutions and the National Science Foundation (NSF) for partnering with the USGS through cooperative landslide hazards and risk grants to perform short-term work needed to close critical knowledge gaps and data acquisition needs.
- USGS for playing a coordination role by bringing together and maintaining landslide datasets, and leveraging findable, accessible, interoperable, and reusable (FAIR) data principles.
- National Aeronautics and Space Administration (NASA) for coordination with the USGS to ensure that satellite data products on precipitation, soil moisture, land-cover, and land-surface deformation can be readily integrated into USGS landslide research and products.

Ongoing Efforts

Current research and development efforts are diffuse and coordinated only loosely among Federal agencies, State agencies, Tribal and territorial governments, and academic partners. A preliminary landslide-inventory database for the United States is being compiled from existing maps by the USGS (Belair and others, 2022), but it is known to be incomplete and requires dedicated cyberinfrastructure to improve its usability (Strategic Action 1.3). Research on automated landslide detection is underway by NASA (Amatya and others, 2020) and others and holds promise to close some data gaps. Landslide researchers have developed a variety of methods that explain why different types of landslides start and how they move. These methods have been tested at only very local scales (for example, Baum and others, 2005), however, partly owing to insufficient information on landslide occurrence nationwide and a lack of resources to access and characterize landslides that have recently taken place. For example, methods for rapidly assessing debris-flow hazards in recently burned areas are highly successful in southern California and arid climates (Staley and others, 2016) but may be less useful in more humid regions of the United States. Improving post-fire hazard assessments and expansion of the partnership with the NWS for debris-flow alerts is needed to support the increasing demands of Burned Area Emergency Response (BAER) teams activities in these areas. Pilot studies for using rainfall and hydrologic data as thresholds to inform the NWS of potential imminent landslide hazards for inclusion in severe weather watches and warnings show promise (NOAA–USGS Debris Flow Task Force, 2005); however, systems to inform the NWS have been deployed only in a limited number of landslide-prone areas of the country. Technology for remote detection and monitoring of landslide activity is rapidly developing (for example, Mondini and others, 2021), but broader satellite coverage and more rapid collection and availability of data are needed to implement them nationwide.

Specific Actions and Initiatives

- Develop a plan for prioritizing landslide research and development based on the potential for reducing societal risks from landslides identified through efforts outlined in Strategic Action 1.1.
- Improve understanding of landslide behavior, including where landslides will initiate and where debris could move after an event, to better incorporate the following:
  - Influence of land use and management on landslide likelihood and magnitude;
  - Cascading hazards of landslides, such as seiches, tsunamis, hazardous materials release, wildlife disease, and failure of engineered structures; and
  - Effects of changing environmental conditions attributed to climate change on the location, frequency, and severity of landslides.
- Improve landslide detection and monitoring by—
  - Developing a robust, distributed sensor network for a range of landslide types (Strategic Action 4.1) that also leverages existing sensor networks for earthquakes, volcanoes, and meteorological events;
  - Exploiting high spatial and temporal resolution satellite imagery, including synthetic aperture radar (SAR);
  - Developing the necessary cyberinfrastructure and computing resources to process and integrate remotely sensed and ground-based data.
- Improve inventorying of past landslides in a publicly accessible database that—
  - Integrates similar efforts of State, Tribal, and territorial governments;
  - Leverages similar efforts by Federal land managers, such as data collected for the unstable slope management program;
  - Efficiently integrates field investigations and surveillance networks (Strategic Action 4.1); and
  - Can be used to improve the national-scale, landslide hazard map (Strategic Action 1.1) and the national hazard and risk database (Strategic Action 1.3).
- Improve long-term landslide hazard mapping by—
  - Developing mapping best practices and tools in collaboration and coordination with State, Tribal, territorial, and local governments;
  - Developing methods to integrate landslide occurrence data and advances in landslides research; and
  - Incorporating climate projections of increased precipitation intensity, sea-level rise, Great Lakes level rises, and changes in groundwater conditions.
- Develop medium-term landslide outlook products (for a timespan of weeks to months) that address potential increases in landslide potential related to seasonal trends (for example, El Niño forecasts) or recent disturbances to the landscape (for example, wildfires, earthquakes, hurricanes, human development, and Great Lakes level rises).

- Develop methods and systems for short-term landslide surveillance (for a timespan of hours to days) that—
  - Recognize storm conditions that are conducive for triggering landslides;
  - Integrate real-time data from multiple sensors, platforms, and agencies;
  - Support post-fire debris-flow warning systems and NWS flash flood products to enable evacuations and other immediate actions to minimize losses (Strategic Action 4.1); and
  - Reduce the uncertainty in near-real-time estimates of landslides triggered by earthquakes, including the potential for cascading hazards.

Strategic Action 1.3—Develop a Publicly Accessible National Landslide Hazard and Risk Database

Overview

Endeavors to improve the Nation's understanding of landslide hazards and associated risks described in Strategic Actions 1.1 and 1.2 will have limited utility if this information cannot be easily accessed by policymakers, land managers, planners, emergency managers, the business community, and the general public. Landslide-related information outlined in this strategy document will need to be organized and delivered through a flexible, easily updated, and interactive database that is accessible to multiple audiences (fig. 4). Doing so will make it possible for landslide information to be delivered at different scales and tailored to a user's area or topic of interest. Developing and delivering such a database will require coordinated data collection across multiple agencies, as well as investments in data visualization, web application development, communication, and user-centered design to ensure that products are relevant, accessible, and understandable to a diverse set of stakeholders (Highlight 6). Dedicated efforts to evaluate the database will be critical to ensure that it continues to meet the needs of users over time.

Description of Involved Parties

The USGS will coordinate with State offices, Tribes, territories, units of local government, and agencies represented in the ICCLH (Strategic Action 2.2).

Ongoing Efforts

A comprehensive national landslide database is needed to better assess, analyze, and communicate landslide hazards. Such a database would be composed of an inventory of known landslide locations and national-scale geospatial data on landslide susceptibility. Although nascent efforts to develop a national landslide inventory are underway (Belair and others, 2022), this inventory is not complete, is coarse in scale and difficult to access, and does not account for information on societal or economic losses associated with landslides.

The USGS is currently coordinating with State and territorial geological agencies to manually compile landslide map data. Ultimately this database will provide a centralized portal to access mapped landslide occurrences and will promote landslide information sharing. Existing national-scale landslide susceptibility maps (Mirus and others, 2020) exclude Alaska, Hawaii, and other parts of the United States and are incomplete, outdated, and not sufficiently detailed to support emergency or planning decisions. Recent evaluations of landslide susceptibility revealed that approaches that rely on currently available data may underestimate landslide potential, especially in areas previously considered to be of moderate to low risk, and thus cannot provide actionable information to local decision makers (Mirus and others, 2020). This revelation has motivated efforts to improve the Nation's ability to identify landslide hazard zones with more and higher resolution data. Some State geological agencies provide web-based mapping applications that allow users to overlay maps of State-based landslide hazard zones with satellite imagery and a limited number of societal assets. These efforts are not available for all States with landslide threats, however, nor are they consistent.

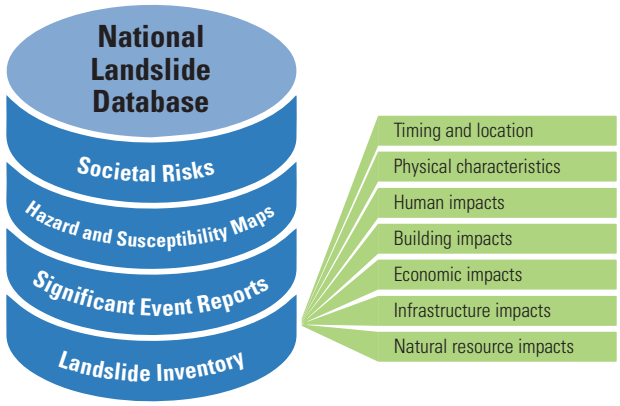
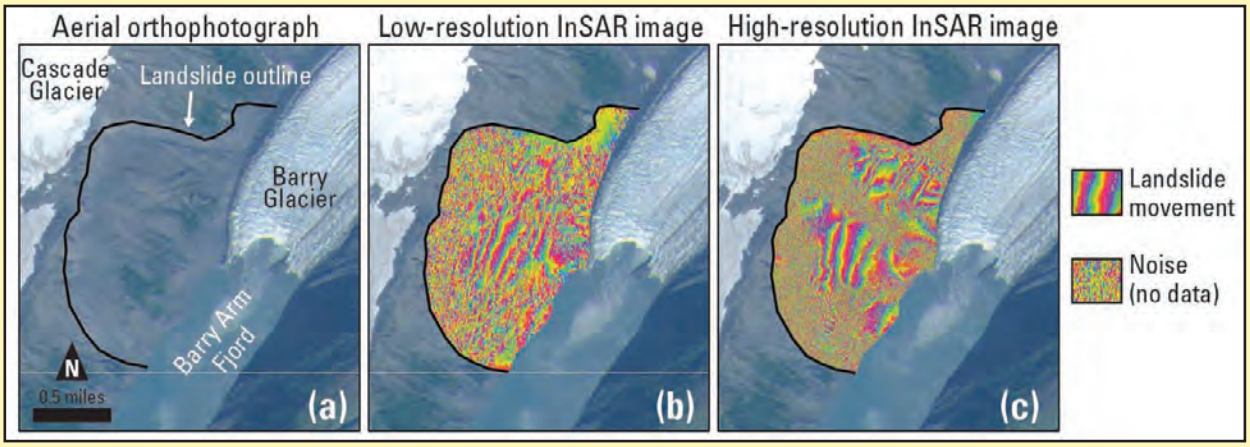


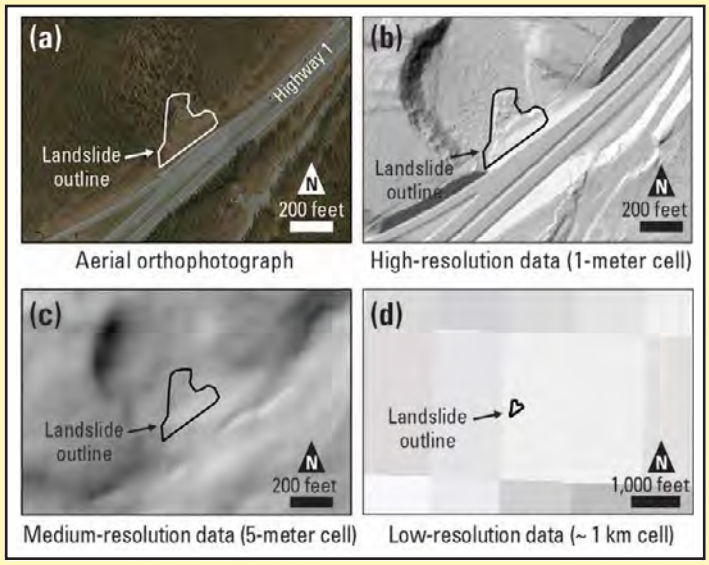
Figure 4. The national landslide hazard and risk database would include data to inventory and describe the effects of past landslide occurrences, archive significant landslide event reports (Strategic Action 1.4), and provide access to landslide hazard maps and data related to societal risks from hazards.

6. The best landslide hazard assessments require the best data

Hazard assessments and forecasting efforts are only as good as the data used to create them. Nationwide high-resolution imagery can help scientists understand where landslides are likely to occur, quickly make assessments of site safety and damage extent following a landslide event, and accurately monitor ongoing landslide threats. Acquiring, processing, and storing this imagery is no small undertaking, however. It requires substantial cyberinfrastructure, high-performance computing, machine learning, cloud storage, and new aerial and satellite technologies.



These images depict a large, steep slope in the Barry Arm fjord located 30 miles northeast of Whittier, Alaska. This slope is moving and has the potential to fail into the water and generate a tsunami that could have devastating effects in northern Prince William Sound. The left image (a) is a satellite image. The other images compare InSAR (interferometric synthetic aperture radar) maps of movement on the Barry Arm landslide using low-resolution (b) and high-resolution (c) satellite data. These images demonstrate signs of land movement across much of the 1.5-mile-wide landslide. The higher-resolution InSAR image (c) has less data noise and therefore provides better insights as to the amount and extent of the landslide's movement, which is critical for creating accurate landslide failure and tsunami scenarios for emergency managers (modified from Schaefer and others, 2020).



These images of Highway 1 demonstrate how high-resolution imagery (a) and topographic data (b) make it possible to see landslides caused by the magnitude 7.1 earthquake near Anchorage, Alaska, in 2018. Accurate landslide inventories result in more accurate hazard assessments, but landslide mapping efforts are often hampered by low- and medium-resolution data. Medium-resolution data (c) are the best Statewide data available for Alaska, but they are inadequate to identify land features or Highway 1. Low-resolution data (d) are the best data available across the United States, but they are not sufficiently detailed to make landslide mapping possible. Landslide polygon modified from Martinez and others (2022); topographic data from the Alaska Division of Geological and Geophysical Surveys Elevation Portal (https://elevation.alaska.gov) and Earth-Explorer (https://www.usgs.gov/tools/earthexplorer).

Specific Actions and Initiatives

- Create a national landslide hazard and risk database that—
  - Is publicly available and easily searchable using the internet;
  - Provides user-driven access to data and a mapping application to visualize past landslide occurrence and areas where future events are possible;
  - Allows USGS and its partners to add information easily; and
  - Is evaluated during the design and development phases as well as after its public release to maximize accessibility and utility;
- Ensure that this national landslide hazard and risk database provides the following two types of content:
  - A national inventory of landslide occurrences that includes—
    - An inventory of all past events that meet a threshold defined by the ICCLH (see Strategic Action 2.1) and are updated with a frequency determined by the database working group. This inventory will be compiled by the USGS using data provided by Federal land management agencies and partners with State offices, as well as Tribal and local governments;
    - Attributes for each landslide occurrence to include identifying factors (timing, location); physical characteristics (its geology); and socioeconomic, environmental, infrastructure, human health, and cultural impacts; and
    - Identification of those landslides that also fall into the category of significant landslide events (Strategic Action 4.1).
  - A national landslide hazard and risk assessment, including—
    - Maps of landslide hazard zones;
    - Identification of societal assets in landslide hazard zones, including populations, communities, economic assets, land cover, critical facilities and infrastructure, environmental assets, and natural resources; and
    - Areas where landslide risk reduction has been implemented, including hazard stabilization and documented reduction in losses.
- Establish a database working group to do the following:
  - Develop protocols for how to compile, maintain, standardize, and evaluate data regarding landslide occurrence, landslide hazard assessment, and societal risks associated with landslides;
  - Develop an outreach and communication strategy for the database to ensure that a wide range of decision makers and land managers are aware of and understand the utility of this product;
  - Identify the cyberinfrastructure and computing resources needed to provide this database to the public;
  - Determine the approach and cycle timeline needed to evaluate the utility of the database; and
  - Deliver recommendations to the USGS and the ICCLH.

Strategic Action 1.4—Provide Publicly Available Reports of Significant Landslide Events

Overview

Significant landslide events (SLEs) are defined as those that are a part of Presidentially declared disasters under the Robert T. Stafford Disaster Relief and Emergency Assistance Act (Public Law 100–707; Stafford Act), or those determined to be significant by the ICCLH (Strategic Action 2.2). This definition will be finalized by the ICCLH once that group is formed. These events will be included in the national landslide hazard and risk database (Strategic Action 1.3) but warrant additional indepth analysis and reporting given the magnitude of losses associated with the landslide (fig. 5). Currently, there is no official or consistent mechanism for reporting on SLEs. Future reports on SLEs would provide an interagency, indepth analysis to document landslide generation, effects, response, and recovery. Some significant benefits of these reports include (1) documented knowledge of the effects of landslides, (2) data to improve future hazard assessments and warning alerts, (3) an opportunity to examine how mitigation and response to landslide events could have been improved, and (4) improved understanding of what natural and societal factors contributed to losses.

Description of Involved Parties

All agencies that participate in the ICCLH (Strategic Action 2.1) would likely play some role in the preparation of an SLE report. Interested State, Tribal, county, and local representatives for the area where the event occurred could also contribute to the report.

Ongoing Efforts

As noted above, SLE reporting is not done consistently. In the past, summaries of large or damaging landslides have been discussed in isolated government reports, journal articles, academic reports, and the news media (for example, Jibson, 1992; Wooten and others, 2008). For example, the NWS Service Assessments that describe the agency's response to significant weather events may mention landslides, but landslides are rarely, if ever, the focus of these assessments. The NWS Service Assessment model could be used for analysis and reporting on SLEs.

Specific Actions and Initiatives

- Create a working group within the ICCLH (Strategic Action 2.1) to finalize the definition of SLEs and create guidance on the report writing and dissemination process.
- Within 1 year after each SLE, the DOI, in collaboration with relevant partners, will publish a report that includes:
  - A description of the landslide event and the implications of the event for communities, including consideration of disproportionate impacts to life and property;
  - Recommendations for how landslide risk could have been reduced prior to the event, with a particular focus on environmental justice considerations;
  - An assessment of the effectiveness of any warning and risk communication, including the dissemination of warnings by Federal, State, Tribal, territorial, and local partners in the affected area;
  - Recommendations to improve risk identification, reduction, and communication to residents, landowners, and Tribal and local governments;
  - Recommendations to improve landslide hazard preparedness and emergency response activities; and
  - Any other findings as the Secretary of the Interior or senior leadership determines appropriate.
- Make all SLE reports available on a publicly accessible website.

Figure 5 Significant landslide event (SLE) reports will include descriptions of the physical event and the societal effects as well as recommendations for assessing and communicating risk, disseminating warnings, and improving preparedness and response efforts.

Goal 2. Landslide Hazard Mitigation, Preparedness, Response, and Recovery Efforts Are Coordinated Across Federal, State, Tribal, Territorial, and Local Levels

More than 10 different Federal agencies are responsible for research or emergency management activities related to landslide hazards. Currently, there is no platform for these agencies to exchange data, best practices, and guidance, or to collaborate on issues related to landslide hazards. Further, there is no forum for similar exchanges across the numerous State, Tribal, territorial, local, private, and academic entities that study, mitigate, prepare for, respond to, or recover from landslide hazards. Creating formal and informal mechanisms to foster these exchanges is critical to advancing landslide preparedness, mitigation, response, and recovery. The communities of practice that emerge from these coordination efforts and the professional relationships that are established in advance of disaster events will improve and streamline the Nation's readiness for future landslide hazard events across all phases of the emergency management cycle.

Landslide hazard mitigation requires the input and coordination of all units of government; that is, from State, Tribal, territorial, and local community planners and emergency managers, to professional engineering associations and organizations, to Federal scientists and planners at such agencies as the USGS and the Federal Emergency Management Agency (FEMA). There are numerous mitigation and preparedness efforts that should be considered when discussing landslide hazards, including improving land-use management strategies; hardening structures against the effects of landslides; promoting landslide education, outreach, and engagement; and developing consistent landslide hazard

mitigation and response plans across all levels of government. Each of these actions can and should be informed by high-quality and cutting-edge scientific information and technology as well as frequent and reliable coordination among different professional entities.

Coordination among the research, private industry, land management, and emergency management communities as well as across various levels of government is key to ensuring that the right information is in the right hands at the right time. Such coordination includes improving and standardizing linkages between landslide hazard research and operational entities responsible for providing watches and warnings, evacuation planning, and communication strategies. Formalizing roles and responsibilities for landslide response and research, as well as increasing coordination, will streamline landslide hazard responses and can result in improved short- and long-term outcomes to protect lives, property, infrastructure, and the environment.

Goal 2 Vision Statement

The vision for Goal 2 is that planners, land managers, scientists, emergency managers, community leaders, and policymakers at multiple levels can share information and learn from each other. In implementing this goal, future communication to the public about landslide mitigation, preparedness, response, and recovery will be standardized and based on the best-available information. Future exercises and exchanges enabled by these coordination efforts will result in better collaboration during responses, when strong preexisting relationships are critical to smooth operations.

Strategic Action 2.1—Establish an Interagency Coordinating Committee on Landslide Hazards

Overview

Coordination of landslide-related efforts at the Federal level is critical to reducing redundancies and leveraging limited resources (fig. 6). Coordination will be done by the interagency coordinating committee on landslide hazards (ICCLH).

Description of Involved Parties

As per the National Landslide Preparedness Act, the ICCLH will include designees of the Secretary of the Interior, who shall serve as Chairperson of the Committee; the Secretary of Agriculture; the Secretary of the Army; the Secretary of Commerce; the Secretary of Homeland Security; the Secretary of Transportation; the Director of the National Science Foundation; the Director of the Office of Science and Technology Policy; and the Director of the Office of Management and Budget.

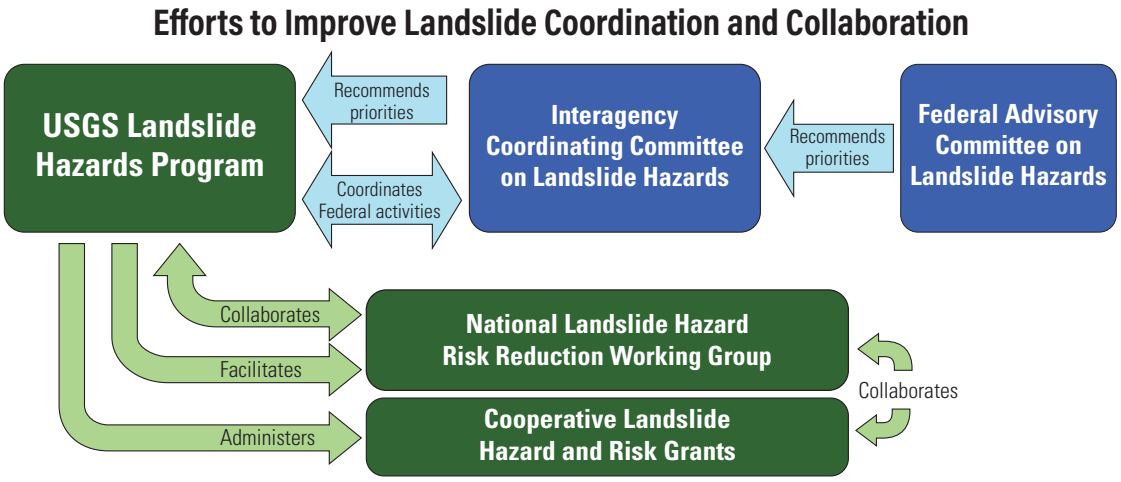


Figure 6. Coordination, collaboration, and information flow across groups involved in landslide hazard risk reduction.

Ongoing Efforts

Currently, there is no official ICCLH. Coordination efforts are ad hoc and event-driven. The DOI will name a chairperson for the ICCLH and will transmit invitations to the named members of the group. To meet the January 2022 deadline for this strategy document, the USGS convened an interim interagency working group composed of technical representatives from the agencies named in the National Landslide Preparedness Act, as well as representatives from additional agencies with landslide hazards interest or relevant capabilities. Once assembled, the ICCLH will be engaged to help shape and approve the associated management plan for the national strategy.

Specific Actions and Initiatives

The ICCLH will meet at the call of the Chairperson. The purpose and duties of the committee will be to–

- Advise and oversee the program, including the development of national goals and priorities;
- Facilitate communication and coordination across Federal agencies in the planning, management, budgeting, and execution of landslide activities;
- Support the development, execution, and implementation of the national strategy by articulating Federal agency roles, responsibilities, and resources for carrying out the national strategy;
- Establish a Federal interagency working group to coordinate landslide-related activities at the Federal level; and
- Produce a biennial report that includes a description of the following:
  - The goals and accomplishments of the ICCLH in carrying out the national strategy; and
  - The extent to which any recommendations of the ICCLH have been implemented.

Strategic Action 2.2—Establish a Formal Federal Advisory Committee on Landslide Hazards

Overview

A Federal advisory committee on landslide hazards is needed to provide recommendations for priorities to the ICCLH.

Description of Involved Parties

As per the National Landslide Preparedness Act, the Federal advisory committee on landslide hazards will be composed of no fewer than 11 members and include representatives of geological organizations and emergency management agencies from States, Tribes, territories, and local government; research institutions and institutions of higher learning; and industry standards development organizations (fig. 7).

Ongoing Efforts

Currently, there is no official Federal advisory committee on landslide hazards. Previous efforts to recommend landslide-related priorities have come from ad hoc committees organized by the National Academies of Sciences, Engineering, and Medicine—for example, the report titled "Partnerships for Reducing Landslide Risk—Assessment of the National Landslide Hazards Mitigation Strategy" prepared by the National Research Council (2004).

Figure 7. The Federal advisory committee on landslide hazards will include representatives from geological organizations and emergency management agencies; research institutions and institutions of higher learning; and industry standards development organizations.

Specific Actions and Initiatives

The Federal advisory committee on landslide hazards will submit recommendations for implementing the national strategy for landslide loss reduction to the ICCLH, including–

- Recommendations regarding landslide hazard and risk reduction and planning;
- Tools for communities;
- Research topics; and
- Other topics that the advisory committee deems appropriate.

Strategic Action 2.3—Develop and Maintain Cooperative Landslide Hazards and Risk Grants

Overview

Success in reducing risks of landslides will be propelled by state-of-the-art research and projects with external partners at the State, Tribal, territorial, and local levels. Competitive cooperative landslide hazards and risk grants could be used to fund these activities (fig. 8). There are several models that can be drawn upon to create such a program, including the USGS National Cooperative Geologic Mapping Program, the USGS Earthquake Hazards Program, and the National Oceanic and Atmospheric Administration (NOAA) National Tsunami Hazard Mitigation Program.

Description of Involved Parties

Responsibilities would be as follows:

- Implementation of the cooperative landslide hazards and risk grants would be led by the USGS.
- Eligible organizations for competitive cooperative landslide hazards and risk grants would be State, Tribal, territorial, and local governments to research, map, assess, collect, and communicate data on landslide hazards within the jurisdictions of those governments.
- Yearly guidance on grant priorities would be provided by the Federal advisory committee on landslide hazards (Strategic Action 4.1). The national landslide hazard risk reduction working group (Strategic Action 2.4) could also offer informal input on the process.
- The USGS will coordinate with the NSF to advance the objectives of the cooperative landslide hazards and risk grants in accordance with priorities set by the academic research community.

Ongoing Efforts

Currently, there is no official mechanism for providing grant assistance related to landslide hazard issues to non-Federal entities. Setting up and maintaining a cooperative landslide hazards and risk grants program would create a sustained and strategic funding mechanism for landslide risk reduction research and projects in addition to the current system of one-off contracts or agreements.

Specific Actions and Initiatives

- The Federal advisory committee on landslide hazards will advise the USGS on external grant priorities beyond those explicitly stated in the National Landslide Preparedness Act and the national strategy document.
- The program will support cooperative landslide hazard mapping and assessments through—
  - Competitive cooperative landslide hazards and risk grants, which would provide State, territorial, and Tribal entities (including both geological agencies and emergency management agencies) direct funding on an annual cycle to improve landslide-related risk-reduction efforts. Priority would be given to projects that—
    - Achieve the greatest landslide hazard and risk reduction;
    - Reflect the goals and priorities of the national strategy document

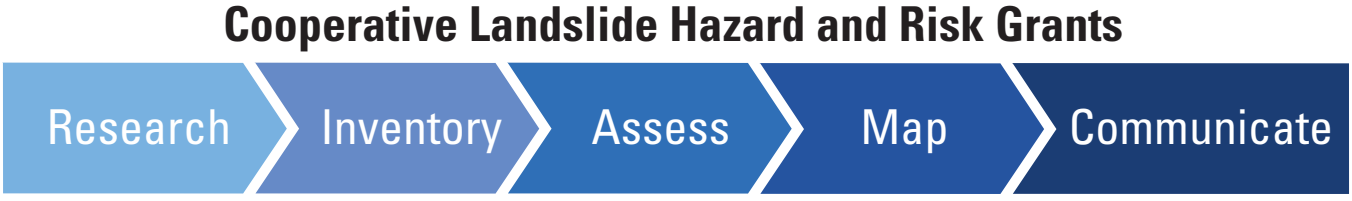


Figure 8. A cooperative landslide hazards and risk grants program would provide funding for various activities to improve the Nation's ability to reduce landslide risks.

- Address the priorities of underserved or historically marginalized communities; and
- Include acquisition of enhanced elevation data that are consistent with the USGS 3D Elevation Program.

◦ Cooperative landslide hazards and risk grants, which would be implemented by a USGS grants coordinator and include a grants review panel to establish annual priorities, review grant requests, and document deliverables on an annual basis.

◦ Recommendations for grant priorities and projects, which would be informed by input organized by the national landslide hazard risk reduction (NLHRR) working group (Strategic Action 2.4).

- To advance the objectives of the cooperative landslide hazards and risk grants, the USGS will collaborate with the NSF to—

◦ Advance the priorities of the research program, including ways to implement annual, competitive grants to fund research related to the causes, mechanisms, triggers, hydrology, and geology of landslides; and ways to reduce landslide hazards and risks to minimize loss of life and property, including landslide hazard and risk communication, decision making, tools, and technologies.

◦ Determine eligibility for grants and publish an annual report of grant-supported activities and their findings on a publicly available website.

Strategic Action 2.4—Establish and Support a National Landslide Hazard Risk Reduction (NLHRR) Working Group

Overview

Landslides are primarily local events. Thus, effective landslide risk reduction requires the collaboration of not only Federal partners through official coordinating committees but also coordination among State, Tribal, territorial, and local agencies, community leaders, land managers, and nonprofit organizations (Highlight 7). A national landslide hazard risk reduction (NLHRR) working group would create a common platform for (1) leveraging expertise that exists within individual agencies, (2) sharing of best practices, (3) development of collaborative products, and (4) providing input on priorities for the cooperative landslide hazards and risk grants described in Strategic Action 2.3 (fig. 9).

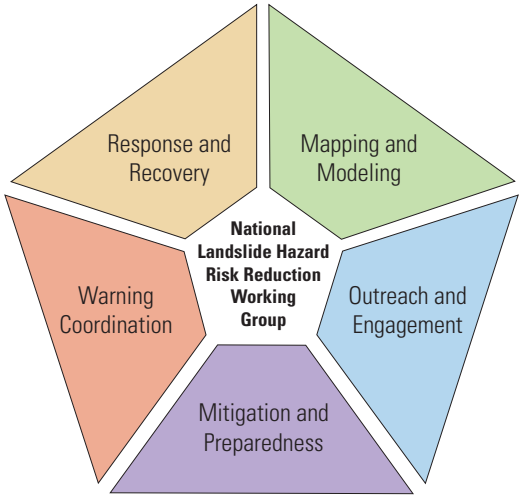


Figure 9. A national landslide hazard risk reduction (NLHRR) working group would include representatives from groups interested in various aspects of landslide hazard risk reduction to promote collaboration and share best practices.

Description of Involved Parties

The NLHRR would welcome voluntary participation from State, Tribal, territorial, and local agencies; community-based organizations; and private sector, land management, emergency management, and academic organizations interested in meaningful engagement in efforts to reduce landslide risks. The NLHRR working group would also actively facilitate the engagement of underrepresented or historically marginalized groups. The coordination of the NLHRR working group would be officially directed and supported by the USGS.

Ongoing Efforts

Currently, there is no mechanism for sustained communication or collaboration among the agencies that study landslides, the agencies that decide how to best reduce potential losses, and the groups affected by landslides. Discussions have been informal and ad hoc, typically occurring either at annual professional scientific meetings or intermittent interagency meetings convened in response to a landslide event.

Specific Actions and Initiatives

The NLHRR working group would do the following:

- Promote collaboration and share best practices for—
  - ◦ Warning coordination;
  - ◦ Mapping, modeling, and data management;
  - ◦ Landslide hazard mitigation and preparedness;
  - ◦ Post-landslide response and recovery; and
  - ◦ Outreach and engagement.

- Create a publicly available website for disseminating relevant information to working-group members;
- Organize annual meetings of the working group and associated interest groups to determine priorities, discuss potential collaborations, and showcase collaborative products;
- Organize quarterly meetings of the interest groups within the larger NLHRR working group (fig. 10) to discuss challenges and provide updates of ongoing projects;
- Hold workshops on landslide topics of national interest;
- Establish searchable repositories for content developed by the interest groups, such as best practices in assessing and mapping landslide hazards, consistent talking points and outreach products (Strategic Action 3.2), templates for response and mitigation planning (Strategic Action 3.1), guidance for media interactions, and archives of institutional and (or) traditional knowledge related to landslide hazards.

7. The power of collaboration

Partnerships strengthen the capabilities and capacities of all those involved. Existing landslide working groups demonstrate the benefits of partnerships. The following examples of non-landslide State and Federal interagency groups demonstrate the potential for even more collaboration.

Following a fatal landslide in the Alaskan community of Sitka in 2015, the NSF funded a project to explore the next generation of local landslide warning and alert systems. The Sitka Sound Science Center (2016) coordinated the involvement of community members, city planners, emergency managers, researchers in the academic and private sectors, leaders from the Sitka Tribe of Alaska, and State and Federal representatives during this process. This partnership benefited not only the Sitka community, but it led to better coordination of emergency response efforts following the 2020 fatal landslide in Haines, Alaska.

The Mount Rainier Working Group includes representatives from State, county, and local government agencies, the USGS, FEMA, and Mount Rainier National Park. The group originally formed to develop operational response plans, but it also works on public education initiatives, guidance documents, mitigation efforts, and recovery plans.

The U.S. National Tsunami Mitigation Program (2018) connects 28 States and territories with NOAA, FEMA, and the USGS to coordinate warnings, hazard mapping and modeling, mitigation, education, and island-specific challenges. A similar approach could be used to reduce landslide risks.

A debris flow runout associated with a 2015 landslide event in Sitka, Alaska. This fatal and surprising event lead to a collaborative effort to better prepare the community for landslides. Partnerships built as a result of this event also improved emergency response efforts following a landslide that occurred in Haines, Alaska, in 2020. Photograph by Joel Curtis, National Weather Service.

Goal 3. Communities and Land Managers Are Prepared and Plan for Landslide Hazards

Reducing landslide losses requires incorporating the best available hazard information in planning and preparedness decisions at all levels before the next landslide occurs. For the best available scientific information to be used, it must be delivered in a manner that is tailored to the scale and intent of the decisions and actions of its users in an accessible way. Effective loss reduction also requires education and training for at-risk people and communities, for land managers, and for other entities.

Incorporating landslide hazard information into all-hazards planning efforts will enable land managers and communities to (1) address exposure of existing and future assets to landslide risk; (2) mitigate potential losses to the built environment, natural and cultural resources, and habitats that may be in these areas; and (3) respond and recover in ways to reduce the long-term effects of landslides. Preparing individuals that live and work in, or visit areas prone to landslides will help make sure that they have the capacity to evacuate and avoid injuries and (or) loss of life.

Goal 3 Vision Statement

The vision for Goal 3 is that where landslides are part of the landscape, they become part of the local culture and are recognized in all facets of community and land-management planning and preparations. People living, working, and recreating in potentially hazardous areas are aware that landslides are possible and recognize under what conditions they might occur. When landslides are about to occur, people know the places to avoid and the actions to take. When they do occur, landslides may be perceived as short-term annoyances to the quality of life in communities and do not lead to casualties or persistent and recurring damage to the built environment and (or) natural resources.

Strategic Action 3.1—Provide Guidance, Tools, and Training to Include Landslide Information in Hazard Planning

Overview

Information related to landslide hazards is needed to inform all four phases of emergency management: mitigation, preparedness, response, and recovery. Inclusion of this information into existing Federal doctrine, guidance, and training documentation, such as the National Response Plan, would serve two important roles. First, including landslides in these documents will improve overall awareness of landslide hazards across Federal, State, Tribal, territorial, and local emergency management, infrastructure, and planning communities. Second, by raising awareness of landslides as a potential hazard, it is possible to point emergency, land, and transportation managers and planners to the most up-to-date information on landslide occurrence as well as information on how to mitigate and prepare for, respond to, and recover from landslides (Highlight 8).

8. Federal land management prevents landslide disasters

Rockfall hazard mitigation at Yosemite National Park's Curry Village in California. (*a*) Cabin damage resulting from an October 2008 rockfall. (*b*) The same area following the removal of more than 200 cabins in 2013. (*c*) Successful mitigation of rockfall risk is indicated by the dashed white lines, which show the footprints of the removed cabins; the yellow arrow, which identifies where a boulder fell in February 2014; and the yellow shaded area, which shows the impact crater from this boulder. Photographs by Greg M. Stock, National Park Service.

In 2010, the National Park Service (NPS) and the USGS collaborated on a rockfall hazard and risk assessment for Yosemite Valley in Yosemite National Park, Calif. Rockfalls from steep cliffs are a common hazard here where they threaten the approximately 4 million annual visitors. USGS and NPS researchers developed probabilistic assessments of where rockfall might land in the valley and potential casualties (Stock and Collins, 2014). NPS managers used the results of these assessments 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 landed where two wooden cabins had been removed. Had the cabins not been removed, they would have been severely damaged, and injuries and (or) fatalities could have occurred.

Description of Involved Parties

A number of agencies would be consulted regarding the inclusion of landslide hazards information in guidance and doctrine pertaining to the four phases of emergency management, such as—

- FEMA;
- Department of Transportation;
- Army National Guard;
- Department of Energy;
- USACE;
- USDA Forest Service;
- DOI; and
- NWS.

Ongoing Efforts

No Federal guidance documents specifically related to planning for landslides and their associated hazards currently exist. Often, Federal agency guidance for "all-hazards" plans includes references to specific natural hazards, such as hurricanes or earthquakes, but only rarely are landslides included. Some State agencies have produced guidance documents for landslide-related planning by local governments.

Specific Actions and Initiatives

- Develop landslide planning and risk reduction guidance, maps, tools, and training materials to help inform Federal land managers, as well as State, Tribal, territorial, and local governments, and decision makers across the emergency management industry with respect to the following:
  - The use and implementation of landslide hazard assessments (Strategic Action 1.1);
  - The applied use of the landslide hazard and risk database (Strategic Action 1.3);
  - Reducing losses from landslides; and
  - Resources available for communities working to improve landslide hazard preparedness.
- Develop landslide preparedness curricula and training modules for (1) State, Tribal, territorial, and local officials; (2) Federal, State, Tribal, territorial, and local emergency managers; and (3) the Army National Guard. Possible venues for these training modules are a course offered by FEMA, a landslides crisis awareness course offered by the National Disaster Preparedness Training Center at the University of Hawai'i, or coursework related to the Emergency Manager Accreditation Program.
- Develop guidelines on the design of landslide-related emergency management exercises as well as an inventory of exercise scenarios and scripts already developed by emergency managers.
- Develop a guidance document that identifies ways to add authoritative landslide-related content to existing Federal planning doctrine and products (fig. 10); for example—
  - **Risk assessments:** (1) The national Threat and Hazard Identification and Risk Assessment (THIRA); (2) FEMA guidance documents for THIRAs conducted by State, Tribal, territorial, and local governments; (3) a landslide-specific module in FEMA's Hazus loss-estimation software; (4) national web applications, such as FEMA's National Risk Index; and (5) products developed in FEMA's Risk Mapping, Assessment and Planning (Risk MAP) initiative;
  - **Mitigation planning:** FEMA's Local Mitigation Planning Handbook that advises local governments on how to develop or update local hazard mitigation plans;
  - **Preparedness planning:** Various FEMA guidance documents, such as "Comprehensive Preparedness Guide 101—Developing and Maintaining Emergency Operations Plans," "Planning Considerations—Evacuation and Shelter-in-Place," and "Hazardous Materials Incidents";
  - **Response planning:** The "Response Federal Interagency Operational Plan"; and
  - **Recovery planning:** The "Recovery Federal Interagency Operational Plan" and FEMA's "Planning Considerations: Disaster Housing" document.
- Create a "Landslide Ready" recognition program that recognizes community-level planning for future landslides. This program can be modeled on the TsunamiReady Program developed by the NWS (National Weather Service, 2015).

Figure 10. Multiple opportunities exist for incorporating landslide information in hazard planning efforts from the local to the national level.

Strategic Action 3.2—Develop Landslide Outreach Initiatives to Improve Public Knowledge and Preparedness Planning

Overview

People exposed to landslide hazards may have only seconds to minutes to act if a landslide were to initiate without warning in their area. In other cases, people may be asked by public officials to evacuate areas where landslides could occur given weather forecasts. Integrated public education and preparedness planning done well in advance of both situations are needed to ensure that people make informed decisions (Highlight 9). Creating an environment that changes people's perceptions and behavior towards landslides is a major commitment and requires long-term and diverse activities to ensure that landslide knowledge and preparedness are ingrained into local culture. Shaping effective communication products and outreach efforts requires an understanding of (1) the informational needs of individuals, stakeholders, and other partners engaged with landslide risk reduction, and (2) the appropriate formats and delivery channels to effectively reach these groups (fig. 11).

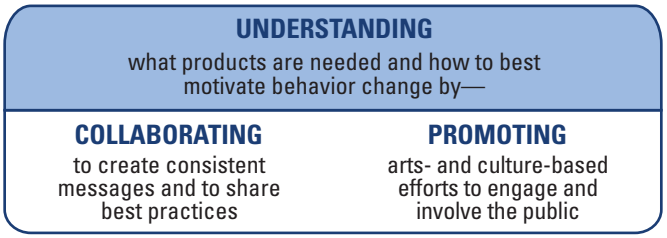


Figure 11. Improving public knowledge and preparedness involves making efforts to understand user needs, enabling collaborations to create consistent products, and promoting new and innovative ways to engage the public.

Description of Involved Parties

A number of agencies, organizations, and groups could play a role in informing, creating, or coproducing landslide-related communication products, such as—

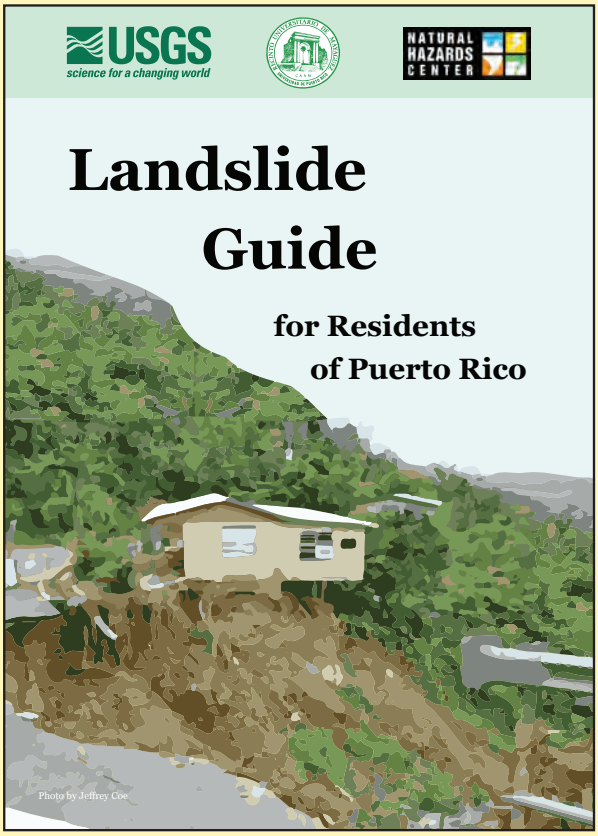
- USGS;
- NASA;
- Federal and State departments of transportation;
- State and territorial geological agencies;
- State, Tribal, and territorial emergency management agencies;
- Nonprofit organizations;
- Community-based organizations;
- K–12 education groups;
- Communities previously affected by landslide events; and
- Indigenous scholars and practitioners.

9. Public education campaigns to raise landslide awareness

After Hurricane Maria devastated Puerto Rico in 2017, a bilingual landslide guidebook intended to help residents of Puerto Rico understand and reduce landslide risk was produced in partnership among the USGS, the University of Colorado Boulder, and the University of Puerto Rico—Mayagüez (West and others, 2021).

This geographically and culturally specific educational resource was created to explain the causes, signs, and consequences of landslides as well as to describe practical steps that can be taken to enhance preparedness and help mitigate the effects.

The guidebook was also used as a tool for organizations, universities, agencies, emergency managers, and planners to promote landslide awareness and resilience throughout the island as part of hazard education and outreach activities. Public education campaigns such as this are essential to future protection of both life and property.



Front cover of a landslide guide developed by Davis and others (2020) as a collaboration of the U.S. Geological Survey, the University of Colorado Boulder, and the University of Puerto Rico—Mayagüez. Photograph by Jeffrey Coe, USGS.

Ongoing Efforts

Currently, there is no official and sustained mechanism for developing and delivering landslide-related communication products. Current products and outreach efforts by various government and nongovernmental groups are not coordinated, are largely ad hoc, and are often pursued only in the aftermath of a damaging event.

Specific Actions and Initiatives

Collaboratively, the agencies, organizations, and groups listed above would do the following:

- Identify the outreach products and efforts needed by—
  - Compiling a list of potential audiences and use cases informed by social and behavioral research (Strategic Action 1.1) for landslide-related communication to support local outreach efforts and preparedness planning;
  - Conducting systematic and coordinated risk perception and preparedness studies of communities with high landslide risks (Strategic Action 1.1);
  - Developing targeted messaging and outreach products using evidence-based approaches in social and behavioral sciences that (1) best promote positive behavior change in diverse populations, (2) recognize the range in sociocultural settings where landslides occur, and (3) promote coproduction where possible; and
  - Evaluating the content, format, and delivery of landslide outreach efforts and products to understand if communication approaches and products are resulting in positive behavior change to reduce landslide risks.
- Leverage the NLHRR working group (Strategic Action 2.4) and other partners to develop outreach products and efforts that use consistent hazard-related messaging and information, such as—
  - A national landslides communication plan;
  - A national landslide curriculum that can be adapted by K–12 educators;
  - "Train the trainer" materials for use by community organizations and land managers; and
  - Strong State and local working groups that share best practices and lessons learned for effective landslide outreach and preparedness planning.
- Develop innovative ways to communicate landslide hazards and risk reduction to the public, such as by—
  - Fostering public participation in landslides communication, such as public art, community exchanges, and storytelling programs to commemorate landslide disasters; and
  - Creating visually rich digital communication campaigns to memorialize significant landslide events (Strategic Action 1.4) and maintain an online archive of these digital memorials.

Goal 4. Surveillance, Warnings, and Responses to Landslide Events Are Effective, Efficient, Cooperative, and Data Driven to Protect Life, Property, and Resources

In the minutes to weeks before, during, and after a significant landslide event occurs, it is imperative that Federal, State, Tribal, territorial, and local entities work together to effectively, efficiently, and safely react and respond. Failure to do so leads, at best, to redundancies of efforts and the waste of precious time and, at worst, to greater losses and negative effects.

Improved response to landslide events requires awareness and information on impending landslide occurrence and coordinated, streamlined, and well-informed decisions and actions by land and emergency managers and those potentially at risk. Well-informed decisions and effective actions are aided by the delivery of critical information prior to landslides occurring. Although warning systems are operated for some natural hazards, notably those provided by the NWS for meteorological hazards, most landslides occur without any prior alerts. In limited locations following wildfire incidents, the USGS has partnered with the NWS to provide information on debris-flow potential as part of NWS flash-flood forecasting (NOAA–USGS Debris Flow Task Force, 2005). To provide at-risk communities time to take protective actions, it is necessary to (1) expand this NOAA–USGS partnership to a nationwide scale, (2) include other types of landslides induced by meteorological events, and (3) develop systems to identify locations with elevated landslide potential.

Initial response to landslide emergencies typically falls to local emergency management personnel who often have little experience or training with landslide hazards. Access and use of scientifically derived landslide information would require geologists with expertise in landslide science to be (1) known to Federal, State, Tribal, territorial, or local emergency responders in areas at high risk of landslides, (2) able to deploy to a landslide event quickly and efficiently, and (3) able to provide the appropriate tools and resources to aid in the field. Onsite and on-call geologists could help emergency managers answer the following questions:

- Where are search and rescue crews most likely to find survivors?
- Is it safe for search and rescue or recovery crews to enter the landslide zone?
- Is landslide movement likely to continue? If so, how big might it be and where will it go?
- Where are safe locations to stage people and equipment?
- Which transportation corridors or other lifelines are likely affected?

Goal 4 Vision Statement

The vision for this goal is that a nationwide landslide surveillance system is operational and enables the NWS and other organizations to provide information to the public of when landslides may be more likely given current or forecasted conditions. Signs of activity are not detectable prior to all landslides; however, landslide situational awareness products could help at-risk individuals take protective actions. Situational awareness information gives critical facility and infrastructure operators, as well as land managers, advance notice of heightened landslide threats so that they can implement short-term mitigation actions to reduce losses and be ready to respond effectively. Debris-flow risks are reduced greatly as local partners monitor stormwater drainage in high hazard zones. Response personnel can quickly identify and easily request landslide expertise to support them during a landslide response. In doing so, they can operate safely amidst an unstable landscape, and landslide experts can collect ephemeral data for improving the Nation's understanding of landslide hazards and effects.

Strategic Action 4.1—Support Existing Warning Systems to Include Landslides

Overview

Outside of recently burned areas, rainfall-induced landslides typically occur when precipitation falls in areas where the ground is already nearly saturated with water from previous storms. Alerting the public that conditions are ripe for landslides requires three components working together (Baum and Godt, 2010):

- A surveillance system that monitors environmental and landslide conditions based on satellite-based detection, ground-based sensors, and weather forecasts;
- Research to understand the conditions and environmental thresholds at which landslides are likely to occur in a given location, such as geologic setting, certain levels of rainfall intensity, soil water content, groundwater pressure, and slope deformation; and
- A mechanism to disseminate timely alert messages for individuals and organizations to respond effectively.

In an effort to advance the first two components, the USGS currently operates landslide monitoring sites (the "USGS landslide surveillance network") in several States and in Puerto Rico in cooperation with State and local government organizations (Highlight 10). The goal of these monitoring sites and the research they support is to identify which environmental conditions and their respective thresholds are most relevant for predicting landslides. The USGS also has developed ground-based sensors to alert communities and land managers when debris flows have been generated and are flowing downhill. Both the monitoring and the alert technology can be coupled with satellite-based detection and weather forecasts to improve landslide surveillance capabilities. For landslides that are not directly or obviously initiated by precipitation or other environmental factors, existing and emerging technologies may provide surveillance of landslide activity. The data generated by these surveillance technologies are useful for advancing process understanding as well. To address the third element, landslide warning criteria for shallow rainfall-induced landslides and debris flows could be developed in cooperation with the NWS. The objective would be for information obtained from the USGS landslide surveillance network to be conveyed to NWS and other partners to support existing alert products.

Expansion of landslide monitoring and alert systems in high-risk, landslide-prone locations nationwide (Strategic Action 1.1) and integrating them with satellite-based detection and weather forecasts would provide multiple societal benefits (fig. 12), including:

- More site-specific environmental data to support existing alerts;
- Improved ability for critical facility or infrastructure managers to identify where specific segments of their systems could be affected during prolonged or intense rainfall events; and
- Informing land managers, emergency managers, and at-risk individuals as to when the threat of landslides is heightened and that they should be ready to respond quickly if a landslide occurs.

Such strategic actions are designed to address the primary research, technological, coordination, and messaging challenges of building an effective landslide surveillance system that can support NWS warning products.

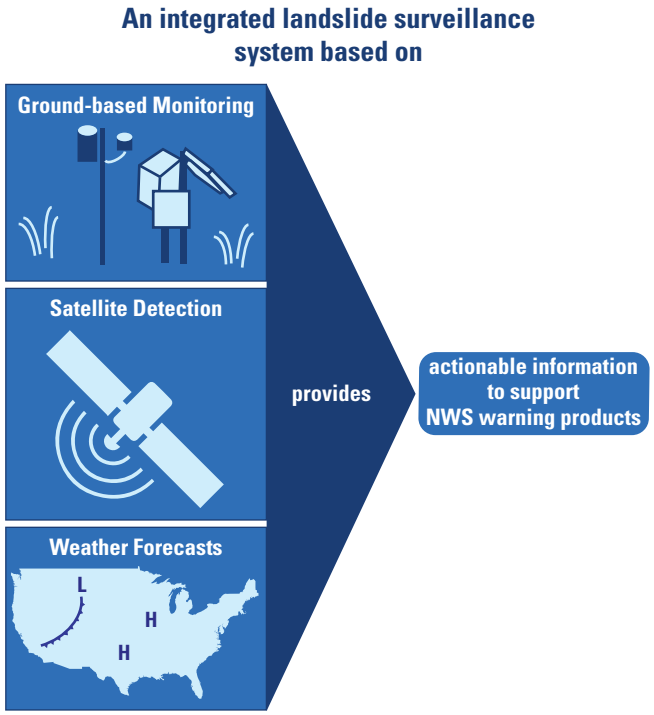


Figure 12. An integrated landslide surveillance system involves ground-based monitoring, satellite-based detection, and weather forecasts. NWS, National Weather Service

Description of Involved Parties

A number of agencies could be involved in the creation and dissemination of content to support landslide-related alert products. The primary groups would include the following:

- The USGS, which would maintain landslide monitoring networks and integrate satellite data to provide surveillance information to the NWS and other partners;
- The NWS, which would produce and disseminate landslide-related warning products for shallow, rainfall-induced landslides based on data provided by the USGS landslide surveillance network; and
- State, Tribal, territorial, and local governments, which would help disseminate alert messages and provide feedback on alert products.

Ongoing Efforts

Currently, USGS science support for NWS warning products is mostly limited to semiarid parts of the Nation where recent wildfires have elevated debris-flow hazards. In these areas, the NWS may issue debris-flow information as part of flash flood warning products. In a few locations, where landslide monitoring systems are deployed, the USGS and the NWS coordinate to assess the potential for widespread rainfall-induced landslides when intense or prolonged rainfall is forecasted. Presently, landslide monitoring systems are deployed in only a few geographic locations.

Specific Actions and Initiatives

- Develop USGS landslide surveillance system by—
  - Expanding the number of monitoring-research sites to ensure environmental thresholds reflect the range of U.S. geographies that have landslide potential;
  - Using the national landslide hazard and risk database (Strategic Action 1.3) to identify new areas that warrant ground-based monitoring and alert systems and where their implementation would best support timely, protective measures by individuals and organizations;
  - Developing surveillance products and the necessary cyberinfrastructure that integrate ground-based monitoring and alert systems, satellite-based detection, and weather forecasting capabilities of various Federal partners; and
  - Supporting research and development initiatives in cooperation with private entities to develop near-real-time estimates of landslide effects on critical infrastructure or other assets.
- Improve the understanding and use of landslide surveillance products by—
  - Developing consistent messaging on product use and interpretation among the USGS and its cooperators using evidence-based approaches from the social and behavioral sciences (Strategic Action 3.2); and
  - Conducting social science research that continually evaluates how the public, emergency managers, and land managers receive, interpret, disseminate, and act on information.
- Expand USGS–NWS collaborations to support NWS alert products by—
  - Continuing to refine weather and ground-condition thresholds that reflect a higher rainfall-induced landslide threat;
  - Expanding the NOAA-NWS post-wildfire, debris-flow alerts to include all recently burned areas across the Western United States;
  - Developing requirements, information, and methods for assessing post-fire debris-flow hazards in temperate environments;
  - Expanding and improving support for NWS alerts for landslide-induced tsunamis;
  - Improving the necessary cyberinfrastructure for transferring surveillance data to the NWS so the agency can more quickly generate and disseminate landslide and landslide-related information; and
  - Providing pertinent landslide surveillance information to non-NWS Federal partners, such as the interagency BAER program, allowing them to acknowledge and communicate heightened landslide threats in existing warnings for extreme events or post-event notifications (Highlight 11).

10. Landslide surveillance systems in action

Landslides are commonly induced by intense or prolonged rainfall associated with strong winter storms. The USGS, in cooperation with State and local government organizations, operates shallow landslide monitoring sites in several States and in Puerto Rico. The goal of these sites is to identify thresholds of meteorological and soil-moisture conditions for creating shallow landslides and related high-mobility debris flows. This information is being used to develop landslide warning criteria with the National Weather Service. Expanding the landslide surveillance system can better protect both people and property from impending landslide hazards.

This U.S. Geological Survey "BALT1" landslide surveillance site is located near Castro Valley in the San Francisco East Bay of California. The site includes a cattle-protected enclosure with dataloggers that monitor the hillslope. The steep slope shown here is typical for many places in the East Bay region that have generated mobile debris flows in the past. The area consists of grasslands over an approximately 1-meter-deep sandy soil layer, which is underlain by sandstone. Photograph by the U.S. Geological Survey.

This U.S. Geological Survey "BALT2" landslide surveillance site is located near San Rafael in Marin County, Calif. The site includes enclosures for the dataloggers, a solar panel to power the site, and sensors that measure air temperature, relative humidity, and rainfall. Photograph by the U.S. Geological Survey.

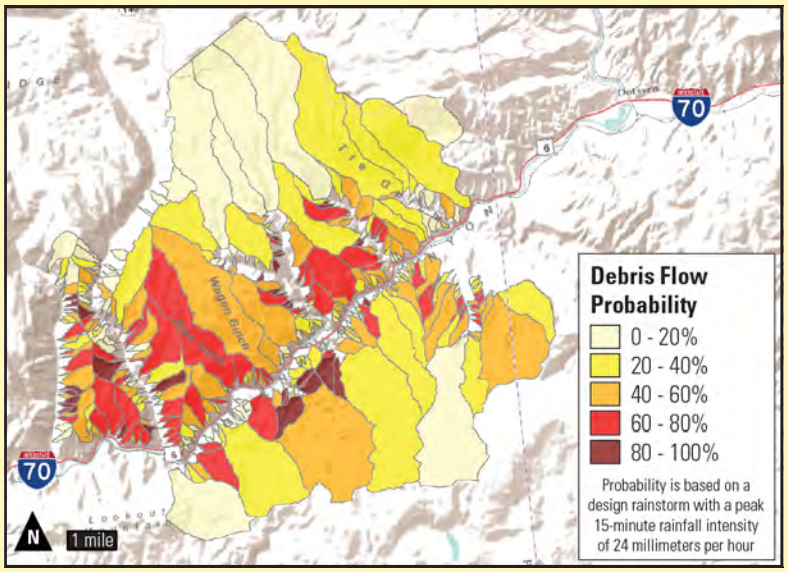
11. Science informs burned area emergency response

Wildfires burn away vegetation that holds soils on steep slopes in place and can make these soils less able to absorb water and more erodible. Rain that falls on these areas can run off rapidly, pulling soil, rocks, and other materials with it downhill, creating a debris flow. These debris flows can be deadly; for example, a 2018 debris flow following the Thomas Fire in southern California destroyed more than 100 homes, killed 23 people, and caused the hospitalization of dozens more (Lancaster and others, 2021).

The interagency Burned Area Emergency Response (BAER) program helps decision makers obtain crucial information on a variety of post-fire risks. BAER teams are responsible for assessing the effects of fires and delivering this information as quickly as possible. USGS predictive debris-flow modeling helps BAER teams understand the probability and size of a debris flow from burned watersheds in response to a storm event.

These assessments can be done in a matter of days, offering critical information to BAER teams and emergency management while also informing the public about potential protective actions. The assessments also inform debris-flow alerts issued by the National Weather Service for recently burned areas in several States. In 2020 alone, the USGS assessed 82 major wildfires across more than 6.6 million acres of land.

House damaged by debris flows created after a 2010 rainstorm. The drainage basin above this home in Los Angeles County was burned in 2009 by the Station Fire. Photograph by Susan Cannon, USGS.



USGS map that displays estimates of the likelihood of debris flows for individual drainage basins related to the 2020 Grizzly Creek Fire that affected the White River National Forest, Colorado. Highway 70 also runs through the affected area. This map is one of many compiled by the U.S. Geological Survey Landslide Hazards Program to depict the probability and volume of debris flows that may be produced by a storm in a recently burned area (https://landslides.usgs.gov/hazards/postfire_debrisflow/).

Strategic Action 4.2—Improve Response Actions by Having Technical Experts On Site

Overview

When substantial landslide events occur, first responders have only a limited amount of time to rescue victims who may be buried or trapped within debris. Emergency managers and other decision makers have similar time constraints to contain cascading hazards that could further affect a community. All onsite response (and eventually recovery) personnel would benefit from assistance in understanding how the disturbed landscape may continue to move after an initial landslide and what potential cascading hazards should be considered (fig. 13). To perform these tasks effectively, efficiently, and safely, landslide geologists should deploy onsite to assist response personnel in understanding the new landscape as well as plan and communicate about the hazard and protective actions effectively.

Figure 13. Improving landslide responses includes increasing the number of landslide specialists who participate, improving policies for how they contribute to a response, and raising the awareness of the benefits of having landslide specialists participate in the response effort.

There are several issues with the current approach to deploying technical experts and integrating them into a landslide response. First, the deployment of technical experts is unorganized and dependent on an individual agency's ability, capacity, and willingness to send and support them. Second, when landslide experts are deployed to a response, they are often not provided with the necessary instruments, training, or technology to complete their duties most effectively. Third, onsite first responders and emergency managers may not fully understand the skills and insight that landslide experts and other technical support can bring to a landslide response. Fourth, the presence of technical experts could be perceived as interfering with response activities unless there is shared understanding of how field data are collected and communicated. For these reasons, more formal planning and training for the better integration of technical experts in responses to significant landslide events for both technical experts and emergency responders is warranted.

An example of the integration of technical specialists into emergency response is the case of meteorologists and wildfires. Weather is often a substantial driving force in wildfire behavior, and as wildfire complexity and effects upon the built environment increase, incident meteorologists have become key members of Incident Management Teams (IMTs). The meteorologist uses their weather expertise to help the IMT make critical decisions, from firefighter safety to evacuating communities. The deployment of landslide geologists could follow a similar model (Highlight 12). Deployed geologists can assist IMTs by providing subject matter expertise and experience with landslide behavior to help emergency managers address such questions as where and how to safely deploy search and rescue assets and what might the potential cascading effects of landslides be. Following response events, deployed geologists who participate in after action reviews can identify science and technology gaps to inform the research and development community, making the response community better prepared for the next event.

Description of Involved Parties

To understand how to better respond to landslides, the USGS will engage external partners, including the following:

- Tribal land managers and Federal land management agencies, such as the Bureau of Land Management, the USDA Forest Service, the U.S. Fish and Wildlife Service, and the NPS; and
- Other Federal agencies that respond to or support responses to landslides, such the FHWA, the Bureau of Reclamation, the USACE, and FEMA.

Ongoing Efforts

Currently, there is no national, organized landslide response process. Agencies such as the USGS, after learning about a landslide, reach out to the respective State geological agency or local authorities to offer technical support and assistance. This process is heavily dependent on established relationships and can be an unreliable process to deploy technical specialists. In addition, there is no cadre of response scientists prepared for immediate deployment to a landslide emergency (for example, Reid and others, 2021). Scientist deployment to an incident would usually fall under the Incident Command System (ICS); however, prospective scientists may not realize they need their organization to register them in the Interagency Resource Ordering Capability (IROC) system to make it possible for them to be "ordered" to an incident. Further, many landslide geologists are unaware that to enter into that system, and to integrate into the ICS, they need to have taken the required trainings in ICS and the National Incident Management System (NIMS) prior to deployment. Conversely, emergency managers may not be aware of the landslide-related technical expertise that exists within various Federal agencies.

In addition to scientists, a landslide response would likely require readily deployed monitoring instruments, which can help scientists understand landslide behavior to keep first responders and the public safe. There is currently no dedicated cache of monitoring instruments or cadre of specialists to operate and interpret data from the instruments intended for emergency deployment.

Specific Actions and Initiatives

- Increase the number of landslide experts that are available for incident response. Toward this end—
  - Encourage agencies to register landslide experts in the IROC system to make landslide experts and related technical experts across Federal agencies available to emergency responders. Encourage interested experts to take the required ICS and NIMS training noted in documents such as the DOI "Incident Positions Qualification Guide" for their positions.
  - Standardize qualifications for landslide experts and support administration, dispatch, training, and response.
- Improve policies and procedures for integrating onsite technical experts into landslide response. Specifically—
  - Establish emergency response procedures for the rapid deployment of Federal scientists and equipment to significant landslide events to support responders, and improve data collection pertinent to situational awareness and to understanding the causes, effects, and reduction of landslide hazards;
  - Develop technical data collection protocols, a code of scientific ethics, and guidance on communication with responders for deployed technical experts;
  - Develop guidelines for a significant landslide event response that clarify response roles and responsibilities among all participating entities and include flow charts to support landslide-related decision making;
  - Prepare after action reviews that evaluate areas for improving the coordination among response personnel and technical experts;
  - Include landslide-related language in the National Response Plan and the National Recovery Plan and other response guidance, where applicable (Strategic Action 3.1).
  - Develop guidelines for the collection of information on science and technology gaps identified during event response that can be used to inform research and development activities.
- Raise awareness of the benefits of onsite technical experts by—
  - Developing training modules to educate emergency managers, ICS commanders, public information officers, and other response personnel on (1) the role of landslide experts and other technical experts in a landslide response, and (2) how to access the technical tools and expertise available to them from other agencies. Possible venues for these training modules are a FEMA course, a landslides crisis awareness course for the National Disaster Preparedness Training Center at the University of Hawai'i, or coursework related to the Emergency Management Accreditation Program (Strategic Action 3.1); and
  - Developing table-top exercise templates and guidance documents to demonstrate the integration of technical experts in a landslide response, including when it may be warranted to request technical support.

Conclusion

Landslides are inevitable, but landslide disasters are not. Landslides occur in all 50 States and most territories and can be triggered by a range of factors, including other hazards, such as hurricanes or earthquakes. Landslides are part of the geological processes that erode steep slopes. Where these natural processes intersect human activities, landslides present a risk to lives, the environment, and the economy. Many actions can be taken to mitigate, prepare for, respond to, and recover from the effects of landslide hazards. Underpinning those actions is the need for more and better data and understanding as well as the means and capacity to deliver that information to people and organizations potentially at risk from landslides. This strategy document describes these actions aligned with four specific goals:

Assess: Provide decision makers with detailed, nationwide information on landslide hazard and risk.

Coordinate: Landslide hazard mitigation, preparedness, response, and recovery efforts are coordinated across Federal, State, Tribal, territorial, and local levels.

Plan: Communities are prepared and plan for landslide hazards.

Respond: Landslide surveillance, warnings, and responses to events are effective, efficient, equitable, cooperative, and data-driven to protect lives, property, infrastructure, and the environment

These goals are ambitious, but also necessary to better protect lives, property, infrastructure, and the environment from landslide hazards. Historically, there has been little emphasis on landslide hazards in national discussions about disasters even though landslides cause billions of dollars of damage and kill people each year. Accomplishing the goals laid out in this strategy document will be challenging, but achieving them is the best and most cost-effective way to reduce overall losses from landslide hazards in the future.

12. Landslide experts supporting response efforts

Bill Schulz, a U.S. Geological Survey research geologist, taking photographs of Puerto Rico hillsides from a U.S. Army helicopter in 2017 to document landslides generated by rainfall from Hurricane Maria. Photograph by Jason Marineau, U.S. Department of the Interior Office of Emergency Management.

USGS geologists joined Puerto Rico geologists to assist emergency response efforts after Hurricane Maria in 2017. Having onsite expertise soon after the passage of the storm was beneficial in two important ways. First, landslide geologists were able to quickly identify the types of landslides that had occurred—an assessment that was critical to inform search and rescue efforts. Second, the work of USGS geologists helped identify areas around Puerto Rico with the highest risk of future landslides. The locations of these areas were then shared with the Federal Emergency Management Agency (FEMA), allowing the agency to determine the best landslide hazard mitigation and preparedness strategies for those at risk.

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For more information about this publication, contact:

Program Coordinator
USGS Landslide Hazards Program
National Hazards Mission Area
Reston, VA 20192

For additional information, visit: https://www.usgs.gov/programs/landslide-hazards

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